

Original Article

Evaluating Calcium Hydroxide Removal Techniques in Endodontics: A Comparative Analysis

Vahid Fallahi Sarvenoei ¹, MScD; Mohsen Aminsobhani ², MScD; Babak Farzaneh ², MScD; Mohammad Ali Ketabi ², MScD;

¹ Dept. of Prosthodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.

² Dept. of Endodontics, School of Dentistry, Aja University of Medical Sciences, Tehran, Iran.

KEY WORDS

Calcium Hydroxide;
Endodontics;
Ethylene-Diamine-Tetra-
Acetic Acid;
Sodium Hypochlorite;
Root Canal Preparation;

Received: 30 June 2024;
Revised: 2 October 2024;
Accepted: 1 March 2025;

Copyright

© Journal of Dentistry, this is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International License, (<http://creativecommons.org/licenses/by/4.0/>) which permits reusers to copy and redistribute the material in any medium or format if the original work is properly cited, and attribution is given to the creator. The license also permits for commercial use.

ABSTRACT

Background: Endodontic therapy plays a pivotal role in dentistry, with effective removal of intracanal medications crucial for successful treatment. The lingering presence of calcium hydroxide within dentinal walls can impede sealer adhesion and compromise treatment outcomes.

Purpose: This study aimed to compare the efficacy of various methods for removing calcium hydroxide from different regions of the root canal wall.

Materials and Method: In this *in vitro* randomized trial study, 108 extracted teeth underwent canal cleaning and shaping using the Dentsply Protaper Gold rotary system. Subsequently, except for the negative control group, all teeth were filled with calcium hydroxide and divided into eight groups. These groups underwent different cleaning protocols involving Gentle Brush or Gentlefile #021 files or master apical file in combination with ethylene-diamine-tetra-acetic acid or sodium hypochlorite solutions. After tooth splitting, stereomicroscopic images were taken, and Digimizer software was utilized to calculate residual calcium levels in coronal, middle, and apical regions. Mann-Whitney test was used to check the effect of the cleaning method and type of washing solution among the methods employed. All the analyses were conducted using SPSS 22.

Results: The results indicated that the Gentle Brush method's superior efficacy in calcium hydroxide removal compared to other files, which was statistically significant (p Value <0.01). Similarly, the ethylene-diamine-tetra-acetic acid rinse solution proved more effective than sodium hypochlorite in clearing calcium hydroxide from the canal wall (p < 0.05).

Conclusion: The findings suggest that a Gentle Brush combined with an ethylene-diamine-tetra-acetic acid washing solution represents the most effective method for canal cleaning and calcium hydroxide removal. This study underscores the importance of employing efficient techniques to enhance treatment quality in endodontic practice.

Corresponding Author: Ketabi MA, Dept. of Endodontics, School of Dentistry, Aja University of Medical Sciences, Tehran, Iran. Tel: +98-2156729825 Email: Maketabi21@gmail.com

Cite this article as: Fallahi Sarvenoei V, Aminsobhani M, Farzaneh B, Ketabi MA. Evaluating Calcium Hydroxide Removal Techniques in Endodontics: A Comparative Analysis. *J Dent Shiraz Univ Med Sci.* December 2025; 26(4): 325-335.

Introduction

Endodontic therapy is a cornerstone in dentistry and is pivotal in ensuring the success of dental treatments. Endodontic therapy, also known as root canal treatment, aims to alleviate pain and preserve natural teeth by treating infections and inflammation within the tooth's pulp chamber and root canals [1]. A key determinant of this success lies in effectively eradicating microorganisms

within the root canal system [2-3]. To achieve this, using intracanal medicaments for disinfection is a widespread practice to enhance treatment outcomes [4]. Among these medicaments, calcium hydroxide [$\text{Ca}(\text{OH})_2$] is favored for its antimicrobial properties and ability to deter root resorption [5-6].

Complete removal of intracanal medicaments, particularly $\text{Ca}(\text{OH})_2$, remains a critical challenge in en-

odontic practice [7-8]. Residual Ca(OH)_2 within dentinal walls can compromise treatment quality by obstructing sealer adhesion, promoting apical liquefaction, and interfering with the bond between filling materials and dentinal tubules through the formation of calcium eugenol [9]. These residues not only reduce the sealing ability of root canal fillings but also create unfavorable conditions for tissue healing, potentially leading to delayed periapical repair and persistent symptoms [10-12]. Systematic reviews emphasize the technical difficulty of removing Ca(OH)_2 , highlighting the need for advanced irrigation techniques to ensure thorough debridement [13-14]. These insights underscore the importance of meticulous intracanal cleaning to enhance clinical outcomes in endodontic treatment [15-16].

Various techniques have been developed to optimize this process. Among these, the most commonly employed method involves recapitulation with a master apical file (MAF) in combination with copious irrigation, which remains a fundamental technique for effective Ca(OH)_2 removal [17-19]. More advanced methods, such as passive ultrasonic irrigation and laser-activated irrigation, have demonstrated significantly higher efficacy in removing Ca(OH)_2 [20-21]. Additionally, sonic activation techniques like EDDY have also been shown to be effective, achieving comparable results to passive ultrasonic irrigation. Other methods include chelating agents like ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite (NaOCl), which enhance the chemical dissolution of Ca(OH)_2 when used in conjunction with mechanical agitation [22-23].

Despite advancements in endodontic techniques, studies have demonstrated that using EDTA as a standalone irrigation method is often insufficient for effectively removing Ca(OH)_2 from root canals. While EDTA is effective at chelating inorganic materials, its use alone may not achieve optimal cleaning results. Consequently, it is recommended to employ a combination of techniques, such as using NaOCl or EDTA in conjunction with recapitulation using the MAF or employing ultrasonic activation. These methods enhance the mechanical agitation and chemical efficacy needed to thoroughly clear residual Ca(OH)_2 from the canal walls. The ongoing search for a definitive solution underscores the imperative to improve treatment efficacy

and patient outcomes, highlighting the need for innovative irrigation protocols that integrate multiple strategies to ensure comprehensive cleaning of the root canal system [24-25]. This pursuit is essential not only for effective disinfection but also for enhancing the overall success of endodontic therapy [16, 26].

In light of the challenges mentioned above, the present study aims to evaluate the efficacy of Gentle Brush and Gentlefile #021 compared to standard washing methods for removing Ca(OH)_2 from various regions of the root canal wall. Gentlefile, with the respective hand-piece operating at 6500 rpm, has a unique shape and special structure that can match the wall of different channels. By meticulously assessing these instruments using a stereomicroscope, we aimed to provide insights into their effectiveness in achieving thorough canal cleaning and rinsing [27]. Ultimately, this manuscript sought to contribute to the ongoing discourse on optimizing endodontic treatment protocols to enhance treatment quality and patient satisfaction [28].

Materials and Method

Study design

This research was approved by the Ethics Committee of the Department of Endodontics, School of Dentistry, Aja University of Medical Sciences, Tehran, Iran, under the identification number IR.AJAUMS.REC.1399.079. The study was designed as an *in vitro* randomized trial, utilizing 108 single-canal central and lateral teeth extracted for orthodontic or periodontal reasons. The inclusion criteria were strictly defined to ensure sample homogeneity among samples. They included single-canal morphology, absence of both internal and external pathology, no history of prior root canal treatment, absence of visible fractures or cracks, lack of calcification within the canal, complete apical root development, and the presence of severe root curvature.

Standardized periapical radiographs were obtained at mesial and distal angles to confirm these criteria, following established radiographic protocols. These radiographs were used to evaluate root morphology apical formation and to detect any potential fractures or calcifications [29]. Teeth were ethically sourced from dental clinics in Kermanshah, and proper consent and compliance with ethical guidelines for biological specimen handling were ensured.

Sample preparation

Severe curvature ($>30^\circ$) was excluded to reduce confounding variables, ensuring uniformity among samples [29-30]. Additionally, the crowns of all teeth were sectioned at the cemento-enamel junction (CEJ) using a diamond disk (Bego, Berman, Germany) to standardize the working length across specimens [31]. Surface disinfection was performed by immersing the teeth in a 5.25% NaOCl solution for 30 minutes, followed by storage in a physiological saline solution at room temperature to preserve sample integrity. The working length was determined with #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) and established at 1mm shorter than the apical foramen [32].

For canal preparation, a glide path was first created manually, followed by rotary file shaping using the Protaper system (Dentsply Sirona, NitiGold, Switzerland) up to the F3 file, as per manufacturer guidelines [32]. Throughout instrumentation, irrigation with 5ml of 5.25% NaOCl (Cerkamed, Stalo-wa Wola, Poland) was utilized to ensure proper cleaning [33]. This standardized approach to canal preparation, irrespective of the initial canal diameter, enabled a consistent baseline for comparing the efficacy of $\text{Ca}(\text{OH})_2$ removal techniques while minimizing the influence of anatomical variations.

Sample size

The sample size for this study was determined based on a prior study [34], assuming an estimated variance of 1.5 and a minimum detectable difference of 0.5. A confidence level of 95% and statistical power of 80% were applied to ensure robustness. The calculation resulted in approximately 17 samples per group. With six groups of 17 samples each and two control groups of three samples each, the total sample size was set at 102.

Experimental Protocol

There were six groups of 17 samples and two control groups of three. All specimens were enveloped in hot wax following canal preparation to simulate periapical tissue (Cavex modeling wax, Holland BV, Haarlem, Netherlands) [35]. $\text{Ca}(\text{OH})_2$ was then uniformly filled into the canals using Lentulo spirals, ensuring comprehensive filling by successive compaction with a #80 plugging instrument. $\text{Ca}(\text{OH})_2$ used in this study was a premixed formulation (Golchai, Iran). The premixed nature ensured uniform consistency and ease of applica-

tion during canal filling. The material was delivered into the canals using Lentulo spirals to achieve homogeneous distribution across all regions of the canal. Premixed $\text{Ca}(\text{OH})_2$ was chosen to minimize variability associated with manual preparation and ensure reproducibility of results in future studies. This standardized approach facilitates the replication of our methodology by researchers aiming to evaluate similar techniques for $\text{Ca}(\text{OH})_2$ removal. Subsequently, a 3mm diameter Cavit™ dressing (3M ESPE, Seefeld, Germany) was used to seal the coronal portion of the canal completely.

To ensure the integrity of the coronal section and eliminate the potential influence of the temporary filling material (Cavizol), all temporary fillings were meticulously removed using a diamond burr under magnification before analysis. This step was performed uniformly across all groups to standardize the canal conditions and minimize any potential bias in the results for the coronal section. Additionally, stereo microscopy and Digimizer software were employed to quantify residual $\text{Ca}(\text{OH})_2$ only after ensuring the complete removal of temporary fillings and associated debris. This approach aimed to ensure that the results obtained for the coronal section accurately reflect the efficacy of cleaning techniques rather than artifacts introduced by the temporary material. Radiographic confirmation of complete filling was obtained, and any incompletely filled samples underwent refilling [36].

Following a ten-day incubation period at 37°C in physiological saline solution, as per established protocols, teeth were thoroughly cleaned with temporary dressing. The samples were then randomly divided into six groups of 17 cases (Figures 1-2). Two positive and negative control groups (three in each group) were divided into six experimental groups of 17 cases each, alongside positive and negative control groups (three in each group), to facilitate subsequent comparative analysis. The experimental groups were delineated as follows:

Group A: Seventeen teeth were subjected to Gentle Brush irrigation combined with 4 ml of EDTA solution per tooth for $\text{Ca}(\text{OH})_2$ removal. Following dressing removal, a glide path was established in the canal using the MAF file, tailored to each tooth's specific operating length. Subsequently, 2ml of EDTA was injected into the canal, followed by a final rinse with an additional 2ml of EDTA.

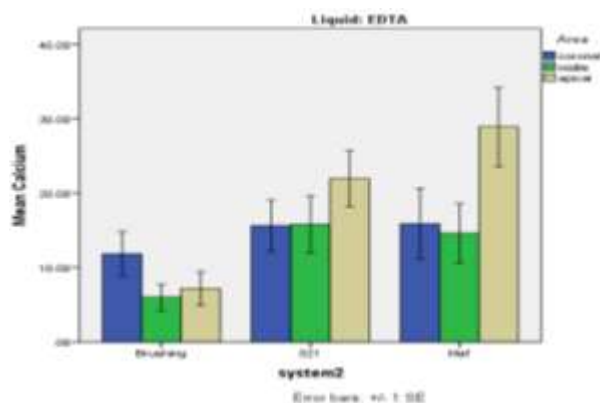


Figure 1: Percentage of residual Ca(OH)_2 in different groups with ethylene-diamine-tetra-acetic acid (EDTA) rinsing solution

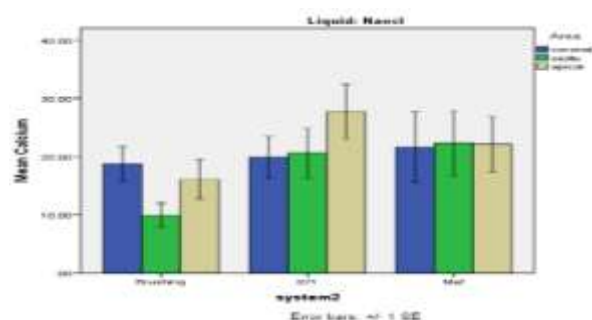


Figure 2: Percentage of residual Ca(OH)_2 in different groups subjected to NaOCl rinsing solution

Group B: In this cohort, 17 teeth underwent irrigation with Gentle Brush accompanied by 4ml of NaOCl. After using each file, the flutes were cleaned with gauze dipped in alcohol. First, a #10 K-file was used to the working length to ensure apical patency. Next, a Gentle Brush was used with a pecking motion and gentle pressure for 5 seconds to reach the apical third of the canal. After reaching the working length, a final rinse was performed. Similar to Group A, dressing removal was followed by glide path creation and irrigation with 2ml of NaOCl. One-minute irrigation was performed using Gentle Brush, followed by a final rinse with 2ml of EDTA.

Group C: Consisting of 17 teeth, this group was subjected to Gentlefile #021 irrigation coupled with EDTA solution for Ca(OH)_2 removal. Following dressing removal, a glide path was created using the relevant MAF file, followed by injection of 2ml of EDTA into the canal, with an additional 2ml of EDTA used for final rinsing.

Group D: Similar to Group C, 17 teeth underwent irrigation with Gentlefile #021 paired with NaOCl. After dressing removal, a glide path was established, and 2 ml of NaOCl was injected into the canal. Gentlefile #021 was utilized for one-minute irrigation, followed by a final rinse with 2 ml of NaOCl.

Group E: Seventeen teeth received irrigation with M-AF and EDTA solution. Following dressing removal, a glide path was created using the relevant MAF file, and 2ml of EDTA solution was injected into the canal, followed by a final rinse with an additional 2ml of EDTA.

Group F: In this cohort, dressing removal was followed by glide path creation using the relevant MAF file for each of the 17 teeth. Subsequently, 2 ml of NaOCl was injected into the canal, followed by a final rinse with 2 ml of NaOCl.

Group G (Positive Control): This group was included to serve as a baseline for comparison, representing conditions where Ca(OH)_2 remained fully retained within the canal. Teeth in this group were intentionally prepared without subsequent irrigation or cleaning protocols, ensuring the presence of Ca(OH)_2 throughout the coronal, middle, and apical regions. This configuration provided a reference point for evaluating the effectiveness of different cleaning techniques applied in the experimental groups.

Group H (Negative Control): The negative control group comprised teeth devoid of Ca(OH)_2 . After completing the procedures above, a decision was made to utilize a chisel for tooth splitting rather than a cutting method. This decision was based on the need for the disc to effectively remove Ca(OH)_2 while maintaining the integrity of the canal surface during the subsequent fracture steps [37]. To facilitate this process, a diamond fissure bur 008 (D&Z, Germany) was employed to create a groove around the tooth, aiming to achieve a more controlled and efficient halving with reduced energy expenditure. This approach was adopted to mitigate potential issues such as incomplete tooth breakage, thereby ensuring optimal experimental outcomes (Figure 3) [38].

After the specimens were individually fragmented, stereo microscopy, a specialized ocular instrument capable of providing three-dimensional visualization, was employed. This microscopy technique allows for capturing images at appropriate magnifications, facilitating detailed examination. Images of each tooth half were captured at a magnification of $1\times$ (10 times). Subsequently, Digimizer software version 4.5 was utilized to analyze these images and quantify the levels of Ca(OH)_2 present in each tooth. The software delineated different regions within the images, including the coronal, middle and apical levels, distinguishing areas containing Ca(OH)_2 from



Figure 3: Broken teeth with chisels

calcium-free surfaces. The software then computed the surface area of these regions in square millimeters (mm^2) (Figure 4 for an illustration of the Digimizer software interface).

Statistical Analysis

The data from each group were entered into Microsoft Excel 2019. Ca(OH)_2 levels for each sample were calculated as percentages relative to the total level, and group averages were computed. Statistical analysis was performed using SPSS 22, with the Kolmogorov-Smirnov test used to assess data distribution and the Kruskal-Wallis test employed for intergroup comparisons.

Results

Quantification of Residual Ca(OH)_2

The quantification of residual Ca(OH)_2 was performed by a blinded evaluator. Figure 1 summarizes the mean percentage of residual Ca(OH)_2 for each group treated with EDTA, displaying residual levels across experimental groups. Figure 2 presents the residual Ca(OH)_2 levels for the NaOCl groups. The positive control group



Figure 4: The user interface of Digimizer software used for the analysis and quantification of Ca(OH)_2 levels in root canal specimens

(Group 7) retained 100% Ca(OH)_2 , while the negative control group (Group 8) had no residual calcium. The Kolmogorov-Smirnov test ($p < 0.001$) confirmed a non-normal data distribution, leading to the use of the Kruskal-Wallis test for intergroup comparisons.

Comparative Efficacy of Cleaning Systems

Statistical analysis identified significant differences in residual Ca(OH)_2 levels among irrigation techniques and specific root canal regions. Gentle Brush exhibited significantly lower residual Ca(OH)_2 levels in the middle region compared to Gentlefile #021 ($p = 0.021$). In the apical region, Gentle Brush also showed significantly greater Ca(OH)_2 removal efficacy than Gentlefile #021 ($p = 0.001$) and MAF ($p = 0.008$).

Furthermore, when Gentle Brush was used with EDTA, it achieved the lowest residual Ca(OH)_2 levels in the apical region, representing the only statistically significant finding for this region. No significant differences in Ca(OH)_2 removal were observed among the experimental groups in the coronal and middle thirds. Figure 5 presents the results of the Mann-Whitney U test, comparing residual Ca(OH)_2 levels across the Gentle Brush, MAF, and Gentlefile #021 groups.

Comparison of Irrigation Solutions (EDTA vs. NaOCl)

A statistically significant difference in residual Ca(OH)_2 levels was observed between teeth treated with Gentlefile #021 and those treated with Gentle Brush ($p < 0.001$), with Gentle Brush demonstrating lower residual Ca(OH)_2 levels. The Mann-Whitney U test was performed to compare the efficacy of EDTA and NaOCl in Ca(OH)_2 removal. Table 1 presents the mean residual Ca(OH)_2 levels across different root canal regions for both irrigation solutions, while Figure 6 visualizes these comparisons. According to Table 1, EDTA exhibited superior efficacy in Ca(OH)_2 removal across all root canal regions,

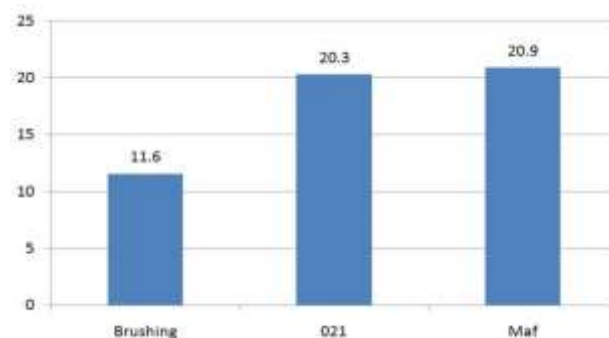


Figure 5: Comparison of average residual Ca(OH)_2 levels following root canal cleansing using different files (Gentle Brush, MAF, Gentlefile #021)

Table 1: Comparison of mean residual Ca(OH)_2 in different regions of the root canal by ethylene-diamine-tetra-acetic acid (EDTA) and NaOCl irrigation solutions

Irrigation Solution	Standard Deviation	Mean	Cleaning Area
EDTA	22	14.45	Coronal
EDTA	19.9	12.14	Middle
EDTA	24.7	19.34	Apical
NaOCl	20	20.07	Coronal
NaOCl	25	17.67	Middle
NaOCl	25.5	21.97	Apical

leaving lower residual levels than NaOCl. The most significant difference was in the middle segment (12.14 vs. 17.67), while EDTA also outperformed NaOCl in the coronal (14.45 vs. 20.07) and apical (19.34 vs. 21.97) regions. These findings confirm EDTA's higher efficiency, particularly in the middle segment. Figure 6 illustrates the mean residual Ca(OH)_2 levels across different regions of the root canal following irrigation with EDTA and NaOCl solutions. The results indicate that NaOCl irrigation led to higher residual calcium hydroxide levels in all three regions- coronal, middle, and apical—compared to EDTA. The difference is particularly notable in the middle and coronal regions, where EDTA demonstrated a more effective removal of Ca(OH)_2 . The error bars represent ± 1 standard error, highlighting the variability of the measurements.

Regional Variability in Residual Ca(OH)_2 Removal

Table 1 and Figures 6-7 further substantiate EDTA's superior performance across all regions. The data underscore Gentle Brush's design advantage, facilitating enhanced EDTA activation and thorough Ca(OH)_2 removal, particularly in challenging apical regions. The EDTA rinsing solution was most effective when used with the Gentle Brush system, showing superior results in the coronal ($p = 0.008$), middle ($p = 0.015$), and apical ($p =$

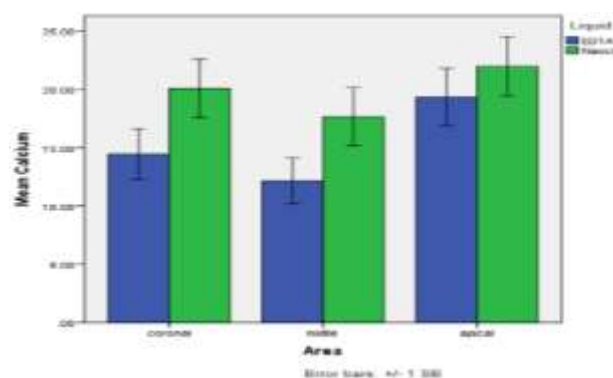


Figure 6: Comparison of mean residual Ca(OH)_2 levels in different regions of the root canal by ethylene-diamine-tetra-acetic acid (EDTA) and NaOCl irrigation solutions

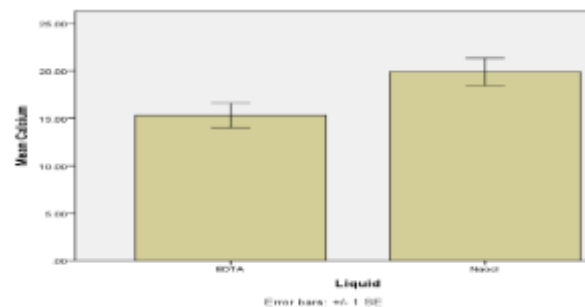


Figure 7: Comparison of mean residual Ca(OH)_2 of teeth by ethylene-diamine-tetra-acetic acid (EDTA) rinses and NaOCl

0.010) regions. Residual Ca(OH)_2 levels were highest in the apical region compared to other areas.

Discussion

Effective root canal cleaning is fundamental for successful endodontic therapy. Ca(OH)_2 is extensively used as an intracanal medicament due to its antimicrobial properties and tissue-dissolving capabilities, attributed to its release of hydroxyl ions in an alkaline environment [39]. However, its residues must be completely removed before obturation to ensure optimal sealer adhesion and prevent treatment failure.

This challenge is particularly pronounced in the apical third of the canal, where the complex anatomy hinders effective debridement. Residual Ca(OH)_2 can obstruct sealer penetration and bonding, leading to compromised treatment outcomes. Thus, employing advanced irrigation protocols is crucial to overcome these anatomical barriers and achieve thorough cleaning [40-41].

This study confirmed EDTA's superior effectiveness over NaOCl in reducing residual Ca(OH)_2 across all root canal regions, particularly in the middle third (Table 1) [3]. EDTA's chelating properties facilitate the dissolution of calcium ions and the removal of the smear layer, which otherwise obstructs sealer adhesion and dentinal tubule penetration [42]. In contrast, NaOCl, while highly effective at dissolving organic tissue and exhibiting antimicrobial properties, lacks the chelating ability needed for efficient Ca(OH)_2 removal.

The middle third of the canal exhibited the greatest reduction in residual Ca(OH)_2 with EDTA, reflecting its superior performance in this region [43-44]. However, both EDTA and NaOCl faced challenges in the apical region, where higher residual levels persisted due to anatomical complexity and reduced accessibility.

EDTA's ability to reduce dentin microhardness further enhances its capacity to disrupt Ca(OH)_2 bonds on

canal walls, emphasizing its critical role in achieving effective debridement and optimal treatment outcomes. Despite EDTA's overall superiority, the study highlights persistent challenges in the apical third, where the intricate anatomy complicates complete debris removal [45]. These findings emphasize the need for continued refinement of irrigation techniques to address this limitation.

The Gentle Brush method proved more effective in Ca(OH)_2 removal than Gentlefile #021. Its design, featuring long strands, enables better agitation and coverage of the canal walls, particularly in the apical region, where its vortex flow activation improves cleaning efficacy [3, 46]. Conversely, Gentlefile #021 demonstrated limitations in agitation and debris removal due to its less efficient mechanical action [47].

The Gentle Brush's design allows for more effective mechanical agitation within the canal, facilitating better contact with the canal walls and enhancing debris removal [48]. Studies have shown that mechanical cleaning methods often outperform manual techniques in terms of efficacy, as they can reach areas difficult for files to access [49-50].

The Gentle Brush method demonstrates superior interaction with irrigants, enhancing its effectiveness compared to the Gentlefile system [51]. Figures 3-6, and Table 1 illustrate the study results, particularly the enhanced removal of Ca(OH)_2 when Gentle Brush is used with EDTA rinsing solution. Figure 3 highlights the effective cleaning achieved in the apical region due to the Gentle Brush file's unique design. The file threads open more efficiently in the apical area, aligning better with the root canal walls compared to the coronal area. This design, combined with the activation of EDTA through vortex flow, results in improved Ca(OH)_2 removal in the apical region.

These findings are consistent with prior studies, which emphasize the limitations of traditional methods in cleaning the apical area. The Gentle Brush's ability to overcome these limitations further validates its efficacy in challenging anatomical regions [52-54].

This study confirmed that EDTA was significantly more effective than NaOCl for removing Ca(OH)_2 , and observed the most notable efficacy in the middle region of the root canal [3]. While advanced techniques like ultrasonic or laser-based systems enhance cleaning, their adoption often requires specialized training and

equipment, making them less feasible for routine practice due to increased cost and complexity. Additionally, the delicate nature of root canal anatomy and potential complications may lead practitioners to prefer more straightforward and conservative methods.

Figure 4 illustrates the residual Ca(OH)_2 levels across groups treated with NaOCl, while Figure 5 compares the efficacy of different cleaning systems- Gentle Brush, MAF, and Gentlefile #021. The Gentle Brush consistently demonstrated superior performance, particularly in combination with EDTA. These findings underscore the importance of selecting effective yet accessible cleaning protocols and highlight the need for continued research to refine existing methods [55].

This study evaluated the efficacy of root canal cleaning systems, focusing on the MAF and the Gentlefile system. The Gentlefile system effectively removed Ca(OH)_2 residues, consistent with findings by Gokturk *et al.* (2017), who highlighted variations in residual Ca(OH)_2 levels across different canal regions [52]. A notable observation is the "packing effect" of the Gentle Brush, which may push Ca(OH)_2 deeper into the canal. This effect facilitates enhanced removal in the coronal region by optimizing fluid dynamics and agitation [56].

Anatomical variations significantly influence cleaning efficacy. The coronal third, with its wider diameter and complex anatomy, tends to trap debris more effectively than the narrower, tapered apical third. This distinction allows for more efficient flushing and debris removal in the apical region. The effectiveness of irrigation solutions, such as NaOCl and EDTA, also plays a critical role, as these solutions can enhance cleaning outcomes, particularly in challenging apical regions [57-58]. Additionally, prior research has demonstrated that irrigation methods yield varying levels of success in removing Ca(OH)_2 across different canal thirds. These differences emphasize the need for tailored approaches to address the unique challenges presented by each region [59-60].

Our study quantified Ca(OH)_2 surface areas, whereas Gokturk *et al.* [52] used a scoring system categorizing residual Ca(OH)_2 as low, medium, or high and expressed results as percentages to highlight distinctions between methods. Gokturk *et al.* [52] also reported enhanced efficacy of NaOCl when activated differently, whereas our findings revealed that EDTA, particularly when paired with the Gentle Brush system, outperform-

ed NaOCl in Ca(OH)_2 removal [52].

Figure 6 highlights the comparative efficacy of EDTA and NaOCl irrigation solutions across various root canal regions. Although the Gentlefile system is designed to enhance irrigant flow and agitation, its mechanical action alone is insufficient to remove all residual Ca(OH)_2 , particularly in complex canal anatomies. Activation improves irrigant penetration but does not ensure complete debris removal, as some remnants may become trapped in irregular surfaces.

The design of Gentlefile, theoretically, provides better access to irregular canal areas, yet studies show that its improved fluid dynamics may still fall short in disrupting the bond between Ca(OH)_2 and dentin. This limitation results in higher residual levels compared to methods like the Gentle Brush, which combines superior mechanical and fluid activation for more effective cleaning outcomes.

This study emphasizes the importance of combining effective irrigation solutions, such as EDTA, with mechanical systems like Gentle Brush to achieve optimal cleaning outcomes. The Gentle Brush outperforms Gentlefile, particularly in the apical third, where its superior design and activation capabilities enhance debris removal. These findings provide clinicians with valuable insights for selecting the most effective cleaning techniques, ultimately improving treatment success and patient satisfaction [61-62].

Conclusion

This study evaluated the effectiveness of root canal cleaning methods for removing Ca(OH)_2 , a crucial aspect of successful endodontic therapy. The Gentle Brush system demonstrated superior performance, particularly in the apical region, where its design and mechanical efficiency ensured thorough cleaning. Additionally, it outperformed Gentlefile #021 in the middle region, further proving its effectiveness in complex anatomical areas. Among the irrigation solutions evaluated, EDTA was significantly more effective than NaOCl in removing Ca(OH)_2 residues from canal walls. This effectiveness was most pronounced when EDTA was paired with the Gentle Brush system, achieving optimal cleaning in all root canal regions- coronal, middle, and apical. However, residual Ca(OH)_2 levels remained highest in the apical region, reflecting the persistent anatomical chal-

enges of complete debridement.

These findings highlight that combining advanced mechanical systems like the Gentle Brush with potent irrigants such as EDTA is the most effective approach for thorough canal cleaning. This integrated method overcomes the limitations of individual techniques and sets a new standard for enhancing clinical outcomes in root canal therapy. Future research should aim to optimize these methods further, evaluate their performance in varied anatomical scenarios, and explore their practical application to refine endodontic protocols.

Acknowledgment

We sincerely thank the Department of Endodontics at the School of Dentistry, Aja University of Medical Sciences in Tehran, Iran (Ethics committee identification number IR.AJAUMS.REC.1399.079).

Conflicts of Interest

The authors declare no conflicts of interest related to this research. We have no financial or personal relationships that could potentially bias our findings or influence the interpretation of results.

References

- [1] Ong TK, Lim GS, Singh M, Fial AV. Quantitative assessment of root development after regenerative endodontic therapy: a systematic review and meta-analysis. *J Endod*. 2020; 46: 1856-1866.
- [2] Khademi AA, Amini K, Ghodsian B, Zahed SM, Teymori F, Shadmehr E. Removal efficiency of calcium hydroxide intracanal medicament with RinsEndo system in comparison with passive ultrasonic irrigation, an in vitro study. *Dent Res J*. 2015; 12: 157-160.
- [3] Kuga MC, Tanomaru-Filho M, Faria G, S6 MVR, Galletti T, Bavello JRS. Calcium hydroxide intracanal dressing removal with different rotary instruments and irrigating solutions: a scanning electron microscopy study. *Braz Dent J*. 2010; 21: 310-314.
- [4] Reyhani MF, Ghasemi N, Milani AS, Asl MA. Antimicrobial effect of nano-calcium hydroxide on the four-and six-week-old Intra-canal enterococcus faecalis biofilm. *J Dent Shiraz Univ Med Sci*. 2023; 24: 194.
- [5] Chawla A, Kumar V. Evaluating the efficacy of different techniques and irrigation solutions for removal of calcium hydroxide from the root canal system: A scanning

- electron microscope study. *J Conservative Dent.* 2018; 21: 394-400.
- [6] Kourti E, Pantelidou O. Comparison of different agitation methods for the removal of calcium hydroxide from the root canal: Scanning electron microscopy study. *JCDE.* 2017; 20: 439-444.
- [7] Gluskin AH, Peters CI, Peters OA. Minimally invasive endodontics: challenging prevailing paradigms. *Br Dent J.* 2014; 216: 347-53.
- [8] Estrela C, Pécora JD, Estrela CR, Guedes OA, Silva BS, Soares CJ, Sousa-Neto MD. Common operative procedural errors and clinical factors associated with root canal treatment. *Braz Dent J.* 2017; 28: 179-190.
- [9] Rödiger T, Hirschleib M, Zapf A, Hülsmann M. Comparison of ultrasonic irrigation and RinsEndo for the removal of calcium hydroxide and Ledermix paste from root canals. *Int Endod J.* 2011; 44: 1155-1161.
- [10] Agrawal P, Garg G, Bavabeedu SS, Arora S, Moyin S, Punathil S. Evaluation of intracanal calcium hydroxide removal with different techniques: a scanning electron microscope study. *J Contemp Dent Pract.* 2018; 19: 1463-1468.
- [11] Reddy S, Prakash V, Subbiya A, Mitthra S. 100 years of Calcium Hydroxide in Dentistry: A review of literature. *Indian J Forensic Med Toxicology.* 2020; 14: 1203-1219.
- [12] Srivastava AA, Srivastava H, Prasad AB, Raisingani D, Soni D. Effect of calcium hydroxide, chlorhexidine digluconate and camphorated monochlorophenol on the sealing ability of biodentine apical plug. *J Clin Diag Res (JCDR).* 2016; 10: ZC43.
- [13] Jamali S, Jabbari G, Mousavi E, Ahmadizadeh H, Khorram M, Jamee A. The comparison of different irrigation systems to remove calcium hydroxide from the root canal: a systematic review and meta-analysis. *Pesquisa Brasileira Odontopediatria Clin Integr.* 2020; 20: e5404.
- [14] Ustun Y, Uzun O, Er O, Canakcı BC, Topuz O. The effect of residual calcium hydroxide on the accuracy of a contemporary electronic apex locator. *Acta Odontologica Scandinavica.* 2015; 73: 132-136.
- [15] Gulabivala K, Ng YL. Factors that affect the outcomes of root canal treatment and retreatment: A reframing of the principles. *Int Endo J.* 2023; 56: 82-115.
- [16] Nouroloyouni A, Safavi Hir F, Farhang R, Noorolouny S, Salem Milani A, Alyali R. Evaluating in vitro performance of a novel stainless steel rotary system (gentlefile) based on debris extrusion and instrumentation time. *Biomed Res Int.* 2023; 2023: 9945236.
- [17] Shi L, Wu S, Yang Y, Wan J. Efficacy of five irrigation techniques in removing calcium hydroxide from simulated S-shaped root canals. *J Dent Sci.* 2022; 17: 128-134.
- [18] Tamil S, Andamuthu SA, Vaiyapuri R, Prasad A, Jambai SS, Chittrarasu M. A comparative evaluation of intracanal calcium hydroxide removal with hand file, rotary file, and passive ultrasonic irrigation: an in vitro study. *J Pharm Bioall Sci.* 2019; 11(Suppl 2): S442-S445.
- [19] Generali L, Cavani F, Franceschetti F, Sassatelli P, Giardino L, Pirani C, et al. Calcium hydroxide removal using four different irrigation systems: A quantitative evaluation by scanning electron microscopy. *Applied Sci.* 2021; 12: 271.
- [20] Petričević GK, Katić M, Anić I, Salarić I, Vražić D, Bago I. Efficacy of different Er: YAG laser-activated photoacoustic streaming modes compared to passive ultrasonic irrigation in the retreatment of curved root canals. *Clin Oral Invest.* 2022; 26: 6773-6781.
- [21] Swathi P, Uloopi K, Vinay C, RojaRamya KS, Chaitanya P, Ahalya P. Effectiveness of Laser-activated and Ultrasonic Irrigation Techniques in Removal of Calcium Hydroxide and Modified Triple Antibiotic Paste from the Root Canals: An In Vitro Evaluation. *Int J Clin Ped Dent.* 2023; 16(Suppl 1): S1.
- [22] Donnermeyer D, Wyrsh H, Bürklein S, Schäfer E. Removal of calcium hydroxide from artificial grooves in straight root canals: sonic activation using EDDY versus passive ultrasonic irrigation and XPEndo Finisher. *J Endo.* 2019; 45: 322-326.
- [23] Salas H, Castrejon A, Fuentes D, Luque A, Luque E. Evaluation of the penetration of CHX 2% on dentinal tubules using Conventional Irrigation, Sonic Irrigation (EDDY) and Passive Ultrasonic Irrigation (PUI) techniques: An in vitro study. *J Clin Exper Dent.* 2021; 13: e37.
- [24] Rossi-Fedele G, Doğramacı EJ, Guastalli AR, Steier L, de Figueiredo JAP. Antagonistic interactions between sodium hypochlorite, chlorhexidine, EDTA, and citric acid. *J Endo.* 2012; 38: 426-431.
- [25] Solana C, Ruiz-Linares M, Baca P, Valderrama MJ, Arias-Moliz MT, Ferrer-Luque CM. Antibiofilm activity of sodium hypochlorite and alkaline tetrasodium EDTA solutions. *J Endo.* 2017; 43: 2093-2096.
- [26] Nouroloyouni A, Shahi S, Milani AS, Noorolouny S, Farhang R, Azar AY. In vitro apical extrusion of debris and instrumentation time following root canal instrumen-

- tation with Reciproc and Reciproc Blue instruments and a novel stainless steel rotary system (Gentlefile) versus manual instrumentation. *J Dent Res Dent Clin Dent Pros.* 2023; 17: 136.
- [27] Ghahramani Y, Mohammadi N, Baghaei S, Jahandizi NG. Time-Dependent Antibacterial Effects of Citrullus Colocynthis Seed Extract Compared to Calcium Hydroxide in Teeth Infected with Enterococcus Faecalis. *J Dent Shiraz Univ Med Sci.* 2024; 25: 77.
- [28] Mesgarani A, Shahrami F, Ehsani M, Poorsattar BMA. Successful Conservative Endodontic Treatment of Fused Maxillary Incisors: A Case Report. *J Dent Shiraz Univ Med Sci.* 2012; 13: 80-84.
- [29] Pabel A-K, Hülsmann M. Comparison of different techniques for removal of calcium hydroxide from straight root canals: an in vitro study. *Odontology.* 2017; 105: 453-459.
- [30] Siqueira Jr JF, Rôças IN. Clinical implications and microbiology of bacterial persistence after treatment procedures. *J Endo.* 2008; 34: 1291-301.
- [31] Karapinar Kazandag M, Sunay H, Tanalp J, Bayirli G. Fracture resistance of roots using different canal filling systems. *Int Endod J.* 2009; 42: 705-710.
- [32] Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. *J Endod.* 2004; 30: 559-567.
- [33] Garg R, Singhal A, Agrawal K, Agrawal N. Managing endodontic patients with severe gag reflex by glossopharyngeal nerve block technique. *J Endod.* 2014; 40: 1498-1500.
- [34] Ziarati P, Moghimi S, Arbabi-Bidgoli S, Qomi M. Risk assessment of heavy metal contents (lead and cadmium) in lipsticks in Iran. *Int J Chem Eng Appl.* 2012; 3: 450.
- [35] Zehnder M. Root canal irrigants. *J Endod.* 2006; 32: 389-398.
- [36] Siqueira Jr JF, Batista MM, Fraga RC, de Uzeda M. Antibacterial effects of endodontic irrigants on black-pigmented gram-negative anaerobes and facultative bacteria. *J Endod.* 1998; 24: 414-416.
- [37] Vatanpour M, Toursavadvkouhi S, Sajjad S. Comparison of three irrigation methods: SWEEPS, ultrasonic, and traditional irrigation, in smear layer and debris removal abilities in the root canal, beyond the fractured instrument. *Photodiagnosis Photodyn Ther.* 2022; 37: 102707.
- [38] Jamshidi D, Tahriri M, Mosleh H, Madadpour M, Heydari S, Heydari MA, et al MJ. Effect of chloroform application on roughness and wettability of the root canal walls in endodontic retreatment. *J Dent Shiraz Univ Med Sci.* 2022; 23: 272.
- [39] Bhalla VK, Chockattu SJ. Intracanal delivery of calcium hydroxide: a literature review. *Saudi Endo J.* 2021; 11: 1-6.
- [40] Ghanbarzadegan A, Ajami M, Aminsobhani M. The effect of different combinations of calcium hydroxide as intra-canal medicament on endodontic pain: A randomized clinical trial study. *Iran Endod J.* 2019; 14: 1-6.
- [41] Stuart CH, Schwartz SA, Beeson TJ, Owatz CB. Enterococcus faecalis: its role in root canal treatment failure and current concepts in retreatment. *J Endod.* 2006; 32: 93-98.
- [42] Sarkees M, Al-Maarrawi K. Chitosan: A natural substitute of EDTA solution for final irrigation in endodontics treatment. *Nigerian J Clin Pract.* 2020; 23: 697-703.
- [43] Singhal P, Raisingani D, Prasad AB, Yadav J, Srivastava H, Kriti S. Qualitative and Quantitative Evaluation of the Effects of Different Chelating Agents on the Calcium Content of Root Canal Dentin Using Atomic Absorption Spectrophotometer: An In Vitro Study. *Int J Clin Ped Dent.* 2024; 17: 647-652.
- [44] Mahanubhav N, Ahuja T, Nanda Z, Reddy K, Gawande J, Rane P. A comparative evaluation of effects of three chelating agents on smear layer of root canals of extracted human teeth-An In Vitro Study. *J Applied Dent Med Sci.* 2020; 6: 1.
- [45] Baasch A, Campello AF, Rodrigues RC, Alves FR, Voigt DD, Mdala I, et al. Effects of the irrigation needle design on root canal disinfection and cleaning. *J Endo.* 2024; 50: 1463-1471.
- [46] Wigler R, Dvir R, Weisman A, Matalon S, Kfir A. Efficacy of XP-endo finisher files in the removal of calcium hydroxide paste from artificial standardized grooves in the apical third of oval root canals. *Int Endod J.* 2017; 50: 700-705.
- [47] Abdelnaby HM, Youssef HA, Sadek HS, Abdullatif S. Evaluation of the efficiency of brush file as irrigation agitation technique versus passive ultrasonic irrigation on biofilm eradication and calcium hydroxide removal from straight root canals: A comparative in vitro study. 2023; 9: 11-18.
- [48] Cahuana-Vasquez RA, Adam R, Conde E, Grender JM, Cunningham P, Goyal CR, Qaqish J. A 5-week randomized clinical evaluation of a novel electric toothbrush

- head with regular and tapered bristles versus a manual toothbrush for reduction of gingivitis and plaque. *Int J Dent Hyg.* 2019; 17: 153-160.
- [49] Zmener O, Pameijer C, Banegas G. Effectiveness in cleaning oval-shaped root canals using Anatomic Endodontic Technology, ProFile and manual instrumentation: a scanning electron microscopic study. *Int Endo J.* 2005; 38: 356-363.
- [50] Reddy KS, Soubhgya M, Begum N, Vuggirala V, Nallagula KH. Comparative evolution of clinical efficacy of manual tooth brush versus chewable tooth brush a randomized clinical trail. *Indian J Dent Sci.* 2021; 13: 219-23.
- [51] Ordinola-Zapata R, Crepps JT, Neelakantan P. Root canal debridement and disinfection in minimally invasive preparation. *Minimally Invasive Approaches in Endodontic Practice.* 2021: 93-107. Available at: http://dx.doi.org/10.1007/978-3-030-45866-9_5
- [52] Gokturk H, Ozkocak I, Buyukgebiz F, Demir O. Effectiveness of various irrigation protocols for the removal of calcium hydroxide from artificial standardized grooves. *J Appl Oral Sci.* 2017; 25: 290-298.
- [53] Behl M, Taneja S, Bhalla VK. Comparative evaluation of novel chelating agents for retrievability of intracanal calcium hydroxide using different irrigation protocols: An in vitro study. *Endodontology.* 2023; 35: 238-242.
- [54] Phillips M, McClANAHAN S, Bowles W. A titration model for evaluating calcium hydroxide removal techniques. *J Appl Oral Sci.* 2015; 23: 94-100.
- [55] Parikh M, Kishan KV, Solanki NP, Parikh M, Savaliya K, Bindu VH, Devika TD. Efficacy of Removal of Calcium Hydroxide Medicament from Root Canals by Endo-activator and Endovac Irrigation Techniques: A Systematic Review of: In vitro: Studies. *Contemp Clin Dent.* 2019; 10: 135-142.
- [56] Peters OA, Peters CI. Cleaning and shaping of the root canal system. *Cohen's Pathway of the Pulp* ed. 12th ed. St. Louis: Elsevier; 2020. p. 236-303.
- [57] Ordinola-Zapata R, Martins J, Niemczyk S, Bramante CM. Apical root canal anatomy in the mesiobuccal root of maxillary first molars: influence of root apical shape and prevalence of apical foramina—a micro-CT study. *Int Endo J.* 2019; 52: 1218-1227.
- [58] Guerreiro-Tanomaru JM, Loiola LE, Morgental RD, Leonardo RdT, Tanomaru-Filho M. Efficacy of four irrigation needles in cleaning the apical third of root canals. *Brazilian Dent J.* 2013; 24: 21-24.
- [59] Eymirli A, Uyanik O, Nagas E, Calt Tarhan S. Effect of calcium hydroxide removal techniques on the bond strength of root canal sealers. *J Adhesion Science and Technology.* 2017; 31: 1196-202.
- [60] Saji SA, Shetty C, Kaur G, Bajpe S, Chandraprabha C, Shroff R, et al. Comparison of various irrigation techniques for the removal of silicone oil-based calcium hydroxide intracanal medicament from the apical third: An SEM study. *J Health Allied Sci NU.* 2024; 15: 103-108.
- [61] Shi L, Wu S, Yang Y, Wan J. Efficacy of five irrigation techniques in removing calcium hydroxide from simulated S-shaped root canals. *J Dent Sci.* 2022; 17: 128-134.
- [62] Adl A, Razavian A, Eskandari F. The efficacy of Endo-Activator, passive ultrasonic irrigation, and Ultra X in removing calcium hydroxide from root canals: an in vitro study. *BMC Oral Health.* 2022; 22: 564.