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Comparative Evaluation Of Smear Layer Removal Using Four Different Irrigation Techniques: An In-Vitro Study

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Abstract

Aim & Background: *To evaluate the in vitro-study was to compare the efficacy of side vent needle, plastic files, endo activator, ultrasonic irrigator and xp-endo finisher.*

Materials and Methods: *Seventy-five freshly extracted single rooted teeth which do not had caries, or were extracted for orthodontic and periodontal reasons with mature apex. Samples were divided into 5 groups randomly before final irrigation as follows: Group I (n=15): Irrigation with side vent needles (Waldent., India); Group II (n=15): Irrigation with sonic irrigator (Waldent), Group III (n=15): In this activation technique, 1 ml of NaOCl was placed into the canal); Group IV (n=15): Plastic files and Group V(n=15): xp-endo finisher irrigation Activation cycle of 30 seconds until 10 ml 3% NaOCl was used, which was activated for 90. Teeth were split using chisel and mallets. One-half of each tooth was chosen for SEM examination to evaluate smear layer removal.*

Results: *The Control Group exhibited the highest smear layer score. The Sonic Activator Group followed with a mean of 2.486 ± 0.135, suggesting a moderate to heavy smear layer. In contrast, the Passive Ultrasonic Group demonstrated the most effective smear layer removal, with the lowest mean score of 1.614 ± 0.107, closely aligned with a minimal smear layer (Score 1). Similarly, the XP-Endo Finisher Group showed improved smear layer removal with a mean of 1.771 ± 0.364, reflecting mild smear layer presence. The Plastic File Group had a mean score of 2.643 ± 0.098, indicating moderate smear layer retention.*

Conclusion: *The findings highlight the superiority of irrigant activation, particularly PUI, in enhancing canal cleanliness.*

Clinical Significance: *This study demonstrates that irrigant activation techniques, especially passive ultrasonic irrigation (PUI) and the XP-Endo Finisher, significantly enhance smear layer removal compared to conventional methods. Incorporating these activation methods in clinical practice can improve treatment outcomes by promoting cleaner canals and reducing the risk of reinfection.*

Keywords: *Side-Vent Needles, xp-Endo Finisher, Plastic File, Passive Ultrasonic, Endoactivator, SEM.*

INTRODUCTION: The success of endodontic therapy is mainly dependent on thorough chemomechanical preparation of the root canal system. Biomechanical preparation of root canal leads to formation of smear layer. This layer comprises both organic and inorganic substances as well as odontoblastic process fragments, other necrotic material, some microorganisms and byproducts. This layer results in prevention of penetration of intracanal medicaments in the dentinal tubules and has a detrimental effect on the sealing ability of obturating material three dimensionally. Therefore, it is imperative to remove the smear layer.[1] Irrigation is responsible for killing organisms, flushing out the debris and removing the smear layer from prepared canals. Also, it has been reported that some of the canal parts remain un-instrumented during canal preparation.[2]

Beyond that, the irrigant remains stagnant, which prevents the canals from being sufficiently cleaned.[2] An upgrade in approaches is necessary to obtain better cleaning, especially in difficult locations, as this irrigating technique's efficiency is not very superior.[3] Over time, a number of innovative methods have emerged, ranging from ultrasonically induced irrigation to the hand dynamic agitation of gutta percha cones.[4] The EndoActivator system, an acoustically triggered irrigation system that forcefully stirs fluid in the canals, is one such method that has emerged for effective cleaning (Advanced Endodontics, Santa Barbara, CA).[5] Another method is called passive ultrasonic irrigation (PUI), which makes use of an ultrasonically actuated file that is neither cutting nor contacting.[3]

Conventional needle irrigation is the most often utilised irrigation method. In the apical portion of the canal, the irrigant is exchanged and refilled. The depth to which the needle penetrates determines how effective this approach is. No more than 1 to 1.5 mm from the needle tip does the irrigant exchange take place. Beyond that, the irrigant stays stagnant, which prevents the canals from being sufficiently cleaned.[4]

Using the passive action of the ultrasonic tip inside the canal, Passive Ultrasonic Irrigation (PUI) is a method that uses ultrasonic energy to improve the cleaning and disinfection of the root canal system. The physical concepts of cavitation, microstreaming, and acoustic streaming—which combine to enhance irrigant distribution and debris removal—are essential to its success. A more recent development in endodontics, neoendo plastic files are made especially to help with cleaning and irrigation during root canal therapy. They were created as a substitute for conventional metal tools and provide clear benefits in specific irrigation processes. The canal system may be effectively cleaned thanks to the design of these plastic files, which are mostly utilised for irrigation activation rather than mechanical debridement. The XP-endo Finisher's XP (eXtra Passive) technology enables the file to alter its shape in reaction to ambient temperature. The file adjusts to the structure of the canal and becomes flexible at body temperature when it is placed within. But as it cools to normal temperature, it gets stiff. This makes it possible to clean sections with intricate canal anatomy or hard-to-reach places like the lateral canals or apical third more effectively. Particularly in narrow or curved canals, the file's suppleness allows it to better adjust to the curvature of the canal, reducing the chance of fractures or canal transportation. Low-frequency sound waves, typically between 1 and 6 kHz, are produced by sonic irrigators, which move the irrigant inside the canal.[6]

The fluid flows along the canal as a result of the acoustic streaming created by these sound waves, enhancing the irrigant's capacity to reach and clean every section of the canal, including those that are challenging to access. Scanning electron microscopy (SEM) is the gold standard for detecting and verifying the existence of smear layers, as well as for evaluating the effectiveness of various debridement techniques.[7] However, in clinical settings, we frequently depend on the agitation and irrigant regimens to presume effective removal. Understanding the effectiveness of various irrigation methods and medications in cleaning the root canal system requires SEM research on the smear layer. Hence, the aim of the study is to compare the efficacy of side vent needle, plastic files, endo activator, ultrasonic irrigator and xp-endo finisher.

MATERIALS & METHODOLOGY

This in-vitro study was carried out in the Department of Conservative Dentistry and Endodontics, Jaipur Dental College and Hospital, Jaipur collaboration with sophisticated analytical instrumentation facility (SAIF, Punjab University Chandigarh).

Inclusion criteria: The selected teeth should be intact, extracted for periodontal reason and non-carious and fully mature apices.

Exclusion criteria: The selected teeth should not have root caries or restorations, open apices, calcifications, fractures, or craze lines.

Sample Size Estimation: Software used G power Version 3.1.9.6 Programme written by Franz Faul University kiel, Formula used $n=d^2/ (Z_{\alpha/2}+Z_{\beta})^2 . (k-1)$

Based on the 90 percent power of the study and 5 percent type I error and effect size of 0.48 (Large effect size), SD=1, the minimum sample size came out to 75 samples which can be divided into five groups of 15 samples each.

Methodology: Seventy-five freshly extracted single rooted teeth which do not had caries, or were extracted for orthodontic and periodontal reasons with mature apex. External surfaces of teeth

were debrided with an ultrasonic scaler (Woodpecker) and kept in normal saline until used. A diamond disc was used to decoronate the samples so as to have a consistent working length of 15mm. #15 K file was used to negotiate the canal, until it passed the apex. Working length was assessed 1mm short of the length, when file tip was visible at the apex. The samples were instrumented in crown- down technique using Heroshaper (Micromega co. ltd.) files 20/.04,25/.04,30/.04 by using J-Morita endomotor with speed of 350 RPM and torque 1.5 Ncm keeping the master apical file 35/.04. During instrumentation, files were coated with Prep Canal (Prime dental, India) for lubrication and irrigated with 1ml of 3% sodium hypochlorite solution (Prevest, India). Samples were divided into 5 groups randomly before final irrigation as follows:

Group I (n=15): Irrigation with side vent needles (Waldent., India): 10ml of 3% NaOCl was delivered over a time period of 90 seconds, followed by 3ml of 17% EDTA for 2 minutes and final rinse with 2ml normal saline for 1 minute.

Group II (n=15): Irrigation with sonic irrigator (Waldent): Activated for 30 seconds until 10 ml 3% NaOCl was used, total activation time was 90 secs, followed by 3 ml of 17% EDTA which was activated for 60 secs and total contact time of EDTA was 2 minutes and final rinse was done with 2 ml of normal saline which was activated for 1 minute.

Group III (n=15): In this activation technique, 1 ml of NaOCl was placed into the canal; then, the): ultra-x Irrigation (Orikam)was placed 1 mm short of the working length and then activated for 1 min, followed by 3 ml of 17% EDTA which was activated for 60 secs and total contact time of EDTA was 2 minutes and final rinse was done with 2 ml of normal saline which was activated for 1 minute.

Group IV (n=15): Plastic files: Activation cycle of 30 seconds until 10 ml 3% NaOCl was used, which was activated for 90 secs, followed by 3 ml of 17% EDTA activated for 60 secs and the total contact time of EDTA was 2 minutes followed by final rinse with 2 ml of normal saline which was activated for 1 minute.

Group V (n=15): xp-endo finisher irrigation Activation cycle of 30 seconds until 10 ml 3% NaOCl was used, which was activated for 90 secs, followed by 3 ml of 17% EDTA activated for 60 secs and the total contact time of EDTA was 2 minutes followed by final rinse with 2 ml of normal saline which was activated for 1 minute.

Paper points were used to dry the canals, and orifices were blocked with cotton pellets. Deep grooves were made on buccal as well as lingual surfaces of root with diamond discs. Teeth were split using chisel and mallets. One-half of each tooth was chosen for SEM examination to evaluate smear layer removal. The smear layer removal was evaluated using a standardized scoring system:

Score 1: No smear layer present; dentinal tubules are open and clearly visible.

Score 2: Moderate smear layer; dentinal tubules partially visible.

Score 3: Heavy smear layer; dentinal tubules completely obscured by smear layer.

Statistical Analysis: The mean smear layer scores for each irrigation technique were statistically analyzed using post hoc Tukey's test followed by Shapiro Wilk Test_to identify significant differences among the groups. The significance level was set at $p < 0.05$.

Results: The mean smear layer values at the apical third varied notably among the different experimental groups. The Control Group exhibited the highest smear layer score with a mean of 2.871 ± 0.111, indicating a predominance of heavy smear layer presence. The Sonic Activator Group followed with a mean of 2.486 ± 0.135, suggesting a moderate to heavy smear layer. In contrast, the Passive Ultrasonic Group demonstrated the most effective smear layer removal, with the lowest mean score of 1.614 ± 0.107, closely aligned with a minimal smear layer (Score 1). Similarly, the XP-Endo Finisher Group showed improved smear layer removal with a mean of 1.771 ± 0.364, reflecting mild smear layer presence. The Plastic File Group had a mean score of 2.643 ± 0.098, indicating moderate smear layer retention. Overall, the Passive Ultrasonic and XP-Endo Finisher groups were the most effective in reducing smear layer at the apical third, while the Control and Sonic Activator groups showed comparatively higher smear layer retention. These findings suggest that activation techniques, particularly passive ultrasonic irrigation, significantly enhance smear layer removal in the apical third of the root canal (Table 1).

Post Hoc analysis indicates that Passive Ultrasonic Irrigation and XP-Endo Finisher techniques are statistically more effective in smear layer removal compared to sonic activation, plastic file, and control methods (Table 2).

Table 1: Intergroup comparison of efficacy of smear layer between the groups

Group	Mean	SD	Std. Error	95% Confidence Interval (Lower – Upper)	Minimum	Maximum
Control Group	2.871	0.111	0.042	2.769 – 2.974	2.700	3.000
Sonic Activator Group	2.486	0.135	0.051	2.361 – 2.610	2.300	2.700
Passive Ultrasonic Group	1.614	0.107	0.040	1.515 – 1.713	1.500	1.800
XP-Endo Finisher Group	1.771	0.364	0.138	1.435 – 2.108	1.400	2.500
Plastic File Group	2.643	0.098	0.037	2.553 – 2.733	2.500	2.800

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	8.579	4	2.145	58.341	.000
Within Groups	1.103	30	.037		
Total	9.682	34			

Table 2: Post hoc analysis

	Mean Difference	Std. Error	P value	95% Confidence Interval	Significance
Group 1 vs 2	0.386	0.102	0.001	0.176 – 0.595	Significant
Group 1 vs 3	1.257	0.102	0.000	1.048 – 1.466	Significant
Group 1 vs 4	1.100	0.102	0.000	0.891 – 1.309	Significant
Group 1 vs 5	0.229	0.102	0.033	0.019 – 0.438	Significant
Group 2 vs 3	0.871	0.102	0.000	0.662 – 1.081	Significant
Group 2 vs 4	0.714	0.102	0.000	0.505 – 0.924	Significant
Group 2 vs 5	0.157	0.102	0.139	0.365-0.053	Non-Significant
Group 3 vs 4	0.157	0.102	0.139	0.365-0.053	Non-Significant
Group 3 vs 5	1.029	0.102	0.000	0.819 – 1.238	Significant

DISCUSSION: A phenomenon known as vapor lock can trap air in the root canal, particularly in the apical section, thereby impeding the exchange of irrigants and negatively impacting the effectiveness of debridement. New devices are being introduced to enhance this process, although conventional irrigation with syringes remains a common practice among both general practitioners

and endodontists. This technique involves administering the irrigant into the canal using needles of various gauges, either passively or through agitation.

In the present study; control group (Group 1) showed significantly higher smear layer scores compared to all other groups, including the Sonic Activator Group (Group 2), Passive Ultrasonic Group (Group 3), XP-Endo Finisher Group (Group 4), and Plastic File Group (Group 5), with p values ranging from 0.001 to 0.033. The Passive Ultrasonic Group (Group 3) demonstrated significantly lower smear layer scores than both Group 1 (Control) and Group 2 (Sonic Activator), indicating superior smear layer removal ($p < 0.001$). Additionally, Group 3 showed a highly significant difference from Group 5 (Plastic File Group) ($p = 0.000$), further confirming its efficacy. However, no significant difference was observed between Group 2 (Sonic Activator) and Group 5 (Plastic File Group) ($p = 0.139$), nor between Group 3 (Passive Ultrasonic) and Group 4 (XP-Endo Finisher) ($p = 0.139$), suggesting comparable performance between those pairs. Overall, the analysis indicates that Passive Ultrasonic Irrigation and XP-Endo Finisher techniques are statistically more effective in smear layer removal compared to sonic activation, plastic file, and control methods. However, factors such as final irrigating solution, technique used for irrigation, root canal thirds, must be taken into consideration.

Evidence in the literature suggests that ultrasonic irrigation is much more effective in this respect than syringe irrigation alone. Goodman et al demonstrated that the application of PUI/UAI with sodium hypochlorite (NaOCl) solution for 3 minutes per root canal significantly improved the cleanliness of isthmuses in the medial roots of the lower molars, as the in vitro study was performed at levels 1 and 3 mm from the apical end of the root canal. Metzler and Montgomery obtained similar results using PUI/UAI for 2 minutes. The studies have confirmed the higher efficiency of removing the smear layer when applying ultrasonically activated 2% NaOCl solution. Cameron has reported less debris and pulp tissue when using PUI/UAI in sequential irrigation with ethylenediaminetetraacetic acid (EDTA) and NaOCl for 1.5 minutes per canal. Literature data have shown that combining NaOCl with EDTA results in significantly greater removal of the smear layer. As the concentration of NaOCl increases, so does its toxicity. Sequential application of ultrasonically activated solutions of NaOCl and EDTA removes the smear layer sufficiently effectively even at lower concentrations of NaOCl. The studies have shown the effectiveness of removing the smear layer when applying ultrasonically activated solutions of 2% NaOCl and 15% EDTA. De Gregorio et al. have found that the ultrasonically activated solution enters the lateral canals, in contrast to a solution applied by a syringe or negative pressure irrigation. Spoorthy et al. have reported similar results.

Lee et al[8] and Sluis et al[9] have found that the greater the enlargement and the taper of the root canal, the better the removal of debris by PUI/ UAI. Rõdig et al[10] have demonstrated that the size of the apical enlargement does not affect the cleaning ability of PUI/UAI. This result contradicts the claim that greater apical preparation improves the effectiveness of ultrasonically activated irrigation with NaOCl.

Supporting this, previous studies by Sabins et al[11] and Capar et al[12] reported that PUI outperforms passive sonic irrigation in removing both smear layer and canal debris. The synergistic effect of EDTA and ultrasonics has been well-documented. For instance, Kuah et al[13] demonstrated that 17% EDTA, when used with ultrasonic activation for one minute, significantly improved smear layer and debris removal in the apical third of root canals. This was confirmed through SEM evaluation of 105 extracted premolars subjected to different irrigation protocols.

Bao et al in their study concluded that XPEF file helps remove biofilm from the main canal as well as from the deep, narrow apical groove. Elnaghy et al[14] in their research found that XPEF file is similarly effective in the removal of smear layer and debris when compared to Endo Activator in curved root canal. XP Endo Finisher file (XPEF) can be used along with root canal preparation with standard NiTi files after XPES. Final cleansing maneuvers are done with the XPEF file.

Conversely, Khalap et al[15] suggested that sonic activation might be more effective than ultrasonics for debris removal. They attributed this to PUI's sensitivity to contact with canal walls, which dampens the acoustic streaming pattern. In contrast, sonic devices maintain consistent activation regardless of wall contact. While this study found EndoActivator more effective than syringe irrigation, Uroz Torres et al[16] reported no significant difference between the two. Similarly, Rödig et al[17] found no notable difference in smear layer removal among EndoActivator, PUI, and non-

activated irrigation in the apical third, suggesting that methodological differences may account for the variability in outcomes.

Limitations

1. Techniques for smear layer removal, is subject to several limitations. Firstly, the in-vitro nature of the study does not fully replicate the complex biological and clinical conditions found in vivo, such as the influence of periapical tissues, immune response, and fluid dynamics within the root canal system. Consequently, the results may not directly translate to clinical outcomes.
2. Furthermore, the sample size per group, while adequate for preliminary analysis, may limit the statistical power and generalizability of findings.
3. The evaluation method employed, scanning electron microscopy (SEM), though precise, is inherently limited to localized areas of the canal walls. It does not provide a complete assessment of the entire root canal system, particularly in complex or curved canals. Additionally, the smear layer scoring was semiquantitative and may be subject to observer bias, even though calibrated examiners were used.
4. Lastly, while this study focused on smear layer removal, it did not evaluate bacterial reduction or disinfection efficacy, which are essential outcomes in endodontic success. Future studies incorporating microbial assessment, long term outcomes, and clinical trials would help validate and extend these findings.

CONCLUSION: Passive ultrasonic irrigation (PUI) emerged as the most effective technique, followed by the XP-Endo Finisher, both showing statistically superior cleaning results compared to the Sonic Activator and Plastic File groups. The Control Group, which did not use any activation, showed the highest smear layer retention, underscoring the inadequacy of conventional syringe irrigation alone. These results emphasize the importance of incorporating advanced irrigant activation methods, particularly PUI, into clinical endodontic practice to achieve thorough canal debridement and enhance treatment outcomes. Further clinical studies are recommended to validate these in-vitro findings and optimize irrigation protocols for routine practice.

Clinical Significance: Effective smear layer removal is crucial for successful endodontic treatment as it facilitates better disinfection and sealing of the root canal system. This study demonstrates that irrigant activation techniques, especially passive ultrasonic irrigation (PUI) and the XP-Endo Finisher, significantly enhance smear layer removal compared to conventional methods. Incorporating these activation methods in clinical practice can improve treatment outcomes by promoting cleaner canals and reducing the risk of reinfection.

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