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Original Article

Comparative Evaluation of the Effectiveness of Passive Ultrasonic and Laser-Activated Irrigation Techniques on Irrigant Penetration: An *in vitro* Study

Elsy P Simon[1], P Rishana[2], Rohit Mathew[3], P K Nejiya[3], Nimmy Kurian[3]

[1]Professor and Head, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Kozhikode, Kerala, India, [2]3rd Year Post Graduate Student, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Kozhikode, Kerala, India, [3]Senior Lecturer, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Kozhikode, Kerala, India

Abstract

Introduction: Successful endodontic therapy hinges on complete debridement and disinfection, with the apical third being especially difficult due to its complex anatomy, which limits mechanical cleaning and harbors biofilms. Chemical irrigants such as sodium hypochlorite (NaOCl) and ethylene diamine tetra acetic acid are vital, but traditional positive-pressure syringe irrigation often fails near the apex due to vapor lock. Activation systems – passive ultrasonic irrigation (PUI), which uses acoustic streaming and cavitation, and laser-activated irrigation (LAI) with erbium lasers that induce powerful photoacoustic streaming – enhance fluid dynamics and improve penetration into hard-to-reach areas. *In vitro* and *ex vivo* studies consistently show that both PUI and LAI outperform syringe irrigation in deep irrigation effectiveness. This study thus compares positive pressure irrigation (PPI), PUI, and LAI for apical third irrigant penetration to guide clinical protocols and improve treatment outcomes.

Purpose: The purpose of this study was to evaluate and compare the effectiveness of PUI and LAI against conventional PPI in facilitating irrigant penetration in the apical third of root canals.

Materials and Methods: Thirty-six extracted single-rooted premolars were prepared using Nickel-Titanium (Niti) rotary instruments to a size 25/06 taper. Teeth were divided into three groups based on final irrigation protocols: Group 1 – PPI, Group 2 – PUI, and Group 3 – LAI. The final irrigant solution mixture used was prepared with 90% of 3% NaOCl and 10% methylene blue dye. Penetration depth of the dye into the apical 5 mm of the canal was assessed under a stereomicroscope using ImageJ software.

Results: Statistically significant differences were observed among the groups. LAI demonstrated the highest mean depth of irrigant penetration, followed by PUI and PPI.

Conclusion: LAI significantly enhances irrigant penetration in the apical third, outperforming both passive ultrasonic and conventional syringe irrigation. LAI may serve as a valuable adjunct in endodontic disinfection protocols.

Key words: Apical third irrigation, Irrigant penetration, Laser-activated irrigation, Passive ultrasonic irrigation, Positive pressure irrigation

INTRODUCTION

Successful endodontic treatment relies heavily on the complete debridement and disinfection of the root canal system. The apical third remains particularly challenging due to its complex and constricted morphology, presence of lateral canals, apical deltas, and anatomical irregularities. These features significantly limit the effectiveness of mechanical instrumentation and create anatomical niches that harbor microbial biofilms and debris, often inaccessible to conventional cleaning techniques.[1]

Chemical irrigation using agents such as sodium hypochlorite (NaOCl) and ethylene diamine tetra acetic acid (EDTA) play a critical role in disrupting biofilms, dissolving organic tissue, and removing the smear layer created during instrumentation. However, the deep penetration of these

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Corresponding Author: Dr. Elsy P Simon, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Manassery (Po), Mukkam, Kozhikode - 673602, Kerala, India.

agents into the anatomical recesses is essential for effective canal disinfection. The traditional syringe irrigation, also known as positive-pressure irrigation (PPI), suffers from inherent limitation, especially in the apical third. In this constricted space, an apical vapor lock which formed by entrapped air inhibits fluid exchange and restricts irrigant penetration to the critical apical area.[2]

To enhance the efficacy of irrigation and break the vapor lock, activation techniques have been developed that aim to improve fluid dynamics and mechanical energy delivery into the canal system. Passive ultrasonic irrigation (PUI) utilizes ultrasonically oscillating tips to generate acoustic streaming and cavitation which dislodges debris and smear layer. It also enhances irrigant replacement and penetration deeper into the canal depths and recesses.[3,4]

LAI particularly using erbium lasers (Er: YAG and Er, Cr: YSGG) induces photoacoustic streaming through rapid vapor bubble formation and collapse. This generates powerful intracanal fluid movement, capable of disrupting biofilms and dislodging dentinal debris even in areas inaccessible to files.[5,6] While LAI shows promise in enhancing root canal disinfection, its performance relative to ultrasonic methods remains an area of active investigation.

Given these considerations, the present *in vitro* study aims to compare the effectiveness of PPI, PUI, and LAI in facilitating irrigant penetration specifically in the apical third of the root canal. Understanding the comparative efficacy of these techniques could significantly influence clinical decision-making and endodontic treatment protocols.

MATERIALS AND METHODS

The present study was approved by the Institutional Ethics Committee with an IEC/IRB No: KMCTDC/IEC/C/2024/76.

Sample Selection

Thirty-six freshly extracted single-rooted human premolars with mature apices were selected. Teeth with cracks, resorptive defects, or previous endodontic treatment were excluded from the study.

Canal Preparation

Standard access cavities were prepared. Working length was established using a size 10 K-file, and all canals were instrumented up to size 25/06 using NiTi rotary instruments. Syringe irrigation during instrumentation was carried out with 5 mL of 3% NaOCl and lastly 2 mL of 17% EDTA. Thereafter, all specimens underwent a final irrigation protocol.

Grouping and Final Irrigation Protocol

The final irrigant solution used was prepared by mixing 90% of 3% NaOCl and 10% methylene blue dye. The presence of the dye will disclose the extend of irrigant penetration. Specimens were randomly divided into three groups (n = 12)

- Group 1 – PPI: 2 mL of irrigant was delivered over 60 s using a 27-G side-vented needle kept 2 mm short of working length [Figure 1].
- Group 2 – PUI: 2 mL of the irrigant was delivered and activated with a #25 ultrasonic tip inserted 2 mm short of the working length at power setting 5 for 60 s [Figure 2].
- Group 3 – LAI: 2 mL of the irrigant was activated with an Er: YAG laser (2940 nm) operated at 0.5 W, 50 mJ, 10 Hz, and 158 ms pulse for 60 s. The laser tip was inserted 2 mm short of working length [Figure 3].

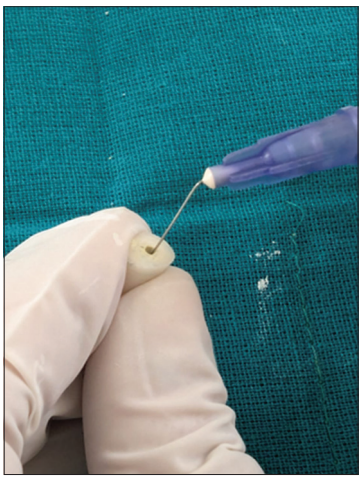


Figure 1: Conventional syringe irrigation

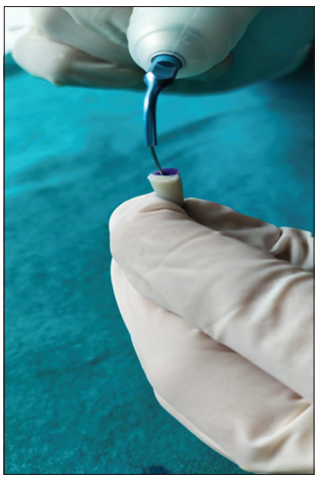


Figure 2: Passive ultrasonic irrigation

Evaluation of Irrigant Penetration

After final irrigation, the teeth were sectioned longitudinally. The apical 5 mm of the canal was examined under a stereomicroscope. Dye penetration was measured using ImageJ software.

Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA) to compare the mean penetration depths among the three groups. A *post hoc* Tukey test was applied to assess pair wise significance. The significance was set at $P < 0.01$.

RESULTS

The extent of irrigant penetration in the apical 5 mm of the root canal was evaluated across the three groups. Mean apical irrigant penetration in dentinal tubules in each group was calculated. Group 3 demonstrated the greatest apical dye infiltration with a mean penetration depth of 2.1442 mm [Figure 4]. This was followed by Group 2 [Figure 5] with 1.4908 mm dye penetration and lastly Group 1 [Figure 6] with a mean value of 0.4100 mm. The ANOVA revealed significant differences ($P < 0.01$) between the three groups. The Tukey test confirmed that LAI was significantly more effective than both PUI and PPI [Table 1 and Graph 1].

DISCUSSION

This *in vitro* study evaluated and compared the efficacy of three irrigation technique, namely, PPI, PUI, and laser-activated irrigation (LAI), in achieving irrigant penetration in the apical third of the root canal system. The results clearly indicated that activation-based techniques, especially LAI, significantly enhance irrigant penetration to the apical third, where mechanical instrumentation and conventional irrigation often fail.

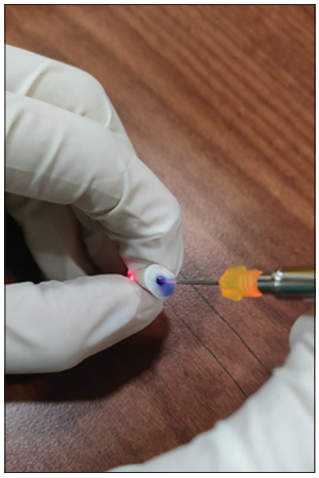


Figure 3: Laser-activated irrigation

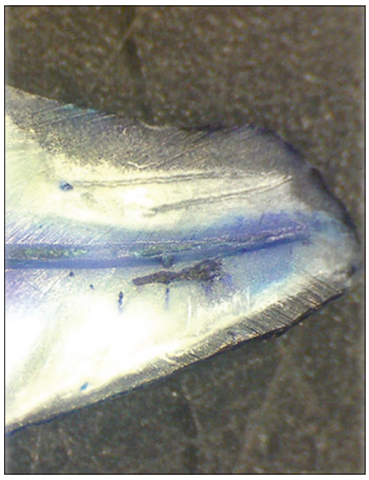


Figure 4: Depth of dye penetration in laser-activated irrigation

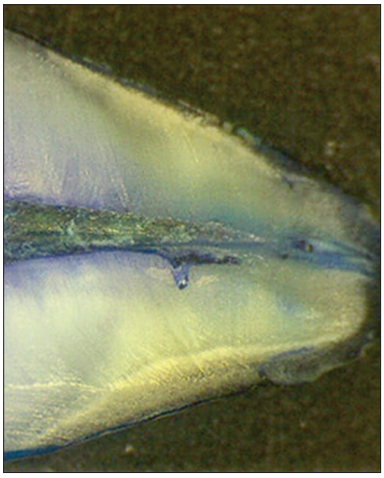


Figure 5: Depth of dye penetration in passive ultrasonic irrigation

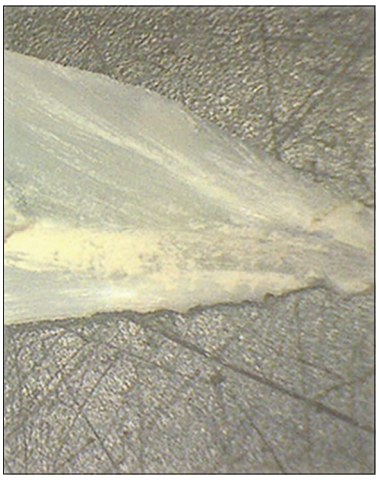
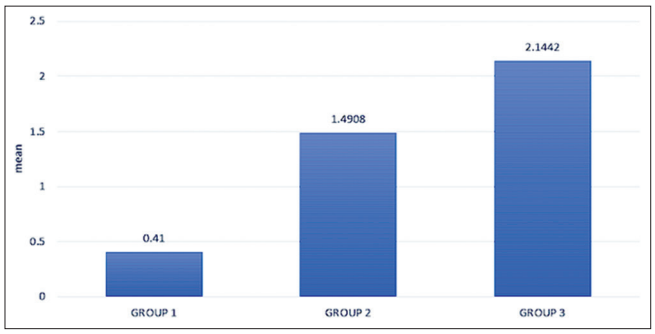


Figure 6: Depth of dye penetration in conventional syringe irrigation

Table 1: Mean extend of apical dye penetration in the dentinal tubules

	N	Mean (mm)	Std Deviation	95%Confidence Interval (Lower bound)	95%Confidence Interval (Upper bound)	*P* Value
GROUP 1	12	0.4100	0.12863	0.3283	0.4917	
GROUP 2	12	1.498	0.25710	1.3275	1.6542	0.001*
GROUP 3	12	2.1442	0.20843	2.0117	2.2766	
TOTAL	36	1.3483	0.75207	1.0939	1.6028	



Graph 1: Bar graph showing mean extend of apical dye penetration in the dentinal tubules comparing three groups

Thus, the null hypothesis was rejected in Group 1, traditional syringe irrigation with a side-vented needle exhibited the least amount of irrigant penetration. This is consistent with the established understanding that syringe irrigation is ineffective in breaking the apical vapor lock in the apical third.[2] Tay *et al.* experimentally demonstrated that this vapor lock significantly compromises apical debridement during conventional irrigation procedures.[3]

PUI achieved markedly greater penetration than PPI, validating the benefits of ultrasonic activation. Ultrasonic devices function through acoustic streaming and cavitation, where high-frequency oscillations induce strong hydrodynamic forces the irrigants deeper into canal irregularities, isthmuses, and lateral canals.[4]

Jiang *et al.*, in 2010, noted that the ultrasonic cleaning efficiency is directly proportional to the intensity and orientation of the oscillating tip.[5] Furthermore, Malki *et al.* observed that ultrasonic files could displace debris up to 3 mm beyond the file tip, illustrating the practical relevance of ultrasonic agitation in clinical endodontics. PUI also disrupts microbial biofilms and enhances the removal of smear layers, contributing to better apical cleaning and disinfection.[7]

De Moor *et al.*, in 2011, stated that LAI is significantly more effective than both ultrasonic and manual irrigation in removing dentinal debris from the apical third.[6] Similar conclusions were drawn in the present study. The efficacy of LAI stems from photoacoustic streaming and bubble cavitation phenomena, where the pulsed laser energy creates rapidly expanding and collapsing vapor bubbles. These implosions generate powerful shock waves and negative pressures that suck irrigants deep into the apical third, even beyond the reach of mechanical instrumentation.[8] Olivi *et al.* demonstrated that photon-induced photoacoustic streaming using LAI was more effective than traditional methods in disrupting *Enterococcus faecalis* biofilms, underscoring LAI's potent antimicrobial potential.[9]

Despite better results reported, the clinical application of LAI must be carefully considered. One major concern is apical extrusion of irrigants, especially when activation occurs near the apical constriction which can potentially cause post-operative pain or periapical damage. Moreover, high capital costs, technical learning curve, and access to specialized equipment may limit widespread use in general dental practice.[10]

Limitations

Despite its findings, the present study is subject to several limitations:

- Although care was taken to simulate clinical conditions using extracted teeth, *in vivo* factors such as patient movement, periapical pressure, and fluid dynamics were not replicated.
- Factors, such as root curvature, root length, and canal width, can also affect the cleaning efficacy. The samples used in this study were single-rooted premolars with wide canals and minimal curvature. Thus, the results of this study may be correlated to similar conditions only.
- The study included only a total of 36 samples. Larger sample sizes could improve the power and generalizability of the results.
- While methylene blue dye provides visual evidence of penetration, it does not directly assess antimicrobial efficacy or debris removal.
- The potential for apical extrusion, particularly with LAI, was not evaluated and remains a concern in clinical application.
- The study used a specific set of Er: YAG parameters;

variation in energy, pulse frequency, and tip design could influence outcomes and warrant further investigation.

- Future research should include micro-computed tomography or scanning electron microscopy imaging, real-time fluid dynamics assessment, and *in vivo* trials to validate and extend these findings under clinical conditions.

CONCLUSION

Within the constraints of this *in vitro* model, it may be concluded that LAI and PUI are effective irrigant activation techniques and LAI is superior to PUI while PPI is least effective. This study supports the integration of irrigant activation methods, particularly LAI and PUI, into standard endodontic protocols to improve apical cleaning, reduce microbial load, and enhance treatment success.

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REFERENCES

1. Siqueira JF Jr., Rôças IN. Clinical implications and microbiology of bacterial persistence after treatment procedures. J Endod 2008;34:1291-301.
2. Gomes BP, Aveiro E, Kishen A. Irrigants and irrigation activation systems in Endodontics. Braz Dent J 2023;34:1-33.
3. Tay FR, Gu LS, Schoeffel GJ, Wimmer C, Susin L, Zhang K, *et al*. Effect of vapor lock on root canal debridement by using a side-vented needle for positive-pressure irrigant delivery. J Endod 2010;36:745-50.
4. Van der Sluis LW, Versluis M, Wu MK, Wesselink PR. Passive ultrasonic irrigation of the root canal: A review of the literature. Int Endod J 2007;40:415-26.
5. Jiang LM, Verhaagen B, Versluis M, van der Sluis LW. The influence of the ultrasonic intensity and working time on the cleaning efficacy of passive ultrasonic irrigation. J Endod 2010;36:1372-6.
6. De Moor RJ, Meire MA, Goharkhay K, Moritz A, Vanobbergen J. Efficacy of ultrasonic versus laser-activated irrigation to remove artificially placed dentin debris plugs. J Endod 2011;37:1580-3.
7. Malki M, Verhaagen B, Jiang LM, Nehme W, Naaman A, Versluis M, *et al*. Irrigant flow beyond the insertion depth of an ultrasonically oscillating file in straight and curved root canals: Visualization and cleaning efficacy. J Endod. 2012;38:657-61.
8. 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;27:273-80.
9. Olivi G, DiVito E, Peters OA, Kaitsas V, Angiero F, Signore A, *et al*. Disinfection efficacy of photon-induced photoacoustic streaming on root canals infected with *Enterococcus faecalis*: An *ex vivo* study. J Am Dent Assoc 2014;145:843-8.
10. Liapis D, De Bruyne MA, De Moor RJ, Meire MA. Postoperative pain after ultrasonically and laser□activated irrigation during root canal treatment: A randomized clinical trial. Int Endod J 2021;54:1037-50..

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