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Efficacy of Diode laser and Photoinduced Photo-acoustic Streaming Irrigation Techniques on Push-out Bond Strength of Endodontically Treated Teeth

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ABSTRACT

Comparative evaluation for the effectiveness of 980nm Diode laser and 2940nm Er:YAG laser irrigation activation on the bond strength of endodontically treated teeth. **Methodology**: Sixty mature permanent teeth with single root canal were gathered for the current study. Teeth were splited into 3 experimental groups, each comprising twenty specimens, according to the final irrigation method utilized. Group I: lateral-vented needle activation; Group II: 980 nanometer diode laser activation; Group III: 2940 nanometer Er:YAG laser activation with PIPS. Irrigation volume was standardized (4 ml) across all groups. Under continuous flush of irrigant solutions, the activation process was done for 40 seconds in every group. Push-out bond test was assessed at three thirds of each specimen by a universal testing machine. **Results:** The push-out bond strength test revealed a statistical significant difference among the laser groups and the lateral-vented needle group, with both the diode and Er:YAG lasers demonstrating higher bond strength compared to the side-vented needle group. Additionally, a statistical significant difference was observed within the three thirds in every group, with the apical third exhibiting the lowest mean bond strength value**. Conclusions:** Utilizing either the Er:YAG laser (PIPS) or diode for activating irrigation solution led to improved irrigant penetration and enhanced bond properties of the resin sealers.

Keywords: Er:YAG laser, Diode laser, irrigation activation, Push-out bond strength..

1. Introduction

Various kinds for activation methods for root canal irrigants are employed nowadays in purpose of achieving better cleaning and sealer penetration with subsequently higher strength properties and a successful treatment. Irrigant agitation can be achieved by different methods, revealing manual-agitation, sonic and ultrasonic apparatuses. Recent investigations explored the utilization of lasers to activate irrigants within the canals. It is recognized as laser-activated irrigation (LAI), which enhanced canal remnants and smear layer removal (Olivi, 2013, Akcay *et al.,* 2015, and Ghorbanzadeh, *et al.,* 2016).

Lasers serve as effective tools for disinfection. Different laser wavelengths react with various targets like dentin, micro-organisms, and irritants, producing biological effects responsible for a therapeutic action, including photothermal, photochemical, photomechanical, and photoacoustic effects (Turkel *et al.,* 2017, Martinho *et al.,* 2020 and Pawar *et al.,* 2014).

Photon-induced photoacoustic streaming (PIPS) is one of irrigant agitation methods that employs the Er:YAG laser. The PIPS activation technique is advantageous to achieve thorough root canals cleaning and enhancing adherence of sealers to the walls of root canals. This suggests that activating the irrigant and generating flow improved the bond strength of resin root canal sealers (Das *et al.,* 2013).

Root canal sealers should completely seal and be highly adaptable to its anatomy. The penetration of sealers into the D. tubules is important, as it improves the adhesion to dentin, thereby facilitating

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mechanical interlocking. (Moura‑Netto *et al.,* 2012 and Faria *et al.,* 2011). In the root canal filling step, sealer flow is crucial, improving both adaptation and adhesion of the root canal filling. (Faria *et al.,* 2011; Jhingan *et al.,* 2015 and Khoshbin *et al.,* 2018) .

Numerous studies have examined the bond strength of various irrigant solutions. However, fewer studies have explored the impact of various types of lasers on the bond strength with root canal sealers. Therefore, considering how distinct the irrigation protocols affect the physical properties of the pulpal dentine walls and, consequently, the obturation. (Khoshbin *et al.,* 2018; Todea *et al.,* 2010; Onay *et al.,* 2010 and Elmessirya *et al.,* 2019).

The current study investigates the effects of 2940nm Er:YAG laser (PIPS) ,980nm diode laser irrigation, and side-vented needle irrigation, on the push-out bond strength of root canal filling procedure.

2. Methodology

2.1. Preparation of the experimental samples

60 extracted single-canal teeth that were collected for this study with the coronal part were sectioned to standardize the roots to 16 ± 2 mm, the teeth were stored in labeled vials within a humidity chamber maintained at 100% relative humidity to prevent desiccation. ProTaper universal rotary files (Dentsply Maillefer, Ballaigues, Switzerland) were assigned for mechanical preparation of root canals starting with S1 till F4 files. The files were mounted on X-Smart motor at 300 rpm/Ncm (Dentsply, Switzerland). Irrigation was performed by utilizing a disposable syringe equipped by a 30-gauge side-vented needle, that was advanced into the RC 2 mm shorter than the working length carrying 2.5% (NaOCl) solution.

2.2. Technique of Irrigation activation

After mechanical preparation, activation of irrigants was performed in the experimental groups utilizing 2.5% NaOCl (4 ml) irrigation solution with total activation time of 40 seconds. Final irrigation was done using distilled water. Paper points were utilized to dried-up all teeth (Dhawan *et al.,* 2020).

2.3. Specimens classification:

The prepared samples were categorized to a 3 experimental groups according to the activation technique utilized during the final irrigation, with random division of the specimens was performed to create three main groups (n=20 each):

Group I: lateral-vented needle (Monoject, Sherwood Medical, Switzerland) activation involved passive irrigant placement. The needle was inserted to a depth of 1 millimeter shorter than the working length (WL) and moved vertically.

Group II: Diode Laser-980 nm Agitation - samples have been irradiated by 980 nanometer diode laser (Wiser Doctor Smile, Italy) employing a four-hundrads micrometer plain fiber tip, which was carefully introduced 2 millimeters shorter than the established WL and activated for a period of 10 seconds to facilitate effective laser energy delivery and activation of the irrigant solution. while maintaining a constant flux of 1 ml of irrigant at 2 W power, which was performed four times, totaling 4 ml of irrigant activated for 40 seconds.

Group III: Photon-Induced Photoacoustic Streaming - The irrigating solutions were energized using an Er:YAG laser (2940 nanometers) (Fotona, Ljubljana, Slovenia) set at a frequency of 15 Hertz, delivering 20 millijoules of energy per pulse at a power output of 0.3 watts. A 400 micrometer quartz PIPS tip (Fotona, Ljubljana, Slovenia) was employed, the distal 3 millimeters of the polyamide sheath removed to expose the active tip. The tip was maintained in a static coronal position, and the coaxial air-water spray was deactivated to prevent interference with the laser's effects.

The three experimental groups received a total volume of irrigant (4 ml). In laser agitated groups, each 1ml of irrigating solution was activated by either types of lasers employed to every group for 10 seconds period, and repeated four times up to a total volume of 4 ml was utilized.

2.4. Obturation of specimens:

All teeth were filled by adjusted single-cone method, with the passive insertion of two auxiliary cones alongside the master apical cone for oval canals. The gutta-percha cones were lightly covered by a thin film of the mixed sealer, AH Plus (Dentsply DeTrey, Konstanz, Germany), and then was seated till the WL of the root canal. Coronal temporization using (Cavit; 3M ESPE, Seefeld, Germany). The teeth were kept in an incubator for one day (100% humidity and 37 °C) to ensure full setting (Akcay *et al.,* 2015).

2.5. Bond strength testing:

The teeth were immersed in a self-cured acrylic resin, then subsequently cut horizontally into 2-millimeter thick sections using an Isomet machine. Three slices were attained (coronal, middle, and apical thirds). (Carmo *et al.,* 2018). Specimens were held with a stainless-steel support in place to ensure stability and proper alignment. The specimens were positioned with the smaller diameter side facing the plunger. A stainless-steel plunger was used to load the filling material utilizing a universal testing machine (Instron, Norwood, Massachusetts, USA). A suitable plunger sizes were selected for each third of the root canal, ensuring that the tip made contact solely with the obturation core. The load was consistently applied apically-to-coronal direction with a crosshead speed of 0.5 millimeters per minute. The force required to dislodge the filling material was then recorded in Newtons (N) as follows: (Mohammadian *et al.,* 2019).

Area is calculated by: 1/2 x (circumference of the coronal surface + circumference of the apical surface) xthickness.

Push-out strength (MPa) was calculated by dividing the force (N) by the area (mm^2). One-way ANOVA with Tukey's post-hoc test was used for groups comparison. Normality was assessed employing the Kolmogorov-Smirnov and Shapiro-Wilk tests. Repeated measures ANOVA was utilized for comparisons between more than two related groups. Where, paired T-tests were employed for two related groups. Significance was set at $p \leq 0.05$. Statistical analysis was done by IBM SPSS Statistics Version 20.

3. Results

The key findings of the current study are presented in Table 1 and Figure 1

Push-Out Bond (POB) results of different sections in each group

I) Group I (Side-Vented Needle):

A significant statistical difference was observed between the coronal, middle, and apical thirds ($p = 0.007$). Notably, significant differences were identified between the apical samples and both the coronal ($p = 0.001$) and middle samples ($p = 0.004$). Nevertheless, a statistical analysis revealed no significant difference ($p = 0.183$) in the outcome variable among the coronal and middle sections, indicating that the treatment effect was consistent across these two regions.

II) Push-Out Bond Strength of Group II (Diode Laser)

The coronal group and both the middle ($p = 0.006$) and apical groups ($p = 0.001$) revealed a significant difference among them. Additionally, a statistically significant difference among the middle and apical sections ($p = 0.024$). With the greatest mean bond strength was recorded by the coronal sections, coming after the middle thirds, while the apical sections had the least mean values.

III) Push-out bond strength of Group III (Er-YAG laser)

A significant statistical difference in all group sections ($p = 0.008$) was observed. Significant differences were found between coronal and middle ($p = 0.028$), coronal and apical ($p = 0.001$), and middle and apical ($p = 0.006$) groups. The greatest mean bond strength was recorded by the coronal group, coming after the middle group, where the apical group exhibited the least means.

Results of Push-out bond strength of different groups in every third: illustrated in table 1 and figure 1

A) Push-out bond strength at Coronal third

A significant statistical difference was noted in the 3 groups ($p < 0.001$). Additionally, Group III had the greatest mean POB, then came Group II, and Group I. A statistical significant difference was observed among Groups II and III ($p = 0.021$).

B) Push-out bond strength at Middle third:

Significant differences were found among all sections ($p < 0.001$). Group III had the greatest bond strength, comes after groups II, and I respectively.

C) Push-out bond strength at Apical third:

Significant difference was found in all samples ($p = 0.003$). Group III had the greatest bond strength, followed by Groups II, and I. Significant differences were found among Groups III and I ($p = 0.002$), but not between Groups I and II or Groups II and III.

Table 1: The mean values, standard deviation (SD) of Push-out bond strength (MPa) of different groups.

Variables	Push-out bond strength (MPa)						*p-value*
	Coronal		Middle		Apical		
	Mean	SD	Mean	SD	Mean	SD	
Group I (Side ventedneedle)	4.24 ^{cA}	`AZAZ	3.75 ^{cA}	0.55	2.21 ^{bB}	0.63	**0.007***
Group II (Diode laser)	6.74 ^{bA}	0.52	5.08 ^{bB}	0.94	3.55 ^{abC}	0.93	**0.009***
Group III (Er-YAG laser)	7.90 ^{aA}	0.83	6.33 ^{aB}	0.85	4.47 ^{aC}	1.16	**0.008***
p-value	**<0.001***		**<0.001***		**0.003***		

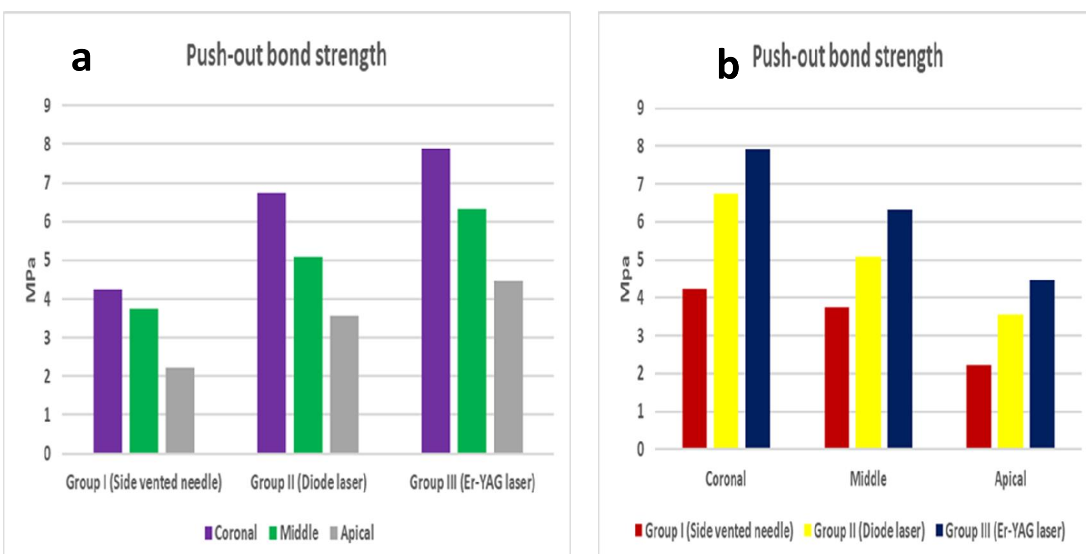

Fig. 1: A) Bar chart illustrates push-out bond values of the experimental groups. B) shows the relation between experimental groups in each section.

4. Discussion

An efficient root canal therapy requires an efficient chemo-mechanical preparation, with complete obturation of the pulpal cavity. This process requires pulp tissues removal and eradication of micro-organisms along with their irritants from the canals space, and the elimination of the smear layer (Do *et al.,* 2020).

Usually, endodontics employs various methods for activating the irrigants to ensure long-term success. Most researches had indicated that the agitation method significantly enhances tissue dissolution more than temperature does. Consequently, diverse agitation techniques have been suggested to improve irrigants efficiency such as sonic and ultrasonic devices, manual agitation, and laser devices. (Natansabapathy *et al.,* 2020). Er:YAG and Diode lasers possess a broad range of features that make them highly effective for smear layer elimination, with antibacterial activity enhancing the disinfection of pulp spaces, contributing to improved outcomes in endodontic treatment. (Natansabapathy *et al.,* 2020).

PIPS is a LAI methods which utilize the photo-mechanical outcomes of lasers at little settings by creation acoustic streaming and cavitation within the endodontic irrigation solutions. The Er:YAG laser, operating at fractionated bi-polar radiofrequency energy levels , producing super-small pulses, generating shockwaves with intracanal cavitation due to its photo-acoustic and photo-mechanical effects. This method can be considered an advanced approach for irrigant activation, enhancing the effectiveness of endodontic treatments. (Do *et al.,* 2020 and Kırmal *et al.,* 2021).

This study focusses on the effect of diode laser and photo-induced photoacoustic streaming (PIPS) agitations on push-out bond strength. The diode optical fiber tip was inserted two millimeters shorter than the WL within the root canal, then it was slowly removed in an in-out motion to address the paralleling laser energy release. This technique ensured that the radiation reached all canal parts. According to previous considers, on utilizing laser parameters 2 W with continuous mode; maintenance of hydration level is a must to prevent plenty of side effects which can occur onusing laser irradiation, as dissolving dentin surface and occluding tubules which was accomplished through continuously irrigating the root canal. (Dhawan *et al.,* 2020).

Never the less, the PIPS tip only inserted inside the coronal cavity, unlike other tips that need to be introduced into the root canal, utilizing the photoacoustic shockwaves that were generated by the laser pulses, enabling the irrigating liquid to travel into the pulp spaces in three dimensions. (Hong *et al.,* 2020).

The Erbium-YAG laser, when activated in a water-based solution, rapidly heated the irrigant to a temperature exceeding the boiling point, resulting in the creation of vaporizing effervescences at the distal end of the fiber rod, where they reach their maximum volume before collapsing. (Otaify *et al.,* 2020). As the bubbles grow and become unstable, they eventually implode, generating lateral and shear forces that can remove surface materials at the pulpal space walls. This phenomenon improves the efficiency of endodontic irrigants through this photoacoustic agitation, promoting 3D streaming of the irrigant solution and effectively eliminating the smear layer. (Dhawan *et al.,* 2020).

The push-out test was employed in this research to assess the bond quality of root canal filling materials to dentin. Assessing bond quality is essential for successful root canal treatment, as it directly impacts the adhesion of root canal sealers to the pulpal walls, thereby preventing microleakage and recurrent infection. (Mancini *et al.,* 2021 and Sreedev *et al.,* 2020). Various research examined the adaptability of the sealers against root canals dentin. Nevertheless, there are few studied the effect of the last irrigant used with the depth of penetration of root canal sealers and the quality of the push-out bond of obturation materials. The smear layer removal affects bond quality aligning with the present results findings. Where the diode laser group (GpII) exhibited high POB strength, that can be referred to the efficiency of removed smear layer and organic tissues from the walls of the canal. This improvement reflects the importance of efficient irrigation techniques in enhancing the bond of root canal fillings. (Mohammadian *et al.,* 2019).

Using both and PIPS and Diode laser proved high efficiency in achieving excellent bond quality. This finding aligns with Moura-Netto *et al.,* 2012), who demonstrated that lasers improve the flow of RC sealers into dentinal tubules. Ultimately accompanied with higher bond strength. This highlights the significant role of advanced irrigation techniques in improving the effectiveness of endodontic sealing materials. (Moura-Netto *et al.,* 2012).

Comparing different areas of the root canal, the cervical thirds recorded the highest bond strength than the other two thirds of the canal. This can be attributed to the fact that incomplete polymerization of the resinmaterial of sealer can cause a decrease in bond strength in deeper regions. (Elmessirya *et al.,* 2019). Laser application in root canal therapy effectively eliminates the smear layer, promoting better flow of sealers within the canal walls. This process enhances the filling of the pulpal space with better dentinal tubules seal. However, significant differences have been observed across different studies due to variations in laser parameters and experimental conditions. The clinical application of lasers requires more standardized experiments to strengthen their use in practice. Overall, the results of the current experiment highlight the promising potential of laser technology in root canal treatment, particularly in enhancing apical sealing when lasers are used for irrigant activation prior to obturation (Elmessirya *et al.,* 2019, Lukac *et al.,* 2017, Ballal *et al.,* 2018, Carmo *et al.,* 2018, Ekim and Erdemir 2015, DiVito *et al.,* 2012, George *et al.,* 2008 and Lukac *et al.,* 2016).

More studies should focus on enhancing the effects of lasers on various irrigating solutions to optimize smear layer removal. Additional in vivo studies are essential to validate the clinical relevance of these results and optimize laser parameters for routine endodontic practice**.**

4. Conclusion

Under the conditions of this study, the results indicate that:

- Bond strength values of AH Plus sealer were affected by combined effect of both irrigation solutions and activation techniques.
- The use of lasers effectively eliminate the smear layer, that contributes to improved adhesion of root canal sealers and canal surfaces.
- Both diode and Er:YAG laser irrigation improved push-out bond strength.
- Er:YAG laser (PIPS) showed the best solution penetration with subsequently more sealer adaptation with the greatest bond values .
- There is significant difference in bond quality among the three thirds of the root canal, indicating that laser activation may have varying effects based on canal anatomy.

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