Dentistry 3000

Vol 13, No 1 (2025)
ISSN 2167-8677 (online)
DOI 10.5195/d3000.2025.972

Citric Acid Irrigation Protocols for Bioceramic Sealers for Root Canal Retreatments

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Abstract

Objective: Root canals treated with bioceramic sealers that need retreatment present a clinical challenge. The presented study assessed 20% citric acid (with and without activation) in removing bioceramic sealer remnants. **Material and Methods**: Thirty extracted human lower premolars teeth were obturated with gutta-percha using bioceramic sealer, and have been split into three groups, each consisting of ten teeth: (1) 20% citric acid without activation, (2) 20% citric acid with ultrasonic activation, and (3) control group utilizing ProTaper Universal retreatment files exclusively. A scanning electron microscope (SEM) was used to investigate the remaining sealer remnants at the coronal, middle and apical thirds. The percentage of the uncleaned canal areas was determined quantitatively with the use of ImageJ software. **Results**: One-Way ANOVA had shown a significant difference between groups (p less than 0.001). At 64.8% ± 3.1, the control group had the greatest mean residual debris. While ultrasonic activation further improved cleaning efficacy (44.0% 2.6), irrigation with citric acid greatly reduced remnants (50.8% 4.9). Applying ultrasonic activation had the biggest cleaning impact in the apical third. In the apical third, the lowest debris was observed in the activation group (41.1% ± 0.9) vs. 45.3% (citric alone) and 65.7% (control). In the middle third, respective values were 44.1%, 51.5%, and 64.1%. In the coronal third, results were 64.8%, 55.5%, and 64.5%, respectively. **Conclusion**: According to our results, citric acid irrigation significantly enhances the removal of bioceramic sealer remnants from root canal walls, particularly when combined with ultrasonic activation. Compared to mechanical retreatment alone, the combination of chemical irrigation and activation resulted in a greater reduction of residual material. Citric acid significantly enhances the removal of bioceramic sealer remnants, particularly in the middle and apical thirds. Ultrasonic activation further improves efficacy, with the apical third showing the most notable improvement (41.1% vs. 65.7% in control). This protocol demonstrates a clinically effective and practical approach to improving the efficiency of endodontic retreatment procedures.

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Citation: Saleh MI, et al. (2025) Citric Acid Irrigation Protocols for Bioceramic Sealers for Root Canal Retreatments. Dentistry 3000. 1:a001 doi:10.5195/d3000.2025.972
Received: June 27, 2025
Accepted: July 26, 2025
Published: August 15, 2025

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Introduction

Preserving the periapical and apical tissues' health and avoiding recontamination of the root-filled canal are the two main objectives of endodontic treatment [1]. The quality related to root canal obturation as well as the materials utilized, such as endodontic sealers, have a major impact on outcomes of endodontic treatments. For the endodontically treated tooth to be successful and survive over the long run, such materials should guarantee a 3D seal within the root canal system, avoiding re-infection. An endodontic sealer is essential to root canal treatment. To create a coherent mass, it fills in the spaces, imperfections, and small differences between core filler material and canal walls [2].

Regarding the obturation of the root canal, gutta percha has been utilized with various sealers. Bio-ceramics, a new high-purity tricalcium silicate sealer class, has just been introduced and may have some advantages when compared to other types of sealers. The two main advantages of using hydraulic calcium silicate-based (HCS) bio-ceramic materials as sealants of the root canal are their biocompatibility in addition to the existence of calcium phosphate. Bonding to the dentin of the root canal has been improved due to the composition and crystalline structures that have near resemblance to the tooth and bone apatite materials [3].

Primary endodontics never achieve 100% success rates. Endodontic retreatment is typically required when an infection is

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ongoing or recurrent and the tooth still shows symptoms, such as ongoing pain, inflammation, or swelling. Furthermore, a second intervention could be necessary for several complications and problems, including inadequate pulp tissue removal, non-hermetic root canal sealing, and missing root canals [4].

Over the past 15 years, bioceramic sealers based on calcium silicate have become more and more popular. A recent survey found that 27% of American Dental Association (ADA) members and 49% of American Association of Endodontists (AAE) members reported utilizing bioceramic sealers, which have overtaken resin-based sealers as the most popular form of sealer among endodontists [5].

However, one of the major disadvantages of the bioceramic materials is the difficulty to remove them from the root canal throughout retreatment. Bioceramic sealer cannot be removed using traditional retreatment processes [6].

Heat-carrying tools, hand files, ultrasonic devices, chemical solvents, and lasers are only a few of the materials and methods that were suggested for the appropriate removal of the root canal fillings. Yet, it is typically very difficult to retreat root canals that have previously been sealed with bioceramic sealers. Because bioceramic materials adhere to the dentin through the formation of mineral infiltration zones and penetrate further into the dentinal tubules, they are seldom removed from the root canal system, even when manually [7]. The bioceramic sealers were not successfully dissolved or dislodged by the irrigating solutions that have been previously tested, which included NaOCl, EDTA, carbonated water, and formic and acetic acids. Thus, the requirement for solvents for HCS materials continues to be a focus of therapeutic interest [8]. Additional techniques were developed to make the removal of the set bioceramic sealers easier. These procedures involve mechanical removal, active irrigation, and using substitute solvents [7].

Regarding endodontic research, citric acid is a colorless organic acid that is frequently studied for various objectives [9]. Citric acid hasn't received much attention, nevertheless, as a possible solvent for bioceramic sealers. According to evidence-based literature currently available on the chemistry of the HCS cements, citric acid causes calcium-based hydration products to gradually dissolve, ultimately compromising the material's structural integrity [10]. Consequently, if the citric acid dissolves the HCS components, it is reasonable to anticipate that the solution might be utilized as a solvent throughout endodontic retreatment as necessary. To determine how well 20% citric acid, without or with ultrasonic activation, removed bioceramic sealers from root canals during endodontic retreatment. The presented work was conducted. In particular, the research aimed to ascertain whether ultrasonic activation may improve the effectiveness of HCS-based sealers in removing residual material from the middle, coronal, and apical thirds of canal, as well as whether citric acid could function as a chemical solvent for these sealers.

Material and Methods

Sample Preparation

Thirty extracted human lower premolars were collected from patients aged between 18 and 28 years who had undergone extraction for orthodontic treatment purposes. All selected teeth exhibited straight canals, fully formed apices, and no signs of internal or external resorption (Garg et al., 2015) [11]. After extraction, the teeth have been rinsed under running water, disinfected, and after that stored in 1% thymol solution in a closed container to prevent microbial growth, as described by D'Attilio et al. (2005) [12].

Diagnostic periapical radiographs have been taken in order to verify the inclusion requirements. Tooth length was measured using a digital Vernier caliper; specimens that were excessively short were not included. A diamond disc bur mounted on straight handpiece attached to a surveyor under continuous water coolant was utilized in order to section the crowns of the last 30 teeth, standardizing their length to 17 mm from apex.

A diamond round bur was used to construct access cavities, and pulp chamber's whole roof was taken off. A size 10K-file and a size 15 K-file were used to confirm canal patency. Through deducting 0.5 mm from the length at which the file tip has been visible at the apical foramen, the working length has been determined to be 16.5 mm (Bernardes et al., 2016).

The Protaper universal rotary system was utilized for preparing the root canal in crown down procedure, beginning with SX and proceeding to S2, S1, F2, F1, and F3 after each sample was placed in a mold filled with heavy body silicon imprint material and mounted on the surveyor (Iqbal et al., 2004). The rotary device's default settings for speed and torque have been followed. The coronal two thirds of the canal were enlarged using SX, after that S1 and S2 were utilized to reach the working length. Finally, files F1 through F3 were finished, with irrigation (5.25% sodium hypochlorite) employed in between each file. Following instrumentation, the canals were cleaned with normal saline, irrigated for one minute with 17% EDTA, rinsed again with normal saline, and dried with F3 paper points.

A heated instrument was after that used for removing the excess core materials after the sealer has been initially placed in the canal and after that the F3 Gutta perch cone was placed into the canal to working length utilizing the single cone technique [13]. The heavy body's obturated teeth were taken out, wrapped in moist cotton, filled with GIC, and put in separate test tubes. To fully set the sealer and age the filling material, the tubes were put on a tray and kept in an incubator set at 37^{o} Celsius and 95% humidity for four weeks [14].

Sample Grouping

Three sets of ten samples each have been randomly selected from all the samples.

- Group 1: Retreatment was carried out utilizing a combination of chemical and mechanical procedures following obturation with bioceramic sealer and subsequent incubation. ProTaper Universal retreatment files (D1, D2, D3) have been utilized in order to instrument canals in such group for removing the majority of filling material. After instrumentation, 20% citric acid has been manually added to help remove any remaining sealer remnants. A 30-gauge side-vented needle that was inserted up to 2 mm short of the working length (WL) was used for irrigation. In this group, no supplementary activation—such as ultrasonic—was used.
- Group 2: ProTaper Universal retreatment files (D1, D2, D3) have been utilized in order to mechanically remove the obturation material as part of the retreatment methodology. Following mechanical retreatment, an ultrasonic tip (size 20, taper 0.01) inserted 2 mm short of the WL was used for activating the canals as well as irrigate them with 20% citric acid. With three activation cycles per canal, the ultrasonic device was run at low to medium power for 20 seconds each cycle. To optimize its chemical impact, the solution was refilled in between activations.
- Group 3: the control group: ProTaper Universal Retreatment files that have been connected to an endodontic motor were used to perform the retreatment operation. ProTaper Universal Retreatment files (D1, D2, D3) have been used for retreatment; no extra irrigation or activation was necessary. The coronal third of the canal was represented by the D1 file, the middle third by the D2 file, and the apical third by the D3 file.

Evaluation of the Residual Bioceramic Sealer

After retreatment, all samples were sectioned longitudinally utilizing a diamond

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disc bur that is mounted on a straight slow-speed handpiece under continuous water coolant. The sectioned specimens were initially evaluated using a digital stereomicroscope connected to a computer. Images have been captured at 5x magnification to visualize full root surface and at 10x magnification to focus on coronal, middle, and apical thirds in a separate manner. Those images have ensured the standardized documentation of every one of the regions and have later been utilized for the quantitative analyses. For additional characterization of the surface, representative samples from every one of the groups have been selected then analyzed under an SEM. Six images were taken per sample—3 per root third—captured from the center of every one of the regions. Images have been obtained at 100x magnification for the general observation, 250x for the evaluation of the smear layer, and 1000x for high-resolution inspection of the sealer remnants and dentinal tubule exposure. SEM analysis had provided a qualitative comprehension of the structural detail and cleanliness of the surface, consistent with methods that have been described by Hess *etal.* (2011) and Zuolo *etal.* (2021) [4,15]. For quantifying residual sealer, all of the SEM images had been analyzed utilizing ImageJ software (v1.53, National Institutes of Health, Bethesda, MD, U.S.). The software was calibrated using the embedded scale bar in each image. The canal wall area has been manually outlined using the polygon tool, and the remaining bioceramic sealer was isolated using the Color Threshold function. The sealer-covered regions were measured in square millimeters using the Analyze > Measure tool, and the percentage of uncleaned area was calculated relative to the total canal surface. Each image was analyzed three times to ensure consistency, and the mean value was used for statistical comparisons [16,17].

Results

A total of 90 root canals area (apical, middle, coronal) were analyzed, divided equally among three groups (2 experimental and one control groups), (n=30 each). The outcome was the percentage of uncleaned canal surface area following different irrigation protocols.

Table 1 shows the mean percentages of uncleaned areas across the groups. The control group showed the highest mean percentage of uncleaned area (64.8% ± 3.1). Shapiro-Wilk test results confirmed normal distribution in all groups ($p > 0.05$). A One-Way ANOVA revealed a statistically significant difference among the groups (Table 2).

Comparative Evaluation: Control vs. Citric Acid Groups

Comparative Evaluation in Coronal Third

The mean percentages of uncleaned areas in the coronal part for selected groups (Table 3) showed the highest residual debris in both the Control (64.5% ± 3.4) and Citric Acid + Activation (64.8% ± 1.3) groups. Citric Acid alone had a lower mean value (55.5% ± 2.4).

Comparative Evaluation in the Middle Third

Table 4 presents the average percentages of uncleaned areas in the middle part of the root canals for the Control and Citric Acid groups. The Control group exhibited the highest mean residual debris (64.1% ± 3.4), followed by Citric Acid (51.5% ± 2.5). Citric Acid + Activation showed improved cleaning efficacy (44.1% ± 1.1).

Comparative Evaluation in Apical Third

The apical portion of the root canal (Table 5) revealed the highest percentage of uncleaned areas in the Control group (65.7% ± 2.5). Citric Acid alone resulted in a mean of 45.3% ± 2.9, while the Citric Acid + Activation group achieved better cleaning outcomes with a mean of 41.1% ± 0.9.

Discussion

The present study examined the effectiveness of 20% citric acid, both with and without ultrasonic activation, in the removal of bioceramic sealer remnants from root canals. Compared with mechanical file-only retreatment, this approach provided more substantial cleaning, especially in the middle and apical thirds**.**

Mechanical instrumentation alone, as seen in the control group, was insufficient to eliminate bioceramic sealers, a finding echoed in multiple studies. For instance, Hess et al. (2011) [15] reported that even with advanced rotary systems, significant residues of bioceramic sealers persist due to their chemical bonding to dentin. Similarly, Neelakantan *et al.* (2015) [18] have demonstrated that the physical integrity and apatite-forming capacity of calcium silicate-based sealers contribute to their resistance to mechanical removal, Mahmmod and Al-Sabawi (2022) [19], who demonstrated that mechanical retreatment using rotary files alone left extensive amounts of sealer residue. Similar observations were reported by Chybowski et al. (2021) [5], highlighting the difficulty in removing bioceramic sealers due to their strong adhesion and formation of a mineral infiltration zone.

Our findings expand on previous research. Attash and Al-Ashou (2022) [2] emphasized the bond strength and tubule penetration of bioceramic sealers as major obstacles during retreatment, which explains the difficulty seen in our control group. Meriem Fejjer et al. (2024) [6] showed that EDTA and NaOCl are inadequate against HCS sealers—a notion supported here, as citric acid alone proved more effective.

In contrast to Mahmmod and Al-Sabawi (2022) [19], who focused on XP-Endo finisher retreatment, our study used conventional ProTaper retreatment files and still demonstrated significant improvements when supplemented with citric acid protocols. While they achieved improved cleaning using XP-Endo, they noted high residue without activation—supporting our finding that activation significantly enhances retreatment outcomes.

Citric acid irrigation alone significantly reduced residual sealer levels (mean 50.8% ± 4.9), and ultrasonic activation further enhanced this efficacy (44.0% ± 2.6). This confirms findings by Yang et al. (2018) [10] that citric acid effectively chelates calcium ions in HCS sealers, weakening their integrity. Gómez et al. (2023) [9] also supported the role of citric acid as a viable chelating agent, showing improved outcomes over EDTA and NaOCl in terms of smear layer and material dissolution.

Regional Differences in Cleaning Efficacy

Coronal-Third

Unexpectedly, both the control group and the Citric Acid + Activation group showed high debris retention in the coronal third (64.5% and 64.8%, respectively). This may be due to debris compaction during coronal activation, as also noted in the root canal rretreatment study by Zuolo et al. (2021) [4]. Similar issues were described by Fejjer et al. (2024), who suggested that excessive pressure or ultrasonic turbulence may lead to localized reinsertion of dislodged debris in larger canal areas.

Middle-Third

The Citric Acid + Activation group outperformed others in the middle third (44.1% vs. 51.5% in citric alone and 64.1% in control). These findings are consistent with studies by Carrillo *et al.* (2022) and Garrib and Camilleri (2020) [7,8], who emphasized the role of agitation in improving irrigant reach and dislodging particles embedded in canal walls.

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Apical-Third

The apical third presented the most striking differences. Activation led to the lowest sealer remnants (41.1%), followed by citric acid alone (45.3%) and control (65.7%). These results strongly correlate with da Silva et al. (2012) [14], who found ultrasonic activation most beneficial in narrow apical regions. Additionally, D'Attilio et al. (2005) [12] highlighted how mechanical-only approaches often fail in this region due to restricted access.

Conclusions

This study investigated the efficacy of 20% citric acid, both with and without ultrasonic activation, for removing bioceramic sealer remnants during endodontic retreatment. The findings revealed that mechanical instrumentation alone (control group) was significantly less effective, especially in the apical third of the root canal. Citric acid irrigation significantly improved cleaning performance, and its combination with ultrasonic activation yielded the lowest residual debris levels across all root thirds, particularly in the apical region.

These results underscore the limitations of conventional retreatment using rotary files and highlight the importance of chemical support, especially when dealing with bioceramic sealers. The use of 20% citric acid, particularly with ultrasonic activation, emerges as a clinically viable and effective supplement to mechanical retreatment techniques. The study supports integrating these protocols into routine retreatment procedures to enhance debridement and improve clinical outcomes.

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Table 1. Uncleaned areas values.

Groups	N	Mean %	SD	SE	Minimum	Maximum
Control	30	64.8	3.1	0.5	60.0	70.0
Citric Acid	30	50.8	4.9	0.9	40.0	60.0
Citric Acid + Activation	30	44.0	2.6	0.4	40.0	50.0

Table 2. Summary of the comparisons.

Percentage of unclean areas						
Groups	N	Mean	SD	Statistics	df	*P-Value
Citric Acid	30	50.8	4.9	310.4	3	< 0.001
Citric Acid + Activation	30	44.0	2.6			
Citric Acid + Laser activation	30	39.2	2.5			
Control	30	64.8	3.1			

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Table 3. The mean percentage of uncleaned areas in the coronal third (selected groups).

Group	N	Mean %	SD	SE	Min	Max
Control	10	64.5	3.4	1.1	60.0	69.0
Citric Acid	10	55.5	2.4	0.7	52.3	60.0
Citric Acid + Activation	10	64.8	1.3	0.4	45.5	50.0

Table 4. The mean percentage of uncleaned areas in the middle third (selected groups).

Group	N	Mean %	SD	SE	Min	Max
Control	10	64.1	3.4	1.1	60.2	70.0
Citric Acid	10	51.5	2.5	0.8	47.6	56.9
Citric Acid + Activation	10	44.1	1.1	0.3	42.2	45.5

Table 5. The mean percentage of uncleaned areas in the apical third (selected groups).

Group	N	Mean %	SD	SE	Min	Max
Control	10	65.7	2.5	0.8	60.0	68.9
Citric Acid	10	45.3	2.9	0.9	40.0	49.2
Citric Acid + Activation	10	41.1	0.9	0.2	40.0	42.2