Original Article

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# Effectiveness of passive ultrasonic irrigation and XP-endo Finisher in removing calcium hydroxide with different vehicles

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**Objective:** The aim of this study was to compare the efficacy of passive ultrasonic irrigation (PUI) and the XP-endo Finisher (XPF) in removing calcium hydroxide (CH) residues from root canal walls across four different formulations.

**Materials and Methods:** Ninety mandibular premolar teeth were used in this study. After accessing the pulp chamber, root canals were prepared using the WaveOne® Gold system up to size 45. The specimens were randomly divided into four experimental groups (n=22): CH powder mixed with distilled water (CP), Ultracal™ XS (UC) representing aqueous-based CH, Metapaste® (MP) representing viscous-based CH, and Vitapex® (VP) representing oil-based CH. Within each group, two teeth were designated as positive controls, and the remaining 20 teeth were further subdivided based on the irrigation technique (PUI and XPF). Scanning electron microscope (SEM) analysis was used to evaluate the efficacy of each method in removing CH residues at the apical level, with statistical analysis conducted using two-way ANOVA with Bonferroni post hoc test.

**Results:** Cleaning efficacy was significantly affected by the type of medication ($p<0.001$), with VP showing the highest amount of remaining CH residue in both irrigation techniques. The percentages of remaining CH were as follows: CP-20.11%, UC-27.69%, MP-30.97%, and VP-55.37% in the PUI group, and CP-31.46%, UC-27.43%, MP-34.33%, and VP-59.37% in the XPF group, with statistical significance.

**Conclusions:** At the apical level, PUI and XPF are comparably effective in removing CH. The vehicle used to prepare CH is the most important factor affecting its removal. CP, UC, and MP showed similar removal efficacy, while VP was notably more challenging to remove at the apical level.

**Keywords:** calcium hydroxide removal, endodontic irrigation technique, passive ultrasonic irrigation, XP-endo finisher

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## Introduction

The goal of endodontic treatment is to prevent and eliminate apical periodontitis. Complete chemomechanical preparation is considered an essential step for effective root canal disinfection. However, achieving total elimination of bacteria is challenging, and intracanal medications are often used to eliminate any remaining bacteria. Calcium hydroxide (CH) has been recommended as an intracanal medicament in several clinical situations and is left inside the canal for different durations, ranging from 7 days for routine root canal treatment to 6-24 months for apexification and the management of large lesions [1].

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In essence, a CH paste for use in endodontics consists of a powder combined with a vehicle. Additional substances may be added to improve physiochemical properties or antibacterial activity. The vehicle plays an important role in the overall CH dissociation into hydroxyl and calcium ions, thereby impacting the material's physical and chemical characteristics [2]. Lower viscosity vehicles promote higher ionic dissociation [3], while the high molecular weight of common vehicles helps restrict the dispersion of CH into tissues and maintain the paste in the desired area for longer periods [4]. Consequently, these pastes are classified based on their vehicle type, commonly falling into three categories: aqueous, viscous, and oily. Oil-based CH pastes are notably more difficult to remove compared to CH mixed with distilled water [5-7]. However, the removal efficacy of viscous-based CH has been debated. Some studies report that viscous-based CH shows similar removal efficacy to aqueous-based CH [8, 9], while others indicate that viscous-based CH leaves significantly more residue than aqueous formulations [10].

In spite of various advantages and indications of CH, it has been demonstrated to be difficult to completely remove from root canal systems. Ricucci and Langeland reported a case of failed root canal treatment due to incomplete removal of CH from the root canal, which was placed as intracanal medicament [11]. Laboratory studies have revealed that residual CH can impede the penetration of sealers into dentinal tubules, hinder the bonding of resin sealers to dentine, and result in a thicker, non-homogenous appearance of root canal sealer, potentially compromising the sealing ability of root canal filling [12, 13]. Therefore, complete removal of CH from the root canal prior to obturation is recommended.

However, it is impossible to ensure that all material has been completely removed from the root canal, especially in the apical part, due to the complexity of root canal anatomy. Several methods have been described to eliminate CH from the canal. The most commonly used method is the use of a master apical file (MAF) to the working length (WL) in conjunction with EDTA and sodium hypochlorite (NaOCl). Despite this, remnants of CH often persist in canal extensions or irregularities.

Passive ultrasonic irrigation (PUI) has been widely advocated as an effective method for cleaning pulpal remnants and dentinal debris from canals and isthmuses. PUI operates by transmitting acoustic energy from an ultrasonic tip to an irrigant within the root canal. The acoustic energy delivered by the ultrasonic tip activates the solution, resulting in acoustic streaming and cavitation, which are more powerful when the root canal wall is deliberately not touched by the oscillating instrument [14]. Many studies have reported that PUI is superior in removing CH from root canal systems [6].

The XP-Endo® Finisher (XPF) is a file based on the shape-memory principles of NiTi alloy, with a small core size of 25 and zero taper. This file maintains the original root canal anatomy and effectively cleans irregular areas because of its enhanced flexibility and ability to expand and adapt to the three-dimensional structure of the root canal [15]. Due to these properties, previous studies have reported that the XPF is effective in removing CH remnants from the root canal [16, 17].

According to our literature review, only a few studies have been conducted to analyze the removal of premixed CH paste using PUI and XPF techniques, focusing solely on aqueous and oily vehicles [7]. Therefore, this study aimed to assess the efficacy of PUI and XPF in removing premixed CH paste combined with four different

formulations, covering all vehicle types, from root canal wall to provide clarification on this topic. The null hypothesis of this study was that there would be no significant difference in the amount of CH remaining in the root canal based on the type of medication or removal technique used.

## Methods

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 guidelines [18].

### Specimen selection

This study and informed consent for this study were exempted from ethical approval from the Human Research Committee, Faculty of Dentistry/Faculty of Pharmacy, Mahidol University Institutional Review Board (No. MU-DT/PY-IRB 2020/066.1812). The sample size calculation was performed using the G*power version 3.1.9 application with a 5% Type I error ($\alpha$=0.05) and 80% study power ($\beta$=0.20). Data from a comparable previous study [19] indicated that the sample size for each group should be at least 7. Therefore, 10 canals were used for each experimental group.

Ninety freshly extracted human single-rooted mandibular premolars with mature root formation and a root length of more than 12-14 mm (measured from the cementoenamel junction (CEJ)) were selected for this study. Teeth with root caries, fractures, or cracks identified through examination with a 5x magnification microscope were excluded. Preoperative mesiodistal and buccolingual radiographs were used to confirm the presence of a single root canal with curvatures <10° according to Schneider's technique [20], and without previous root canal treatment, resorptions, or calcified canal. Figure 1 illustrates the flowchart of the operational procedures.

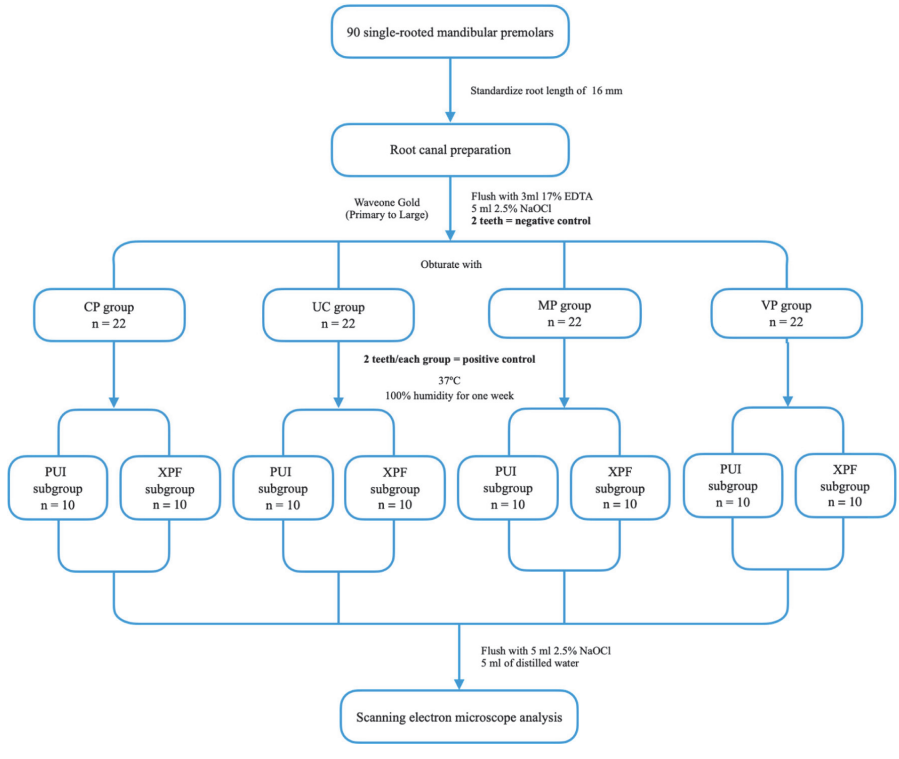



**Figure 1** Flowchart illustrating the operational procedures. CP, Calcium hydroxide paste; UC, Ultracal™ XS; MP, Metapaste®; VP, Vitapex®; PUI, Passive ultrasonic irrigation; XP, XP-Endo® Finisher.

## Preparation of specimens

The external root surface was cleaned with a toothbrush and an ultrasonic scaler after being immersed in 2.5% NaOCl for 10 minutes. Subsequently, the teeth were stored in 0.1% thymol until use. Each tooth was decoronated with a carborundum disc to standardize the specimen length to a final length of 16 mm from the apex. The access opening to the pulp chamber was made using a round diamond bur. The pulp tissue was extirpated using a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland). A #15 K-file was introduced into the canal until the tip was visible at the apical foramen, and the working length was determined by subtracting 1 mm from the measured length. All root canals were instrumented with reciprocating instruments, starting with the Primary size (size 25, 7% variable taper) (WaveOne® Gold; Dentsply Maillefer, Ballaigues, Switzerland) up to a master apical file size Large (size 45, 5% variable taper). Between each file, a #10 K-file was used to maintain patency, and the canals were irrigated with 5 ml of 2.5% NaOCl delivered via a 30-gauge needle with a side opening, inserted into the canal 1 mm short of the working length. After the chemomechanical preparation, the canals were dried with paper points. All roots were grooved longitudinally on the mesial and distal surfaces using a carborundum disc in a straight handpiece, preserving the root canal wall. The canals were finally flushed with 3 ml of 17% ethylenediaminetetraacetic (EDTA) for 1 minute, followed by 5 ml of 2.5% NaOCl for 1 minute, and then dried with paper points.

## Experimental group

Ninety specimens were randomly assigned into four experimental groups (n=22) according to the calcium hydroxide (CH) vehicle preparation. Two teeth from each group served as positive controls, while two additional specimens did not receive CH placement, representing negative controls.

1. CH paste (CP): CH powder (M-dent products, Faculty of Dentistry, Mahidol University, Bangkok, Thailand) mixed with distilled water to a creamy consistency (1:1, w/v).

2. Ultracal™ XS (UC) (Ultradent products, Jordan, UT, USA) represented a CH liquid vehicle preparation.

3. Metapaste® (MP) (Meta Biomed Co., Ltd., Chungcheongbuk-do, Korea) represented a CH viscous vehicle preparation.

4. Vitapex® (VP) (Neo Dental Chemical Products Co., Tokyo, Japan) represented a CH oily vehicle preparation.

The CP was inserted using a lentulo spiral (size 40) 1mm short of the apex. The premixed CH preparations, UC, MP, and VP, were injected to 1 mm short of the working length via the manufacturer's dispenser. Mesiodistal and buccolingual radiographs were taken to confirm the homogeneity of medication. The access cavities were temporarily sealed with a temporary filling (Cavit™; 3M ESPE, Seefeld, Germany) to a depth of 3 mm, and the specimens were stored at 37°C with 100% humidity for one week.

## CH removal

After this period, the temporary filling was removed with a round steel bur, and the canals were irrigated with 2.5 ml of 2.5% NaOCl. A #15 K-file was used to recapitulate at the working length. The remaining 20 teeth were randomly divided into two subgroups (n=10) according to the CH removal techniques: subgroup 1 used passive ultrasonic irrigation (PUI), and subgroup 2 used XP-endo® Finisher (XPF). Both were performed according to the manufacturer's recommendations.

- *Subgroup 1: Passive ultrasonic irrigation (PUI)*

2.5 ml of 2.5% NaOCl was delivered into the root canal with a 30-gauge side-vented needle. After completing the irrigation, a size-20 IrriSafe® tip (Satelec Acteon, Merignac, France) was inserted 1 mm short of the working length, avoiding contact with the dentin walls. The tip was activated for 30 seconds for 2 cycles, at a power setting of 7. Subsequently, 1.5 ml of 17% EDTA was used to irrigate in the same manner for 2 cycles. The canal was dried with paper points between each irrigant.

- *Subgroup 2: XP-endo® Finisher (XPF)*

2.5 ml of 2.5% NaOCl was delivered into the root canal with the 30-gauge side-vented needle. After completing the irrigation process, the XP-endo® Finisher file (FKG Dentaire, La Chaux-deFonds, Switzerland) was inserted to the working length with slow and continuous in-and-out movements of about 8 mm amplitude for 30 seconds (30 strokes) for 2 cycles. Subsequently, 1.5 ml of 17% EDTA was used to irrigate in the same manner for 2 cycles. The canal was dried with paper points between each irrigant. The XPF file was used with an endodontic motor E connect S (Eighteeth, Xinbei, China), set to a speed of 800 rpm and a torque of 1 N.cm. These procedures were performed in a temperature-controlled water bath at 37°C, ensuring no water entered the canal.

Finally, the specimens were irrigated with 5 ml of 2.5% NaOCl followed by 5 ml of distilled water to neutralize the action of the irrigants. All endodontic procedures were performed by a single operator to avoid inter-operator variability.

## Scanning electron microscope analysis

The specimen preparation and outcome assessment were adapted from previous studies [21-25]. After drying the canals with paper points, the roots were split into halves using a mallet and chisel. The sections were dehydrated in a desiccator and coated with palladium. The selected dentinal surfaces, marked at 4 mm from the apex representing the apical thirds, were observed under a scanning electron microscope (SEM) version JSM-6610LV (JEOL Ltd., Tokyo, Japan) at x1000 magnification. To standardize the area examined for each sample, the central beam of the SEM was directed to the center of the apical part of the root canal by the SEM operator under 10x magnification. The magnification was then gradually increased to 1000x, and three images of the canal wall at the apical level were captured. To measure the percentage of remaining CH in each image, images were blindly selected. An examiner manually identified areas containing residual CH and used the ImageJ program to calculate the percentage of these areas (Figure 2).

$$\text{Percentage of CH remaining} = \frac{\text{Area of CH remaining}}{\text{Overall area}} \times 100$$

To control intra-observer performance, 30 images were measured twice with an interval of one week between measurements.

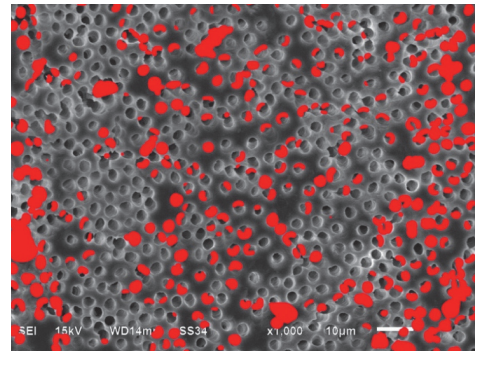



Figure 2 An example image illustrating areas with residual CH (highlighted in red) was analyzed using the ImageJ program to calculate the percentage of these areas.

### Statistical analysis

The intraclass correlation test was used to analyze intra-observer agreement. The data were compared by irrigation techniques and medication types and statistically analyzed using a Two-way ANOVA with Bonferroni post hoc test at a 5% level of significance. All statistical analyses were performed using SPSS 26.0 software (SPSS Inc., Chicago, IL, USA).

## Results

The intra-reliability value was 0.982, indicating excellent agreement. The means and standard deviations of the percentage of remaining CH are presented in Table 1. A two-way ANOVA revealed that cleaning efficacy was statistically significantly affected by medication type ($p<0.001$) but not by irrigation technique. VP demonstrated the highest percentage of remaining CH in both PUI and XPF groups, with statistical significance (Figures 3-4).

## Discussion

CH is a widely used intracanal medicament because it creates a physical barrier against microorganisms, thereby preventing reinfections. However, CH is not easily removed from the root canal system, and its residue may interfere with the sealability of root canal fillings [12]. This interference can adversely affect sealer performance and the long-term prognosis of the treatment. Therefore, complete removal of CH from the root canal before obturation is recommended. The aim of this study was to compare the efficacy of PUI and XPF in removing CH residues from root canal walls across four different formulas. The null hypothesis of this study was rejected. The types of medication have a significant effect on the amount of CH remaining on the root canal wall.

The remaining VP was found to be the highest compared to other medication types in both irrigation techniques (Figures 3-4). This is due to the composition of VP, which contains an oily vehicle resistant to water dissolution, making its removal more difficult than CH mixed with distilled water [5].

**Table 1** The means and standard deviations of the percentage of remaining CH after applying the irrigation techniques.

| | | Irrigation techniques (Mean ± SD) | |
|---|---|---|---|
| | | PUI | XPF |
| Medication types | CP | $20.11 \pm 10.84^{A}$ | $31.46 \pm 20.31^{A}$ |
| | UC | $27.69 \pm 11.31^{A}$ | $27.43 \pm 8.24^{A}$ |
| | MP | $30.97 \pm 7.72^{A}$ | $34.33 \pm 14.35^{A}$ |
| | VP | $55.37 \pm 18.48^{B}$ | $59.37 \pm 16.29^{B}$ |

Different uppercase letters in the same row and column indicate a statistically significant difference ($p < 0.001$)

Abbreviations: PUI, Passive ultrasonic irrigation; XPF, XP-endo® Finisher; CP, CH paste; UC, Ultracal™ XS; MP, Metapaste®; VP, Vitapex®.

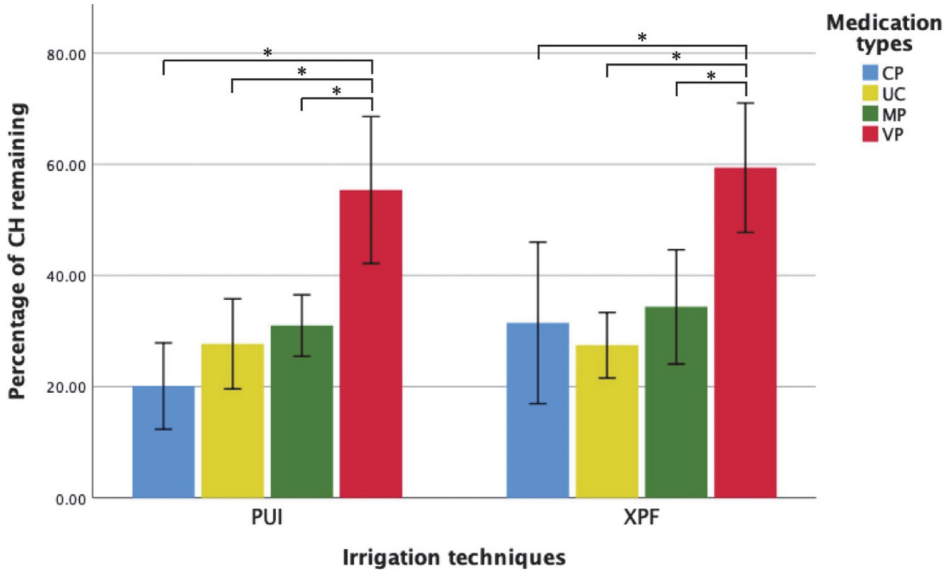



Figure 3 Graphical representation of the percentage of CH remaining after irrigation with different techniques. Asterisks (*) indicate a statistically significant difference ($p < 0.001$). There was no significant difference in CH removal efficacy between PUI and XPF techniques.
Abbreviations: PUI, Passive ultrasonic irrigation; XP, XP-Endo® Finisher; CP, Calcium hydroxide paste; UC, Ultracal™ XS; MP, Metapaste®; VP, Vitapex®

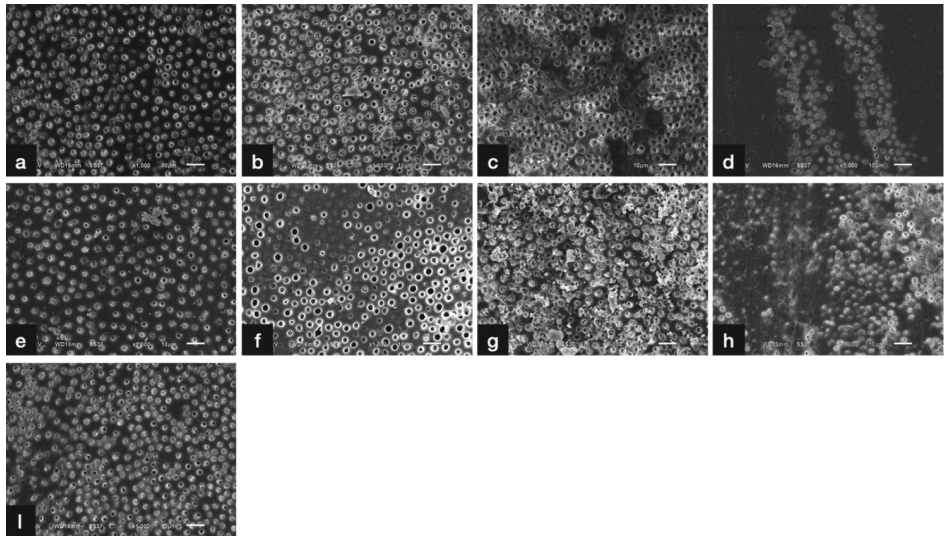



Figure 4 Representative SEM images of residual CH for each group; (a) filled with CP and removed with PUI. (b) filled with UC and removed with PUI. (c) filled with MP and removed with PUI. (d) filled with VP and removed with PUI. (e) filled with CP and removed with XPF. (f) filled with UC and removed with XPF. (g) filled with MP and removed with XPF. (h) filled with VP and removed with XPF, (i) negative control

The removal of CH from the root canal system has been evaluated in several studies [7, 16, 17, 26-30]. None of the techniques used have been able to completely eliminate CH residues from the canal walls. Therefore, it is important to continually explore and improve techniques for effective CH removal in endodontic treatment. PUI and XPF are two commonly used techniques for supplementing irrigation during endodontic treatment. The present study showed no significant difference in CH removal between PUI and XPF. This result aligns with a previous study [30] that used a similar 2-minute operation time (1-minute irrigation with NaOCl followed by 1-minute EDTA). In contrast, a study by Hamden *et al* [16] demonstrated that XPF was more effective in the apical region compared to PUI following a prolonged activation period of 3 minutes. XPF, based on the shape-memory principles, has high flexibility and can expand up to 6 mm in diameter according to the root canal anatomy, enabling it to access and scrape areas that are impossible to reach with standard instruments [15]. PUI relies on the transmission of acoustic energy from an ultrasonic tip to an irrigant, resulting in acoustic streaming and cavitation. This streaming increases the penetration of irrigants into irregular canal areas [14]. Furthermore, previous research assessing various PUI protocols for debris removal found no significant difference between 1-minute and 3-minute activation times [31]. Our study demonstrated that a 2-minute activation time showed no difference in the efficacy of CH removal between PUI and XPF. Therefore, it is important to investigate longer activation periods as recommended by the manufacturer of XPF to gain a better understanding of their effectiveness in removing CH from root canals. However, caution should be exercised to ensure that extended activation times do not compromise the integrity of the root canal system.

Many studies have reported that the apical third of the root canal shows significantly poorer results in CH removal compared to other root canal regions [32, 33], possibly due to reduced velocity and volume of irrigant flow reaching the apical part during irrigation [34]. Consequently, several studies have specifically focused on the challenges of CH removal in this apical area [29, 35-39]. For this reason, the apical third was selected for SEM analysis in this study. Assessing the entire canal could underestimate the actual amount of residual CH in the apical region, potentially explaining why Pibultip's study [7] reported lower CH retention across medication groups compared to our findings.

The amount of remaining CH in the canal can be measured by several methods such as direct visualization, digital microscopy, SEM, and volume analysis [6, 21, 36, 40-42]. In this study, SEM was used for the assessment of the remaining CH. This method was preferred because it is simple, easily accessible, and has been used in many previous studies [23-25, 41]. However, the main disadvantage of this technique is that it evaluates only the superficial layer of CH remnants and does not allow for the three-dimensional evaluation. Additionally, this method requires tooth sectioning, which may cause material loss and influence the results [6, 27]. Furthermore, it is impossible to differentiate CH residuals from the smear layer or dentinal debris [16]. To address this issue, two specimens were irrigated with 17% EDTA followed by 2.5% NaOCl without CH placement and were used as negative controls to ensure that any observed debris resulted from the CH removal process rather than residual debris present in the canal prior to treatment. The percentage of residual debris in the negative control group

was less than 5% (Figure 4), indicating that the detected CH percentage was primarily due to actual CH rather than dentin debris.

## Conclusion

Within the limitations of this study, it can be concluded that

- A 1-minute irrigation with NaOCl followed by 1-minute EDTA, using either PUI or XPF shows comparable efficacy in removing CH from the apical part of root canals. However, neither technique was able to completely remove CH from all specimens.
- The vehicle used to prepare CH is the most important factor for its removal. VP was more difficult to remove than CP, UC, and MP.

With the 2-minute operation time leaving 20-60% of CH in the apical part of the root canal, longer activation periods should be investigated to assess their effectiveness before drawing definitive conclusions. However, caution is recommended to ensure that extended activation times do not compromise the integrity of the root canal system.

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### Abbreviations

PUI: Passive ultrasonic irrigation; XPF: XP-endo Finisher; CH: Calcium hydroxide; CP: CH paste; UC: Ultracal™ XS; MP: Metapaste®; VP: Vitapex®; SEM: Scanning electron microscope.

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