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# EFFICACY OF DIODE LASER ACTIVATED IRRIGATION (980 NM) AND PASSIVE ULTRASONIC IRRIGATION IN TERMS OF SMEAR LAYER REMOVAL IN OVAL-SHAPED CANALS: A COMPARATIVE IN-VITRO STUDY

Sherif Adel Elkhodary * *and* Dina A. Morsy **

## *ABSTRACT*

**Objective:** This study evaluated the effectiveness of Diode laser (980 nm) activated irrigation to passive ultrasonic irrigation and traditional irrigation needles for smear layer eradication.

**Methodology:** To achieve a uniform length of 16 mm, 45 extracted permanent single-rooted mandibular premolars were disinfected and decoronated. After sealing the apices with flowable composite and impeding them in epoxy resin blocks, all teeth were mechanically prepared with ProTaper Next rotary files up to X4. NaOCl was utilized as an irrigant in between each file. According to the activation method, samples were randomly assigned to one of three groups (n=15): Group 1 (DL): a 980 nm Diode laser coupled with an optical fiber of 200 µm; Group 2 (PUI): passive ultrasonic irrigation; and Group 3 (CG): a conventional irrigation protocol without activation (Control group).

**Results:** There was a significant difference between the three groups in coronal middle and apical thirds ($p = 0.01$, $p < 0.001$ and $p = 0.003$ respectively). There were no significant differences between PUI and DL activation-irrigation efficacy regarding the smear layer removal. On the other hand, there was a significant difference between both groups and the control group at the middle third. While only the DL showed significant difference from the CG at the coronal and apical thirds.

**Conclusion:** DL demonstrated excellent cleaning effectiveness at all root-canal sections that was comparable to PUI. However, no activation approach was able to completely remove the smear layer.

**KEYWORDS:** smear layer removal, Diode Laser, Passive ultrasonic activation (PUI), irrigation activation.

* Associate Professor of Endodontics, Department of Endodontics, Faculty of Dentistry, Cairo University. School of Dentistry, Newgiza University.
** Lecturer of Endodontics, Department of Endodontics, Faculty of Dentistry, Cairo University.

## INTRODUCTION

The foundation of a successful endodontic procedure is the chemo-mechanical preparation of the root canal system. To achieve more predictable, quicker, and safer preparation, revolutionary developments in instrumentation have been made during the past few years. No device, however, can completely clean the root canal space, particularly in large oval canals where the presence of untouched buccal and lingual extensions or recesses might harbor bacterial biofilms and tissue debris. Also, the role of irrigation solution is both highly advantageous and crucial due to the organic and inorganic debris that is produced because of the cutting instruments' action and is either packed inside the root canal or adhered to the canal walls.

It is asserted that traditional irrigation techniques and typical irrigation needles have little impact on root canal preparation. This is related to the complicated morphology, including fins, isthmuses, ramifications, accessory canals, and lateral canals, which restricts the penetration of irrigation fluid into regions that cannot be reached by mechanical instruments [1].

Furthermore, the irrigation fluid only extends a few millimeters past the needle tip [2]. Also, the vapor lock effect, which is caused by trapped gases in the apical portion of the canal, decreases the effectiveness of traditional irrigation methods, especially in the apical third of the canal. [3].

To boost the effectiveness of irrigating solutions, various approaches and irrigant delivery devices have been improved. They aim to increase the flow and distribution of irrigating solutions within the root canal. These comprise brushes, manually activated files, gutta-percha cones, ultrasonic, sonic, and laser devices [4].

Passive ultrasonic irrigation (PUI) concept uses a smooth wire or an oscillating file transmitting acoustic energy to an irrigant within the root canal space, it is a non-cutting irrigation technique. This method of irrigation causes the irrigating fluid to stream and cavitate, which disrupts the vapor lock. PUI is more efficient in removing pulpal tissue remnants and dentine debris than syringe needle irrigation. This might be because ultrasonic irrigation creates a considerably higher velocity and volume of irrigant flow in the canal [5]

Following development of the laser techniques and devices, the Diode Laser (DL) has gained increasing value due to its compactness and low cost. The DL is recommended for endodontic treatment because its wavelength is within the infrared range, also thin and flexible fibers can be used. The use of laser-activated irrigation gained interest in endodontics; as it enhances the warming of the irrigant all while agitating it, improving its impact. Diode laser removal of the smear layer using EDTA solution has also been reported to be successful [6,7].

So, the purpose of this study was to evaluate the effectiveness of smear layer removal using the Diode laser (980nm) activated irrigation, PUI and conventional irrigation needle.

## MATERIALS AND METHODS

### Sample size calculation:

Sample size was calculated using the (PS software). Regarding removing of smear layer, we found that a sample size of 8 teeth per group, for a total of 45 teeth (3 groups), is adequate for the study. The power is 80%, and the $\alpha$ error probability is 0.05. The mean and standard deviation of the relevant variable were retrieved from the scientific literature, where **Mancini et al. (8)** reported a standard deviation of 0.76, and were used to assess the size of the effect to be found.

### Sample selection:

Forty-five (45) extracted mandibular premolars in total, were selected. Each with a single root and

a single, oval-shaped canal with fully developed apices. First, buccolingual and mesiodistal two-dimensional radiographs were collected, to confirm the presence of a single oval canal and the exclusion of calcification, root fractures, and/or internal resorption. Hard deposits and adherent tissues were completely removed from the external root surfaces using ultrasonic scaling. Samples were cleaned with sodium hypochlorite (NaOCl) for 30 minutes after that, and they were then kept in saline solution until their use. To achieve 16 mm uniform root lengths, the teeth were decoronated using a low-speed diamond saw while being heavily irrigated. The working length was adjusted using K-file size #15 after a K-file size #10 was put in the canal to verify for patency, yielding a standard working length of 15 mm for all specimens. To prevent irrigation fluid extrusion and replicate in-vivo settings, the apices were sealed with flowable-composite Filtek Supreme (3M ESPE, St. Paul, MN, USA) and impeded in epoxy resin blocks. ProTaper Next rotary files (Dentsply Maillefer, Ballaigues, Switzerland) were used to instrument the root canals in accordance with the manufacturer's recommendations up to X4 (0.40 tip size and 6% taper). After each file, the canals in all groups were irrigated with 3 ml of freshly prepared 2.6% NaOCl using 30-gauge max-i-Probe needle tip (Dentsply Maillefer, Ballaigues, Switzerland) that was positioned 1mm away from the working length. By placing a #10 K-file in between each rotary file, apical patency was maintained.

- According to the final irrigation technique, the specimens were randomized into 3 groups (n=15) as follows:

***Group one (DL):*** Diode laser activated irrigation (980 nm).

***Group two (PUI):*** Passive Ultrasonic Irrigation activated irrigation.

***Group three (CG):*** conventional irrigation protocol without activation (Control group).

**Intervention: For DL,** the canals were irrigated with 5 mL 2.6% NaOCl that was activated by the 980nm Diode laser with the 200 μm fiber optic (Lite medics, Italy) for a total of 20 seconds for each irrigant. The laser's highest output was 12 watts at a 980nm working wavelength. The laser setting employed in this investigation was 1.2-watt power in pulsed mode. The irradiation protocol was as follows: a lasing cycle consisted of a 5 second activation of irradiation, followed by a 20 second pause. For each tooth, the lasing cycle was applied four times, using 1.25 ml of 2.6% NaOCL each time. Radiation lasted for a total of 20 seconds. After rinsing the canals with 2.5 ml distilled water (DW), same protocol of irradiation was applied with the 17% EDTA. Thus, 1.25 mL of EDTA was used at each lasing cycle and the procedure was repeated four times. Consequently, the total radiation exposure for both irrigants was 40 seconds. The tip was placed 1 mm short of the apex, activated, and then slowly pulled-out in a helicoidal movement at a speed of about 2 mm/sec [9] touching the canal walls to promote even light diffusion inside the root canal lumen, to irradiate the root canals from apical to coronal section [10]**.** The canals were then dried with paper points # F4 (Dentsply Maillefer, Ballaigues, Switzerland) after being rinsed with 2.5 mL of DW.

**For PUI,** the woodpecker ultrasonic system (Woodpecker, China) and an IrriSafe tip (Satelec, France) size 25,.00 taper file was used to irrigate the canals with 5 mL 2.6% NaOCl and activate it. One mm short of the WL, the IrriSafe tip was introduced into the canal, and the irrigant was ultrasonically activated for one minute. After rinsing the canal with 2.5 mL of DW, the same PUI method was used to activate 5 ml of 17% EDTA for 1 minute also. To avoid contact with the canal walls, which could dampen the file's oscillatory motion, the file was maintained as centered as it could be. Finally, the canals were rinsed with 2.5 mL DW and dried with paper points (F4).

**For CG (control),** the canals were irrigated with 5 mL 2.6% NaOCl followed by 5 mL 17% EDTA with 2.5 mL distilled DW in between and as final

flush with no activation. Each irrigant (NaOCl and EDTA) was kept in the canals for 1 minute. the canals were rinsed with 2.5 mL DW and dried with paper points (F4).

***Preparation for SEM evaluation:***

- To prevent any form of debris from entering the root canal, the canal orifices were sealed off with a damp cotton pellet.
- To allow longitudinal splitting of the specimens, gypsum molds were then cut in half using a chesil and mallet.
- With a low-speed diamond saw, two vertical grooves were cut into the buccal and lingual surfaces of the root.
- First, the buccal groove was created by setting the specimen in the first half of the gypsum mold. Next, the specimen was retrieved using a tweezer and set once more on the second half of the gypsum mold to create the lingual groove.
- The grooves ended just before the canal, and the specimens were then longitudinally split into two halves using a chisel and mallet. This allowed for the subsequent SEM analysis of the smear layer at specific distances from the apex 3, 6, and 9 mm, which correspond to the apical, middle, and coronal thirds of the roots, respectively.
- The split tooth was then taken out of the gypsum mold using tweezers, and the two halves of each specimen were examined under a stereo microscope (Leica Microsystems, Switzerland) at a magnification of 16X to determine which half was the most representative.
- The chosen half was then dried out and fixed to metal stubs with electro-conductor glue so that it could be analyzed with an environmental SEM (FEI company, Hillsboro, Oregon,USA) which had an acceleration voltage of 20 K.V. and a spatial resolution of 1.5 mm.
- All the specimens were scanned at a 1000X and 2000X magnifications.
- The SEM photographs were evaluated using a scoring method. Two observers were blindfolded as they scored the SEM images.

**Scoring system for assessment of smear layer removal described by Hülsmann et al., 1997 [11]:**

- Score 1: No smear layer, dentinal tubules open.
- Score 2: Small amount of smear layer, some dentinal tubules open.
- Score 3: Homogenous smear layer covering the root canal wall with only few dentinal tubules open.
- Score 4: root canal walls completely covered with smear layer with no open dentinal tubules.
- Score 5: Heavy, non-homogenous smear layer covering the complete root canal wall.

**Ethics**

The protocol of this in-vitro study was reviewed and approved by the ethics committee (EC). Ethics approval number: (29 11 22). After receiving the results and finishing the experiment, all the instruments and teeth samples were sterilized and discarded in a special incinerator under supervision of Microbiology department-Cairo University.

**Statistical analysis**

Data were presented as mean, standard deviation, median, range and 95% confidence intervals. Between group comparisons were conducted using Kruskal Wallis test followed by Mann Whitney U test for pairwise comparisons. Significance level for statistical tests was set at $p < 0.05$. Statistical analysis was performed using SPSS software (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp).

## RESULTS

### Comparison of smear layer scores between the three groups:

The mean and standard deviation values of the smear layer score in the coronal third were 1.58 (0.51) in the diode laser group (DL), 1.92 (0.79) in the ultrasonic group (PUI) and 2.75 (1.06) in the control group (CG). There was a significant difference between the three groups ($p = 0.01$).

The mean and standard deviation values of the smear layer score in the middle third were 1.25 (0.45) in the DL, 1.67 (0.78) in the PUI and 3.08 (0.9) in the CG. There was a significant difference between the three groups ($p < 0.001$).

The mean and standard deviation values of the smear layer score in the apical third were 2.08 (0.9) in the DL, 2.5 (0.8) in the PUI and 3.33 (0.65) in the CG. There was a significant difference between the three groups ($p = 0.003$) (Table 1, figure 1)

### Pairwise comparison between groups:

In the coronal third, the showed significantly less smear layer scores than the CG. The PUI did not significantly differ from the CG, DL, or either group.

In the middle thirds, the DL and PUI showed significantly lower smear layer score than the CG. There was no significant difference between the DL and the PUI groups.

In the apical third, the DL showed significantly less smear layer scores than the CG. There was no significant difference between the PUI and both the DL and the CG groups.

- The SEM photographs were evaluated by two blindfolded assessors using the Hulsmann's scoring method for evaluating smear layer (Fig. 2, 3).

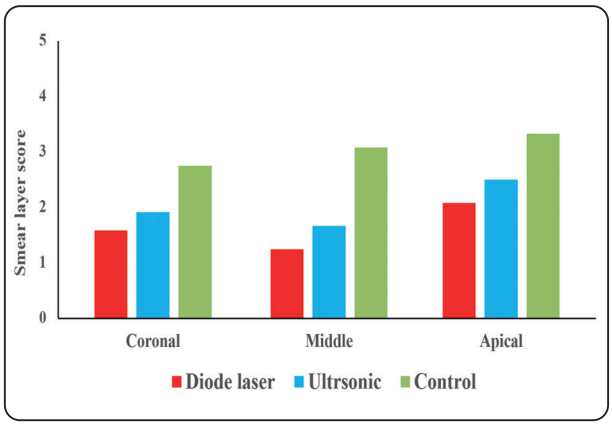


Fig. (1): bar chart representing the mean smear layer score in the three thirds in the three groups.

TABLE (1): Descriptive statistics and the results of Kruskal Wallis test and Mann – Whitney U post hoc test for comparison of the debris scores between the three groups:

| | | Diode laser | Ultrasonic | Control | *p*-value |
|---|---|---|---|---|---|
| **Coronal** | **Mean (SD)** | 1.58$^{b}$ (0.51) | 1.92$^{ab}$ (0.79) | 2.75$^{a}$ (1.06) | **0.01*** |
| | **Median (Range)** | 2 (1 - 2) | 2 (1 - 4) | 2 (1 - 4) | |
| **Middle** | **Mean (SD)** | 1.25$^{b}$ (0.45) | 1.67$^{b}$ (0.78) | 3.08$^{a}$ (0.9) | **<0.001*** |
| | **Median (Range)** | 1 (1 - 2) | 1.5 (1 - 3) | 1.5 (2 - 4) | |
| **Apical** | **Mean (SD)** | 2.**08**$^{b}$ (0.9) | 2.5$^{ab}$ (0.8) | 3.33$^{a}$ (0.65) | **0.003*** |
| | **Median (Range)** | 2 (1 - 4) | 2.5 (1 - 4) | 2.5 (2 - 4) | |

***Significant at p<0.05, ns: non-significant.***

****Means with different small letters in the same row indicates significant difference, means with different capital letters in the same column indicates significant difference.***

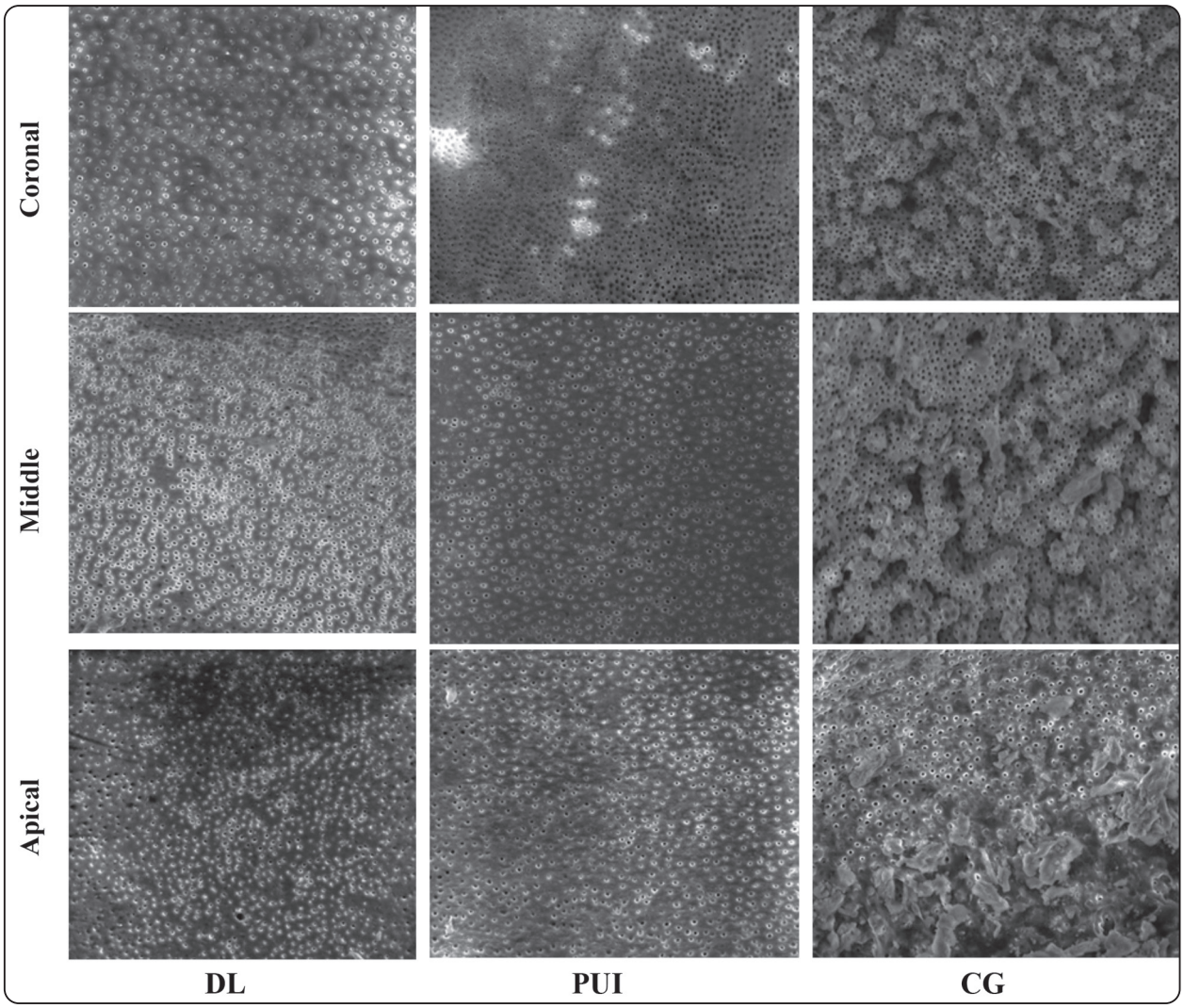


Fig (2): SEM photomicrographs (1000X) of the DL, PUI and CG at coronal, middle and apical thirds

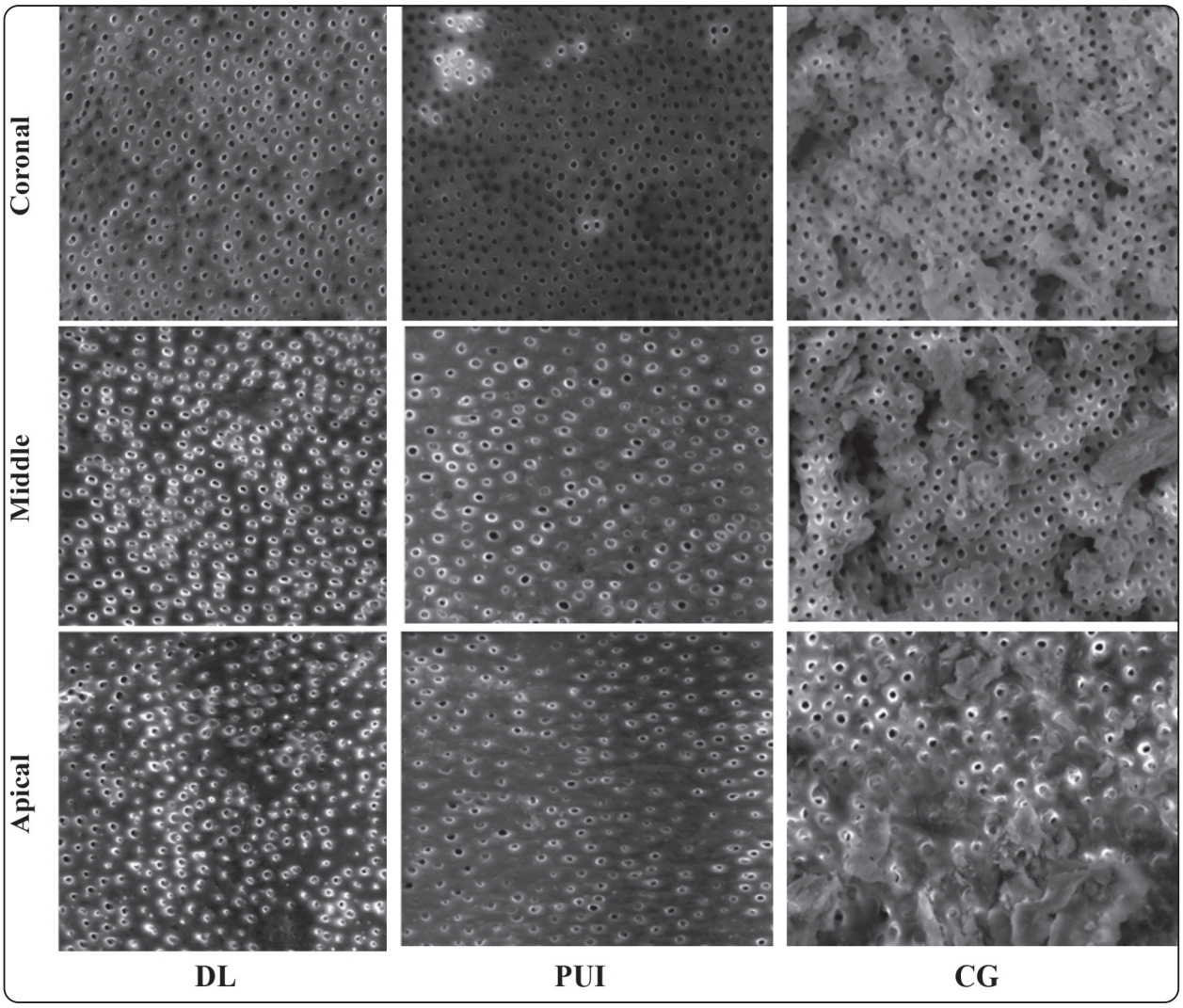


Fig. (3): SEM photomicrographs (2000X) of the DL, PUI and CG at coronal, middle and apical thirds

## DISCUSSION

Regardless of the innovations in the field of instruments, no instrument can entirely prepare the entire internal dentin surface and nearly 35–53% of the root canal surface remains untouched. This developed the paradigm shift in the role of "shaping" from mainly a debridement function to a model of being more as a radicular access for the irrigation to the complex root canal systems [12, 13]. Moreover, the instrumentation process results in creating a microscopic layer "Smear Layer" of about 2–5 micrometers and thickness on the dentin surface with up to 40 micrometers packed into the dentinal tubules by capillary action [14].

The smear layer produced during root canal instrumentation is composed of dentin chips, bacteria and their byproducts, microorganisms, and tissue remnants [15]. This layer coats root canal dentinal walls which preserve bacteria in the dentinal tubules, interferes with deep penetration of irrigating solution and root canal sealer and prevents adaptation between obturation material and root canal wall that can disturb the apical seal which subsequently affects the success rate of endodontic treatment [16, 17].

In the current study, Sodium hypochlorite (NaOCl) followed by EDTA was selected as the irrigation protocol as it is currently recognized as the most efficient irrigating clinical protocol [18–20]. Owing to its effectiveness in the removal of the smear layer where the (NaOCl) has the capability to remove organic components while the EDTA (chelating agent) is concerned with the inorganic part of the smear layer.

Syringe irrigation, while a common practice for root canal irrigation, is incompetent in the apical portion of the root canal. Because the apical third of the root is smaller than the other thirds and so inhibits the circulation and action of the irrigating solutions, hence, it is challenging to eliminate the remnant smear layer there [8, 21]. As the conventional irrigation technique only delivers the solution just beyond the needle tip failing to disrupt the air entrapped in the apical portion thus limiting the irrigant exchange in this area [2].

Hence, variable irrigant delivery systems and activation techniques were introduced to overcome especially the phenomenon of the vapor lock occurring at the apical portion [4, 22]. To increase the efficacy of irrigating solutions in the apical area, acoustic and hydrodynamic properties of irrigants have been investigated **(23)**; agitation with a laser or passive ultrasonic irrigation (PUI) has been utilized in endodontic therapy to decrease the amount of bacteria and alter the surface of the root canal [24].

PUI improves the diffusion of root canal irrigants via acoustic streaming and/or cavitation. This irrigation technique enables to deliver solutions to places that were previously challenging to reach with conventional irrigation methods. The PUI approach aids in the elimination of the hard tissue debris and smear layer. Moreover, PUI improves the disinfection effectiveness of chemical irrigants by lowering bacterial content [23].

Several laser wavelengths in the field of endodontics have been researched. The diode laser (DL) is portable, and efficient for practical disinfection and sterilizing procedures [25-30]. This can be achieved using a thin flexible fiber which can be easily carried into narrow and curved canals and can also reach untouchable areas in the root canals. Wang et al., in 2005; confirmed that root canal preparation combined with 980nm laser irradiation was effective at cleaning canal walls, opening dentinal tubules, and reducing apical leakage [31].

Therefore, the present study was designed to compare the efficacy of DL and PUI in terms of smear layer removal in oval-shaped canals at all root thirds and their effect on the smear layer, evaluated by SEM photographs.

The environmental scanning electron microscope (ESEM) was selected in the current study over Scanning electron microscopy (SEM) owing to its ability to scan samples without pretreatment eliminating the probability of artefacts produced during sample preparation for the conventional SEM [32]. Magnification of 1000X was chosen to evaluate the smear layer scoring in the present investigation despite of obtaining images at 1000X and 2000X since it yields a large surface area with distinguished details [33, 34].

In the present investigation, there was a significant difference between the three groups at coronal, middle and apical thirds. Pairwise comparisons revealed no significant differences between DL and PUI efficacy regarding the smear layer removal at the 3 sections evaluated. On the other hand, there was a significant difference between DL and CG at the 3 sections. While PUI showed only significant difference from the CG at the middle third. This could be attributed to the selection of a large apical preparation to X4 which helped to enhance the volume exchange of the irrigants. This agreed with Mancini et al [35], who found no significant difference between PUI and DL regarding smear layer removal.

In our study, the DL showed better smear layer removal than PUI but with no significant difference. These results can be attributed to the

flushing action on the solution caused by the laser beam. Also, the warming effect of laser radiation on the irrigating solution can improve the action of irrigants. The thermal effect was controlled during laser activation in this study through using of pulsed mode, continuous movement of fiber tip and applied for 5 seconds with 20-sec intervals in between each application [(9)]. In addition, using of flexible thin fiber laser tip that can reach the narrowest area of the root canal up to 1mm of the apical constriction causes irrigation activation at this area. The non significance between the DL and the PUI may be attributed to the difference between the total lasing time (40 sec for both irrigants) versus the ultrasonic time (2 minutes for both irrigants).

The ESEM photomicrographs in our study showed patent dentinal tubules in the apical, middle and cervical thirds indicating removal of the smear layer. LAI showed no morphologic changes in the root canal dentin, which agreed with the findings of Wang et al [(31)] despite of the difference in the irradiation protocol used in his study. However, this disagreed with Parirokh et al **(36)** who showed that laser caused partial to complete occlusion of the dentinal tubules. This may be attributed to the variation in the wavelength and the protocol for laser application.

## CONCLUSIONS

In consideration of this study's limitations, it is possible to conclude that in regards of smear layer removal, irrigation activation with Diode Laser and PUI are both efficient. DL demonstrated excellent cleaning effectiveness at all root-canal sections that was comparable to PUI. However, no activation approach was capable of total elimination of the smear layer.

## REFERENCES


1. Gulabivala, K., Patel, B., Evans, G., & Ng, Y. (2005). Effects of mechanical and chemical procedures on root canal surfaces. *Endodontic Topics*, *10*(1), 103–122.
2. Boutsioukis, C., Lambrianidis, T., & Kastrinakis, E. (2009). Irrigant flow within a prepared root canal using various flow rates: A Computational Fluid Dynamics study. International Endodontic Journal, 42(2), 144–155.
3. Tay, F. R., Gu, L. sha, Schoeffel, G. J., Wimmer, C., Susin, L., Zhang, K., Arun, S. N., Kim, J., Looney, S. W., & Pashley, D. H. (2010). Effect of Vapor Lock on Root Canal Debridement by Using a Side-vented Needle for Positive-pressure Irrigant Delivery. *Journal of Endodontics*, *36*(4), 745–750.
4. Plotino, G., Cortese, T., Grande, N. M., Leonardi, D. P., Di Giorgio, G., Testarelli, L., & Gambarini, G. (2016). New technologies to improve root canal disinfection. *Brazilian Dental Journal*, *27*(1), 3–8.
5. Silva E., Rover G., Belladonna F., Herrera D., De-Deus G. & Da Silva F. (2019). Effectiveness of passive ultrasonic irrigation on periapical healing and root canal disinfection: a systematic review. *British Dental Journal*, *227*(3), 228–234.
6. Ishizaki NT, Kimura Y, Sun Y, Kinoshita J-I, Matsumoto K & Wang X. (2005). Effects of diode laser irradiation on smear layer removal from root canal walls and apical leakage after obturation. Photo Laser Surg., 23: 575–81.
7. Anagnostaki E, Mylona V, Parker S, Lynch E & Grootveld M. (2020). Systematic review on the role of lasers in endodontic therapy: valuable adjunct treatment a review. Dental Journal, 8: 1-18.
8. Mancini, M., Cerroni, L., Iorio, L., Armellin, E., Conte, G., and Cianconi, L. (2013). Smear layer removal and canal cleanliness using different irrigation systems (EndoActivator, EndoVac, and passive ultrasonic irrigation): field emission scanning electron microscopic evaluation in an in vitro study. Journal of endodontics, 39(11), 1456-1460.
9. Shehab NF, Al-Sabawi NA, Alkhalidi EF. Influence of an 810-nm Diode Laser on the Temperature Changes of the External Root Surface: An In Vitro Study. J Int Soc Prev Community Dent. 2020; 10: 445-51.
10. Amin K, Masoodi A, Nabi S, Ahmad P, Farooq R, Purra AR, *et al*. (2016). Effect of diode laser and ultrasonics with and without ethylenediaminetetraacetic acid on smear layer removal from the root canals: A scanning electron microscope study. J Conserv Dent, 19:424-7.
11. *Hülsmann, M., Rümmelin, C., & Schäfers, F.* , (1997b):. Root canal cleanliness after preparation with different

endodontic handpieces and hand instruments: a comparative SEM investigation. *J. Endod*., *23*(5), 301–306.

12. Peters, O. A., Laib, A., Göhring, T. N., & Barbakow, F. (2001). Changes in root canal geometry after preparation assessed by high-resolution computed tomography. Journal of Endodontics, 27(1), 1–6.
13. Peters, O. A., Peters, C. I., & Scho, K. (2003). ProTaper rotary root canal preparation_ effects of canal anatomy on final shape analysed by micro CT I DeepDyve' - www_ deepdyve_com_lp_wiley_prot-053.pdf. 86–92.
14. Eick, J. D., Wilko, R. O. Y. A., Anderson, C. H., & Sorensen, S. E. (1970). Scanning Microscopy by Microprobe. J. Dent. Res, 49, 1359–1369.
15. Torabinejad M, Handysides R, Khademi AA, Bakland LK. Clinical implications of the smear layer in endodontics: a review. Oral Surg Oral Med Oral Pathol Endod. 2002; 94: 658-66.
16. Sterzenbach T, Pioch A, Dannemann M, Hannig C, Weber MT. Quantification of Bacterial Colonization in Dental Hard Tissues Using Optimized Molecular Biological Methods. Front Genet. 2020; 11: 599137.
17. Morago A, Ordinola-Zapata R, Ferrer-Luque CM, Baca P, Ruiz-Linares M, Arias-Moliz MT. Influence of Smear Layer on the Antimicrobial Activity of a Sodium Hypochlorite/ Etidronic Acid Irrigating Solution in Infected Dentin. J Endod. 2016; 42: 1647-50.
18. Garip Y, Sazak H, Gunday M, Hayipoglu S. Evaluation of smear layer removal after use of canal brush: a SEM study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010; 110:62–6.
19. Rödig T, Döllmann S, Konietschke F, et al. Effectiveness of different irrigating agitation techniques on debris and smear layer removal in curved root canals: a scanning electron microscopy study. J Endod. 2010; 36:1983–7.
20. Gonçalves LM, Nabeshima CK, Marting GH, Machado ME. Qualitative analysis of the removal of the smear layer in the apical third of curved roots: conventional irrigation versus activation systems. J Endod. 2011; 37:1268–71.
21. Torabinejad, M., Cho, Y., Khademi, A. A., Bakland, L. K., and Shabahang, S. (2003). The effect of various concentrations of sodium hypochlorite on the ability of MTAD to remove the smear layer. Journal of Endodontics, 29(4), 233-239.
22. Tashkandi, N., & Alghamdi, F. (2022). Effect of Chemical Debridement and Irrigant Activation on Endodontic Treatment Outcomes: An Updated Overview. Cureus, January.
23. Weller, R. N., Brady, J. M., and Bernier, W. E. (1980). Efficacy of ultrasonic cleaning. Journal of Endodontics, 6(9), 740-743.
24. George, R., Meyers, I. A., and Walsh, L. J. (2008). Laser activation of endodontic irrigants with improved conical laser fiber tips for removing smear layer in the apical third of the root canal. Journal of Endodontics, 34(12), 1524-1527.
25. Schoop U, Kluger W, Dervisbegovic S, Goharkhay K, Wernisch J, Georgopoulos A, Sperr W and Moritz A. Innovative wavelengths in endodontic treatment. Lasers Surg Med. 2006; 38:624-30.
26. Moritz A. Innovative wavelengths in endodontic treatment. Lasers Surg Med. 2006; 38:624-30.
27. Moritz A, Gutknecht N, Goharkhay K, Schoop U, Doertbudak O, Sperr W. Irradiation of infected root canals with a diode laser in vivo: results of microbiological examinations. Lasers Surg Med. 1997; 21:221-6.
28. Moritz A, Gutknecht N, Goharkhay K, Schoop U, Wernisch J, Sperr W. In vitro irradiation of infected root canals with a diode laser: results of microbiological, infrared spectrometric, and stain penetration examinations. Quintessence Int. 1997; 28:205-9.
29. Zhang C, Matsumoto K, Kimura Y, Harashima T, Takeda FH, Zhou H. Effects of pulsed Nd:YAG laser irradiation on root canal wall dentin with different laser initiators. J Endod. 1998; 24:352-5.
30. Gutknecht N, Franzen R, Schippers M, Lampert F. Bactericidal effect of a 980-nm diode laser in the root canal wall dentin of bovine teeth. J Clin Laser Med Surg. 2004; 22:9-13.
31. Wang X, Sun Y, Kimura Y, Kinoshita J, Ishizaki NT, Matsumoto K. Effects of diode laser irradiation on smear layer removal from root canal walls and apical leakage after obturation. Photomed Laser Surg. 2005; 23:575-81.
32. Kirk, S., Skepper, J., and Donald, A. (2009): Application of Environmental Scanning Electron Microscopy to Determine Biological Surface Structure. J. Microsc., 233(2): 205-224.
33. Rüttermann, S., Virtej, A., Janda, R., and Raab, W.H.-M. (2007): Preparation of the Coronal and Middle Third of

Oval Root Canals with a Rotary or an Oscillating System. Oral Surg Oral Med Oral Pathol Oral Radiol Endod., 104(6): 852-856.

34. Zmener, O., Pameijer, C.H., Serrano, S.A., Palo, R.M., and Iglesias, E.F. (2009): Efficacy of the Navitip Fx Irrigation Needle in Removing Post Instrumentation Canal Smear Layer and Debris in Curved Root Canals. J. Endod, 35(9): 1270-1273.

35. Mancini, M.Cerroni L, Palopoli P, Olivi G, Olivi M, Buoni C and Cianconi L. (2021) "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, 21(1).

36. Parirokh M, Eghbal M, Asgary S, Ghoddusi J, Stowe S, Forghani F, and Shahravan A. Effect of 808nm diode laser irradiation on root canal walls after smear layer removal: A scanning electron microscope study. Int Endod J 2007; 3:37-42.