Efficacy of Four Techniques for Removing Calcium Hydroxide from the Apical Third of Root Canals: An in Vitro Study

Sabbir G,[1] Moral MA,[2] Zaman M,[3] Bashar A,[4] Akter R,[5] *Nurunnabi M[6]

Abstract

Background: Complete removal of calcium hydroxide [$Ca(OH)_2$] before obturation is critical for optimal sealer adaptation and long-term endodontic success. However, limited irrigant penetration and canal intricacy make cleaning the apical third difficult.

Objective: To assess the effectiveness of four commonly used techniques Passive Ultrasonic Agitation (PUA), Master Apical File (MAF), XP-endo Finisher, and H-file instrumentation in removing $Ca(OH)_2$ from the apical third of root canals.

Methods: This in vitro comparative cross-sectional study was conducted from October 2022 to September 2023 at BSMMU, Dhaka, in collaboration with BUET. A total 64 freshly extracted single-rooted mandibular premolars were purposively selected and randomly assigned to four groups (n=16). Canals were prepared, filled with $Ca(OH)_2$ paste, and stored for one week. $Ca(OH)_2$ was then removed using PUA (Group A), MAF (Group B), XP-endo Finisher (Group C), or H-file instrumentation (Group D). Residual $Ca(OH)_2$ in the apical third was evaluated via SEM (×300–×2000) and scored on a 5-point scale by two blinded examiners.

Results: XP-endo Finisher (Group C) yielded the lowest mean residue score (1.94±0.68), followed by Passive Ultrasonic Agitation (Group A) (2.88±1.09), indicating superior cleaning efficacy. Master Apical File (Group B) and H-file instrumentation (Group D) showed significantly higher residue scores (4.81±0.40 and 5.0±0.0), demonstrating limited effectiveness. Differences among groups were statistically significant ($p<0.001$). Post-hoc analysis confirmed that Groups A and C removed $Ca(OH)_2$ more effectively than Groups B and D, while no significant difference existed between Groups B and D.

Conclusion: XP-endo Finisher removed $Ca(OH)_2$ more effectively from the apical third than PUA, MAF and H-file instrumentation. Advanced irrigant activation techniques may enhance apical cleanliness and improve obturation quality.

[Dinajpur Medical College Journal, 2026 Jan; 19 (1):103-110]
[Former M Abdur Rahim Medical College Journal]
DOI: https://www.doi.org/10.69861/djmcj.2026.19.1.13

Keywords: Calcium hydroxide removal, apical third, XP-endo Finisher, passive ultrasonic agitation, Master Apical File, H-file, SEM evaluation.

1. **Dr. Golam Sabbir, MS Fellow, Department of Conservative Dentistry and Endodontics, Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh. golam.sabbir.93@gmail.com*
2. *Dr. Mohammad Ali Asgor Moral, Professor, Department of Conservative Dentistry and Endodontics, Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh.*
3. *Dr. MSU Zaman, MD Fellow, Department of Dental Pharmacology, Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh.*
4. *Dr. AKM Bashar, Professor, Department of Conservative Dentistry and Endodontics, Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh.*
5. *Dr. Rozina Akter, Senior Research Officer, Public Health Department, Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh.*
6. **Dr. Mohammad Nurunnabi, Assistant Professor, Department of Community Medicine and Public Health, Sylhet Women's Medical College, Sylhet, Bangladesh.* nur.somch@gmail.com

**For correspondence*

Introduction

The development of pulpal and periapical disease is significantly influenced by microorganisms in the root canal system.[1] A major objective of root canal therapy is therefore to eliminate bacteria and their by-products.[2-4] However, the complex anatomy of the root canal characterized by fins, isthmuses, irregularities, and lateral canals limits the ability of mechanical instrumentation to achieve complete disinfection.[5,6] Thus, effective bacterial reduction relies on a combination of instrumentation, irrigants, and intracanal medicaments.[4,7]

$Ca(OH)_2$ remains the most widely used intracanal medicament due to its broad antimicrobial activity, high biocompatibility, and ability to neutralize endotoxins, dissolve soft tissues, control resorption, and promote apical healing.[8,9] Before obturation, however, $Ca(OH)_2$ must be completely removed to ensure optimal sealer adaptation.[10] Residual $Ca(OH)_2$ can impair dentin bonding, alter sealer properties, increase leakage, and lead to long-term void formation at the filling interface.[11-14]

Traditional removal techniques include circumferential filing with Hedström (H) files combined with sodium hypochlorite and EDTA irrigation.[15] However, hand instrumentation alone is often insufficient. Advanced methods such as Ni-Ti rotary files, ultrasonic agitation, EndoActivator/sonic systems, canal brushes, EndoVac, and the self-adjusting file have been introduced to enhance irrigant penetration and debridement.[16,17] Rotary systems, including ProTaper, improve debris removal and irrigant flow, particularly at the apical third.[18] By using cavitation and acoustic streaming, passive ultrasonic irrigation (PUI) improves cleaning effectiveness.[19] Devices such as Ultra X operate at high frequencies to enhance irrigant activation.[20] The XP-endo Finisher, made from a temperature-responsive alloy, expands and adapts to canal irregularities, improving cleaning without altering canal shape.[21,22]

The apical third remains the most challenging region to clean due to its narrow anatomy, reduced irrigant flow, and vapor-lock effect, which limits irrigant penetration.[23,24] In light of all of this, the current study compares the effectiveness of PUA, MAF equipment, XP-endo Finisher, and H-file methods for eliminating $Ca(OH)_2$ from the apical third of the root canal system..

Methods

This comparative cross-sectional study was conducted over 12 months, from October 2022 to September 2023, in the Department of Conservative Dentistry and Endodontics at Bangabandhu Sheikh Mujib Medical University (BSMMU), Dhaka, in technical collaboration with the Department of Biomedical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh. The study aimed to assess the effectiveness of four commonly used techniques: PUA, MAF, XP-endo Finisher, and H-file instrumentation in removing $Ca(OH)_2$ from the apical third of root canals.

Patients attending the Orthodontics Department of BSMMU who required extraction of single-rooted mandibular premolars for treatment purposes were considered. Teeth were included if they were freshly extracted, fully formed, and from patients aged 15–50 years. Teeth with caries, fractures, resorption, previous endodontic treatment, multiple canals, or developmental anomalies were excluded. A purposive sampling method was used for selection, followed by random allocation into four experimental groups (n= 16 per group). The

total sample size of 64 teeth was determined based on prior studies to achieve adequate statistical power.

Tooth Preparation and Instrumentation

Extracted teeth were decoronated to 15 mm and access cavities prepared. Canal patency was confirmed with a size 10-K file, and working length was established 1 mm short of the apex. Canals were prepared using ProTaper Gold rotary files up to F3, with irrigation using 5.25% NaOCl. Smear layer removal was achieved using 17% EDTA activated ultrasonically. Canals were dried and filled with premixed calcium hydroxide paste (UltraCal XS), confirmed radiographically, and stored at room temperature for one week.

$Ca(OH)_2$ removal procedures: After one week, calcium hydroxide was removed using one of four techniques:

- **Group A:** Passive Ultrasonic Agitation (PUA)
- **Group B:** Master Apical File (MAF)
- **Group C:** XP-endo Finisher
- **Group D:** H-file instrumentation

Each group followed a standardized irrigation protocol with NaOCl and EDTA. Agitation or instrumentation was performed for 60 seconds, and canals were then rinsed and dried.

Evaluation of $Ca(OH)_2$ Removal

Teeth were longitudinally split, dehydrated, and gold-coated for SEM examination. The apical third of the canal was evaluated at ×300, ×1000, and ×2000 magnifications. Residual $Ca(OH)_2$ was scored on a 5-point scale: 1= clean canal walls, 5= ≥75% coverage with residue. Two blinded evaluators independently assessed all samples, resolving discrepancies by consensus.

Data were analyzed using SPSS v26.0. Mean and standard deviation were reported. One-way ANOVA followed by Bonferroni post-hoc tests was used to compare groups, with $p<0.05$ considered statistically significant.

Ethical approval for this study was obtained from the Institutional Review Board of BSMMU (Reference: BSMMU/2022/11832). All samples were collected following IRB approval and after obtaining written informed consent from participants, in accordance with the Declaration of Helsinki (2013, revised version). The consent form detailed the study objectives, procedures, potential risks and benefits, and the identity of the principal investigator. Participants were assured of confidentiality, the right to withdraw at any time, and appropriate management of any complications arising from the study.

Results

Table I shows the distribution of $Ca(OH)_2$ residue scores in the apical third of root canals among four experimental, using a 5-point scale from 1 (very little to no residue) to 5 (≥75% coverage). In Group A, most teeth exhibited minimal to moderate residues, with 6.25% scoring 1, 43.75% scoring 2, 6.25% scoring 3, and 43.75% scoring 4, and none with heavy residue, indicating relatively effective removal. Group B showed predominantly heavy residue, with 81.25% scoring 5 and 18.75% scoring 4, signifying limited efficacy. Group C demonstrated mostly low to moderate residue, with 25% scoring 1, 56.25% scoring 2, and 18.75% scoring 3, indicating effective cleaning of canal walls. In Group D, all teeth scored 5, highlighting that manual H-file instrumentation was the least effective technique for $Ca(OH)_2$ removal in the apical third.

Table II compares the mean $Ca(OH)_2$ residue scores among the four experimental groups. Group C showed the lowest mean residue score (1.94±0.68), followed by Group A

(2.88±1.09), indicating higher efficacy in $Ca(OH)_2$ removal. In contrast, Group B and Group D had higher mean scores of 4.81±0.40 and 5.0±0.0, respectively, reflecting substantial residual medicament. The differences among groups were statistically significant ($p< 0.001$, one-way ANOVA), confirming superior cleaning performance of XP-endo Finisher and PUA compared to conventional instrumentation methods.

Figure 1 illustrates these findings, showing the superior cleaning efficacy of XP-endo Finisher and Passive Ultrasonic Agitation compared to conventional instrumentation methods.

Multiple comparisons of $Ca(OH)_2$ removal scores using the Bonferroni post-hoc test (Table III) demonstrated substantial differences among the four experimental groups. Group A and Group C showed lower mean residue scores compared to Group B and Group D, indicating higher efficacy in removing intracanal medicament. Group A differed significantly from Groups B and D ($p< 0.001$) and from Group C ($p= 0.001$), while Group C showed significant differences with all other groups ($p\leq 0.001$).

In contrast, there was no substantial difference between Group B and Group D ($p = 1.000$), signifying that conventional instrumentation techniques were similarly less effective in $Ca(OH)_2$ removal. All other pairwise comparisons were statistically significant ($p< 0.001$, Table IV), confirming that XP-endo Finisher and Passive Ultrasonic Agitation achieved more thorough cleaning of the apical third than Master Apical File and H-file instrumentation.

Table I: $Ca(OH)_2$ residue score among the four groups (N=64)

$Ca(OH)_2$ residue score	Group A (n=16)	Group B (n=16)	Group C (n=16)	Group D (n=16)
Score-1 (Very little to no residue, clean root canal walls; all dentinal tubules were clean and open)	1 (6.25%)	0 (0.0%)	4 (25%)	0 (0.0%)
Score-2 (<25% of canal wall covered with small amount of residue and a thin homogenous layer; most of the dentinal tubules were open)	7 (43.75%)	0 (0.0%)	9 (56.25%)	0 (0.0%)
Score-3 (25 to <50% of canal wall covered with moderate amount of residue and a homogenous layer; only a few dentinal tubules were open)	1 (6.25%)	0 (0.0%)	3 (18.75%)	0 (0.0%)
Score-4 (50 to <75% of canal wall covered with large amount of residue and a heavy, homogenous layer; no dentinal tubules were open)	7 (43.75%)	3 (18.75%)	0 (0.0%)	0 (0.0%)
Score-5 (≥75%of canal wall covered with residue and a heavy, non-homogeneous layer)	0 (0.0%)	13 (81.25%)	0 (0.0%)	16 (100%)

Table II: Comparison $Ca(OH)_2$ residue scores among the groups (N=64)

Variables	Group A (n=16)	Group B (n=16)	Group C (n=16)	Group D (n=16)	p-value
$Ca(OH)_2$ residue scores (Mean±SD)	2.88±1.09	4.81±0.40	1.94±0.68	5.0±0.0	<0.001*
Range	(1-4)	(4-5)	(1-3)	(5-5)	

One-way ANOVA test done, p<0.05 considered as a significant value

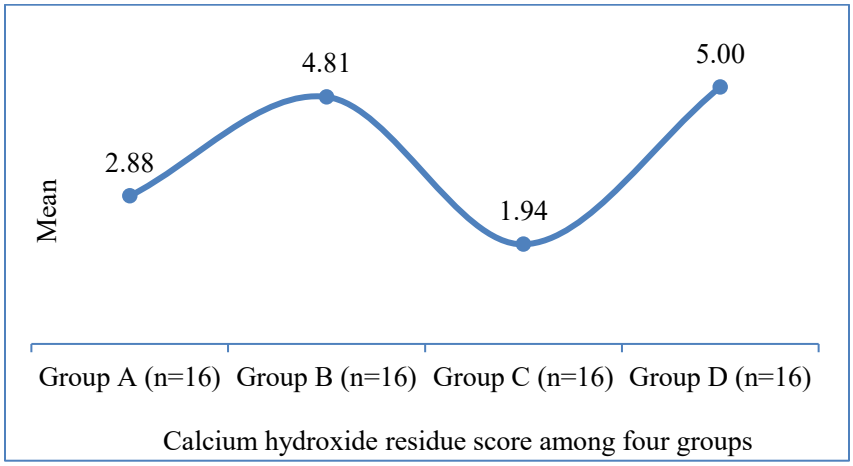

Figure 1. Calcium hydroxide residue score among four groups (N=64)

Table III: Multiple Comparisons of $Ca(OH)_2$ removal score (N=64)

Dependent Variable: Calcium hydroxide removal score

(I) Group	(J) Group	Mean Difference (I–J)	Std. Error	p-value	95% Confidence Interval	
					Lower Bound	Upper Bound
Group A	Group B	−1.93750	0.23772	<0.001*	−2.5861	−1.2889
	Group C	0.93750	0.23772	0.001*	0.2889	1.5861
	Group D	−2.12500	0.23772	<0.001*	−2.7736	−1.4764
Group B	Group A	1.93750	0.23772	<0.001*	1.2889	2.5861
	Group C	2.87500	0.23772	<0.001*	2.2264	3.5236
	Group D	−0.18750	0.23772	1.000	−0.8361	0.4611
Group C	Group A	−0.93750	0.23772	0.001*	−1.5861	−0.2889
	Group B	−2.87500	0.23772	<0.001*	−3.5236	−2.2264
	Group D	−3.06250	0.23772	<0.001*	−3.7111	−2.4139
Group D	Group A	2.12500	0.23772	<0.001*	1.4764	2.7736
	Group B	0.18750	0.23772	1.000	−0.4611	0.8361
	Group C	3.06250	0.23772	<0.001*	2.4139	3.7111

Bonferroni test done, p<0.05 considered as a significant value

Table IV: Comparison of $Ca(OH)_2$ residue score between groups (N=64)

Variables	p-value
Group A vs. Group B	<0.001*
Group A vs. Group C	<0.001*
Group A vs. Group D	<0.001*
Group B vs. Group C	<0.001*
Group B vs. Group D	1.000
Group C vs. Group D	<0.001*

Bonferroni post-hoc test done, p<0.05 considered as a significant value

Discussion

In this in vitro study, the efficacy of PUA, MAF, XP-endo Finisher, and H-file in removing $Ca(OH)_2$ from the apical third of root canals was compared. None of the methods achieved complete removal, but XP-endo Finisher and PUA were substantially more effective than MAF and H-file, which did not differ significantly. The XP-endo Finisher achieved the lowest mean residue score (1.94±0.68) due to its unique metallurgical properties, allowing it to expand and adapt to complex canal anatomy, consistent with the study.[25]

PUA was also effective (mean score 2.88±1.09), though its efficacy can be limited by difficulties in fully adapting the ultrasonic tip to curved canals. These findings are stayed by this study,[26] but differ from studies using artificial grooves or micro-CT evaluation, where no significant difference between XP-endo Finisher and PUA was reported in these study.[27,28] The manual H-file was the least effective (mean score 5.0±0.0), showing no significant difference from MAF in this study, emphasizing the limitations of conventional hand instrumentation in the apical third.

Factors influencing $Ca(OH)_2$ removal include canal anatomy, apical preparation size, irrigant type and activation, duration of irrigation, and the vehicle used with the medicament. Water-based $Ca(OH)_2$ paste, as used in this study, is easier to remove than oil-based pastes.[15,29,30]

Although this in vitro study was conducted on relatively straight mandibular premolars which may not fully represent the anatomical complexity of curved or multi-rooted canals in clinical settings the results show that the XP-endo Finisher and Passive Ultrasonic Agitation achieve superior cleaning of the apical third compared with conventional instrumentation. These findings underscore the importance of advanced irrigant activation techniques for enhanced canal debridement and improved obturation quality. The master apical file instrumentation time was not standardized across groups to minimize the risk of over-preparation, dentin microcrack formation, and potential instrument separation.

Conclusion

This study revealed that XP-endo Finisher was significantly more effective than PUA, MAF and H-file instrumentation in removing $Ca(OH)_2$ from the apical third of root canals. Advanced irrigant activation techniques, such as XP-endo Finisher or PUA should be preferred over conventional instrumentation for improved apical cleanliness and optimal obturation outcomes, while further studies on curved and multi-rooted canals are warranted to validate these findings in clinical settings.

Conflict of interest: No conflicts of interest.

Funding: This research was supported by a grant from Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh.

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