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Original Research Article

A comparative evaluation of efficacy of smear layer removal using a novel handpiece mounted continuous irrigation system – An in vitro stereomicroscopic study

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Abstract

Introduction: The exchange of irrigant apical to the needle tip is dependent on the needle type, design, and gauge and it is usually limited to 1 to 1.5 mm beyond the needle tip. Therefore, to deliver active irrigant apically, the needle is required to be inserted near the working length (WL). The present research focuses on the smear layer removal efficacy of handpiece mounted continuous irrigation system with simultaneous root canal preparation compared with conventional syringe irrigation from the apical third.
Aim and objective: To compare the effectiveness of smear layer removal in the apical third of root canals using a novel handpiece-mounted continuous irrigation system.
Material and Methods: An in vitro study was conducted using 10 extracted human premolars, randomly divided into two groups: Group 1: Continuous irrigation with 3% sodium hypochlorite (NaOCl) through a handpiece-mounted system during rotary instrumentation. Group 2: Conventional syringe irrigation using 2 ml of 3%. All teeth were instrumented to size 30/06 taper, stained with 1% methylene blue dye, sectioned longitudinally, and observed under a stereomicroscope at 40× magnification. The depth of dye penetration in the apical third was assessed as an indirect measure of smear layer removal.
Result: Group 1 demonstrated greater dye penetration in the apical third compared to Group 2, indicating more effective smear layer removal.
Conclusion: The handpiece-mounted continuous irrigation system showed superior smear layer removal in the apical third compared to syringe irrigation.

Keywords: Continuous irrigation system, Smear layer, Sodium hypochlorite

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1. Introduction

Successful endodontic therapy relies heavily on effective cleaning and shaping of the root canal system to eliminate bacteria, pulp tissue remnants, and other organic debris. One unavoidable byproduct of mechanical canal preparation is the formation of a smear layer, a thin film composed of dentinal shavings, necrotic tissue, bacterial fragments, and residual irrigants.[1] A pivotal factor that influences the success of pulp therapy is smear layer. It decreases the penetration of irrigants or obturating materials into the canals by 25%–49%. Therefore, it is crucial to eliminate this layer to achieve a hermetic seal.[2] The smear layer is typically 1–2 µm thick but can extend up to 40 µm and may obstruct dentinal tubules, thereby impeding the penetration of irrigants and root canal sealer.[3]

Smear layer can harbor microorganisms, limit disinfectant action, compromise the seal of obturation materials, and adversely affect the long-term success of root canal therapy.[2] As a result, its removal is considered critical for achieving optimal canal cleanliness and improving sealer adaptation to the dentinal walls.[4] Irrigation aided mechanical instrumentation helps to keep the canal wall lubricated while simultaneously facilitating easy instrumentation within the canal space.[5]

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Conventional root canal irrigation typically involves manual syringe irrigation using sodium hypochlorite (NaOCl), a widely accepted irrigant due to its tissue-dissolving and antimicrobial properties.[7] However, syringe irrigation has limited effectiveness, especially in the apical third of the canal, due to inadequate flow, vapor lock effects, and inability to effectively displace air or penetrate complex canal anatomy.7 The irrigant often does not reach the entire canal wall or deeply into lateral canals and isthmuses, which may leave residual debris and the smear layer untouched.

To overcome these limitations, several irrigation enhancement techniques have been developed, including passive ultrasonic irrigation, sonic agitation, negative pressure systems, and continuous irrigation devices.8 One innovative approach is the handpiece-mounted continuous irrigation system, which allows irrigants to be delivered directly to the file during canal instrumentation.

Previous studies, such as by Sarwar et al. (2021), have demonstrated promising results with similar systems, indicating enhanced debridement and reduced residual debris compared to syringe irrigation.[9]

The apical third is often the most difficult region to clean due to its narrow diameter, complex anatomy, and limited irrigant penetration. Therefore, the current study aims to evaluate and compare the effectiveness of a novel handpiece-mounted continuous irrigation system versus conventional syringe irrigation in removing the smear layer from the apical third of root canals.

2. Material and Methods

2.1. Study design

This in vitro experimental study was conducted to compare the efficacy of smear layer removal from the apical third of root canals using two irrigation techniques: a novel handpiece-mounted continuous irrigation system and conventional syringe irrigation. The assessment was performed using stereomicroscopic evaluation after dye penetration, which served as an indirect indicator of smear layer presence.

2.2. Sample selection and preparation

Ten freshly extracted human premolar teeth with single, straight canals were selected for the study. Teeth with cracks, root caries, multiple canals, or resorption were excluded upon visual inspection and low-power magnification examination. The teeth were cleaned of soft tissue and calculus and stored in distilled water to prevent dehydration until use.

Each tooth was decoronated using a diamond disc under water cooling to obtain a uniform root length and ensure standardization. Working length (WL) was established by inserting a #10 K-file into the canal until the tip was just visible at the apical foramen and subtracting 1 mm from this length.

2.3. Grouping

The samples were randomly divided into two groups (n = 10 per group):

1. Group 1 – Continuous irrigation group:
   Root canals were prepared using a handpiece-mounted continuous irrigation system, in which 3% sodium hypochlorite (NaOCl) was delivered at a controlled rate of 1 ml/min during instrumentation. The irrigant was delivered manually with the help of an assistant while maintaining simultaneous rotary file engagement in the canal. (**Figure 1**)
1. Group 2 – Syringe Irrigation Group:
   Root canals were prepared using standard side-vented syringe irrigation. A 5 ml syringe with a side-vented needle was used to deliver 2 ml of 3% NaOCl after each file during the step-back rotary instrumentation.

Figure 1: Continuous irrigation system

2.4. Canal instrumentation protocol

All canals in both groups were instrumented using 6% tapered rotary NiTi files (up to size 30/06). Irrigation was carried out according to each group's protocol throughout the procedure. The shaping and irrigation protocols were kept consistent except for the mode of irrigation delivery.

2.5. Smear layer visualization: Dye penetration method

To assess the presence of residual smear layer in the apical third:

1. The external surfaces of all roots were coated with clear nail polish to prevent dye infiltration through surface microcracks or defects. The coronal access was left uncoated to allow dye entry through the canal system.
2. All specimens were immersed in 1% methylene blue dye for 24 hours to allow dye penetration through areas not covered by the smear layer.
3. After dye immersion, the teeth were rinsed thoroughly with distilled water and longitudinally sectioned into two halves using a diamond disc under copious water spray to avoid heat generation or additional cracks.
4. The apical third of each sample was examined under a stereomicroscope at 40× magnification, and the depth of dye penetration was assessed visually and recorded as a measure of smear layer removal efficiency.

2.6. Assessment criteria

Dye penetration in the apical third was graded as an indicator of smear layer removal:

1. Greater dye penetration = less smear layer
2. Poor or no dye penetration = presence of smear layer obstructing canal wall

3. Results

Data were analyzed using an Independent Samples t-test to compare the mean values between the two groups. A p-value < 0.05 was considered statistically significant**.**

Group 1 (continuous irrigation) exhibited greater depth of dye penetration, indicating less smear layer retention in the apical third. (**Figure 3**) Group 2 (syringe irrigation) showed reduced penetration, (**Figure 2**) suggesting that manual syringe delivery was less effective in maintaining consistent irrigant flow and debris removal.(**Figure 4**)

The handpiece-mounted continuous irrigation system (Group 1) was statistically significantly more effective (as indicated by the higher mean value) than conventional syringe irrigation (Group 2), with a p-value of 0.001 confirming the reliability of the observed difference. (**Table 1**)

These results highlight the benefit of continuous replenishment and real-time delivery of irrigants during shaping, which likely reduced friction, minimized file clogging, and improved apical debridement.

Table 1: Comparison of depth of dye penetration between the groups

Group	Mean	SD	T Value	P Value
Group 1	60.48	0.55	5.04	0.001*
Group 2	59.65	0.44		

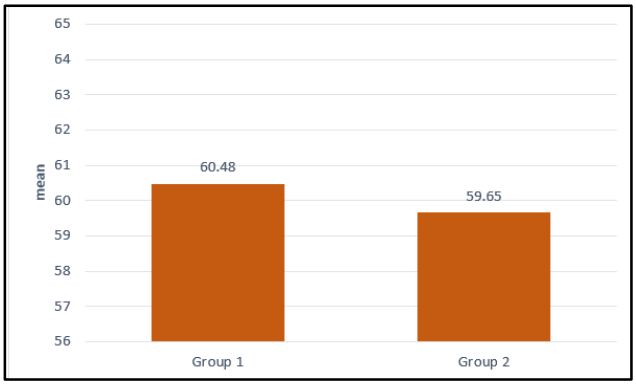

Figure 2: Mean Dye Penetration in Apical Third: Continuous Irrigation vs. Syringe Irrigation

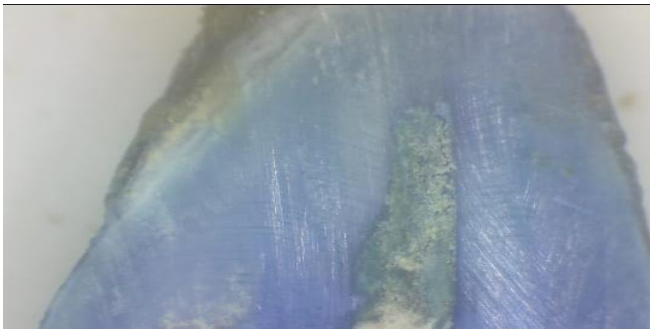

Figure 3: Stereomicroscopic image of premolar specimen from Group 1 (handpiece mounted continuous irrigation system) showing greater smear layer removal in the apical third

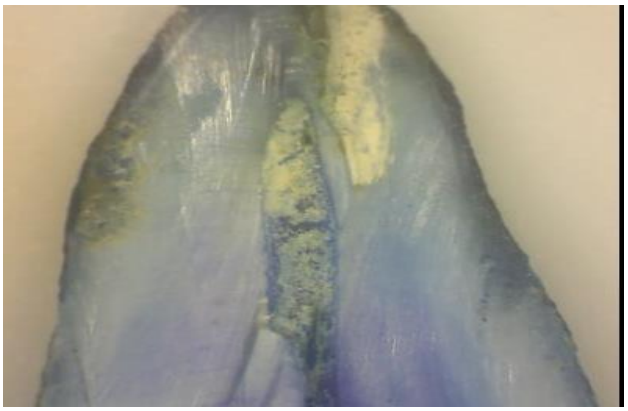

Figure 4: Stereomicroscopic image of premolar specimen from Group 2 (syringe irrigation) showing comparatively less smear layer removal in the apical third

4. Discussion

Effective removal of the smear layer, particularly in the apical third of the root canal, plays a pivotal role in the success of endodontic treatment. The smear layer, a byproduct of mechanical instrumentation, comprises organic and inorganic debris that may harbor residual bacteria and obstruct the penetration of irrigants and sealer.[1] Failure to adequately remove this layer can compromise the seal of root canal obturation and increase the risk of treatment failure.[3]

Due to the complexity of its anatomy, the apical area has been referred to as "the critical area." Because it is frequently located apical to a canal curve, it is the portion that is furthest from the access opening.[10] The mechanical instrumentation of the root canal system alone is insufficient for the complete removal of dentinopulpal debris, especially from the areas inaccessible to the instrumentation.11 Therefore, chemo-mechanical preparation with copious sodium hypochlorite (NaOCL) irrigation is required for effective root canal debridement. Several irrigation methods and devices are available for this purpose.[12]

This indicates more efficient smear layer removal, which can be attributed to the simultaneous delivery of irrigant during canal preparation. This mechanism ensures constant

replenishment of fresh irrigant and immediate flushing of debris generated by the rotary instruments.

4.1. Mechanism behind improved efficacy

Conventional syringe irrigation, while widely used, has several limitations. It often fails to deliver irrigant beyond the needle tip effectively, particularly in the apical third, due to vapor lock and fluid stagnation.[6] Additionally, the intermittent nature of syringe irrigation requires periodic interruption of instrumentation, which can lead to the accumulation of debris and clogging of the file flutes.[7]

In contrast, the continuous irrigation system used in this study allows irrigant to flow directly onto the file during instrumentation. This continuous flow reduces friction, keeps the file lubricated, and prevents debris compaction against canal walls. These features enhance the mechanical flushing action of the irrigant, particularly in narrow and anatomically challenging apical regions.[8]

Sarwar et al. (2021) evaluated a similar handpiece-mounted irrigation system and reported significantly improved removal of pulpal debris compared to conventional irrigation. Their findings support the present study's conclusion that simultaneous irrigation during shaping improves canal cleanliness and efficiency of debridement.[9]

This study was conducted with a small sample size (n=10), and the findings should be considered preliminary within the scope of a pilot/exploratory study.In the present study, extracted human premolars were selected as the experimental model to evaluate the efficacy of smear layer removal using two different irrigation techniques. The use of premolars is widely accepted in endodontic research due to several practical and anatomical advantages that support standardization and reproducibility of results. Premolars, especially mandibular first premolars, often possess a single, straight root canal, which reduces anatomical variability among samples and allows for consistent canal shaping and irrigation across groups. Premolars typically have adequate root length, which provides sufficient space for effective instrumentation, irrigant flow, and post-instrumentation evaluation, such as sectioning and stereomicroscopic examination.[14]

In the continuous irrigation group, the irrigant flow rate was standardized at 2 ml/min. To minimize variability due to manual delivery, the assistant was calibrated prior to the study using a graduated syringe and stopwatch to ensure a consistent flow rate. This procedure was repeated and confirmed before instrumentation of each specimen.

Dye penetration reflects dentin permeability and the ease with which fluids can enter dentinal tubules. Since the smear layer acts as a barrier, increased dye penetration is interpreted as reduced smear layer, and vice versa.[1] However, this method does not allow direct visualization of the smear layer. Factors such as dentinal tubule density, microcracks, and molecular size of the dye may influence penetration, independent of smear layer thickness. [4] Thus, dye penetration is an indirect and surrogate indicator of smear layer removal. Direct evaluation methods such as Scanning Electron Microscopy (SEM) or micro-CT are required for precise assessment.[2]

4.2. Clinical relevance and advantages

One of the major advantages of continuous irrigation systems is their ability to deliver a controlled and steady flow of irrigant without interrupting instrumentation. This real-time irrigation enhances cleaning efficiency and may reduce operative time. Furthermore, improved smear layer removal enhances the penetration of endodontic sealers into dentinal tubules, improving the apical and coronal seal, and reducing microleakage.[14]

Continuous delivery of irrigant during instrumentation reduces friction and file clogging, potentially making canal preparation more efficient compared to conventional syringe irrigation. By lowering friction and preventing debris compaction on file blades, continuous irrigation reduces torsional stresses and minimizes the risk of instrument separation.[9]

Neelakantan et al. (2019) emphasized the importance of irrigant activation and replenishment, showing that passive delivery alone is insufficient to eliminate the smear layer in the apical third. Continuous irrigant replenishment maintains the chemical activity of solutions like NaOCl for longer, improving bacterial reduction compared to intermittent syringe delivery. Continuous flushing of dentin chips during shaping helps avoid canal blockages and maintains apical patency. Real-time irrigation may shorten chairside time, reduce operator fatigue, and enhance patient comfort.[2] The current study reinforces this concept by demonstrating the superiority of a dynamic irrigation approach over static syringe delivery.[4]

Arslan et al. (2014) demonstrated that different irrigation activation protocols, including sonic and ultrasonic agitation, significantly enhanced smear layer removal compared to conventional syringe irrigation. Their findings support the principle that continuous activation and replenishment of irrigants improve debridement efficacy, particularly in the apical third, aligning with the outcomes of the present study.[15]

5. Limitations of the Present Study

While the results are promising, the study has certain limitations:

1. Sample size was small (n=10), limiting the statistical power and generalizability.
2. The irrigant flow rate was manually controlled, which may introduce variability and require an additional

assistant, making the technique more technique-sensitive.
3. Stereomicroscopy and dye penetration were used as indirect measures of smear layer removal. More accurate visualization techniques such as scanning electron microscopy (SEM) or micro-CT could provide better quantification and structural analysis.
4. The clinical implementation of such systems may require additional equipment, rubber dam isolation, and continuous suction, potentially increasing procedural complexity.

6. Future Directions

Further studies with larger sample sizes, quantitative scoring systems, and advanced imaging techniques are needed to validate these findings. Additionally, clinical trials evaluating outcomes such as post-operative pain, time efficiency, and long-term sealing ability will be essential before routine clinical application.

7. Conclusion

Within the limitations of this in vitro study, it can be concluded that the novel handpiece-mounted continuous irrigation system demonstrated superior efficacy in smear layer removal from the apical third of root canals when compared to conventional syringe irrigation. The continuous and simultaneous delivery of 3% sodium hypochlorite during canal instrumentation resulted in greater dye penetration, indicating better debridement and reduced smear layer retention.

The findings highlight the potential of continuous irrigation systems to enhance root canal cleanliness and support better adaptation of sealers, ultimately contributing to improved endodontic treatment outcomes. However, several clinical limitations were noted, including the need for an assistant to manually control irrigant flow, the challenge of maintaining a consistent delivery rate, and the requirement for rubber dam isolation and active suction to manage overflow**.**

The findings of the present study should be interpreted as preliminary due to the small sample size (n=10). While the results suggest that continuous irrigation systems may improve smear layer removal compared to syringe irrigation, these outcomes require cautious interpretation. Dye penetration, used here as an indirect measure, provides only limited evidence of smear layer removal. Future studies with larger sample sizes and the application of advanced imaging modalities such as Scanning Electron Microscopy (SEM) or Micro-Computed Tomography (micro-CT) are necessary to validate and strengthen these observations. Such studies will provide more definitive insights into the clinical relevance and routine applicability of continuous irrigation systems.

8. Author Contribution

All authors contributed to the conception, design, data collection, analysis, and interpretation of the study. Drafting and critical revision of the manuscript were performed collaboratively. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

9. Ethical Committee Approval

Approved by institutional ethical committee. IEC No: KMCTDC/IEC/C/2024/12.

10. Conflict of Interest

None

11. Source of Funding

None.

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