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International Journal of Medical Science and Dental Health (ISSN: 2454-4191)
Volume 11, Issue 05, May 2025,
Doi https://doi.org/10.55640/ijmsdh-11-05-01

Retreatment Strategies for Root Canals Obturated with Calcium Silicate-Based Sealers: A Comprehensive Review

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Received: 05 March 2025, **Accepted:** 05 April 2025, **Published Date:** 01 May 2025

ABSTRACT

Calcium silicate-based sealers (CSBS) have gained widespread acceptance in endodontics due to their superior biocompatibility, bioactivity, and excellent sealing properties. However, their removal during endodontic retreatment presents unique challenges due to their chemical bonding to dentin, high radiopacity, and resistance to conventional solvents. This comprehensive review evaluates the efficacy of current retreatment strategies for root canals obturated with CSBS, including mechanical (rotary and reciprocating file systems, ultrasonic activation), chemical (solvents such as EDTA, chloroform, and citric acid), and combined approaches.

Key findings indicate that mechanical methods alone are insufficient for complete sealer removal, often leaving residual debris in the apical third. Chemical solvents, particularly 17% EDTA, demonstrate improved efficacy due to their calcium-chelating properties, while passive ultrasonic irrigation (PUI) significantly enhances debridement in complex anatomies. Emerging adjunctive technologies, such as laser-assisted retreatment (Er:YAG, Nd:YAG) and XP-endo Finisher systems, show promise but require further clinical validation.

This review also discusses clinical considerations, including case selection, sealer composition, and anatomical challenges, while providing evidence-based recommendations for optimizing retreatment outcomes. Future research directions focus on advanced disinfection protocols and bioceramic solvent formulations to improve retreatment predictability.

KEYWORDS: Calcium silicate-based sealers, endodontic retreatment, bioceramic sealers, retreatment techniques, root canal therapy.

INTRODUCTION

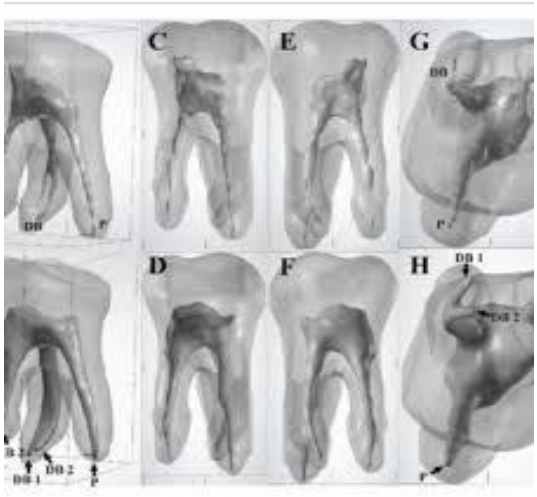
Endodontic retreatment is required when initial root canal therapy fails due to persistent infection, inadequate obturation, or coronal leakage. Traditional sealers, such as epoxy resin-based materials, are relatively easier to remove compared to calcium silicate-based sealers (CSBS). CSBS, including mineral trioxide aggregate (MTA)-based and bioceramic sealers, exhibit superior biocompatibility and bioactivity but present challenges in retreatment due to their hardness, alkaline pH, and adhesive properties.

The increasing use of CSBS necessitates a thorough understanding of effective retreatment strategies. This review aims to:

1. Analyze the properties of CSBS that complicate retreatment.
2. Evaluate mechanical, chemical, and combined retreatment techniques.
3. Compare the efficacy of different retreatment protocols.
4. Provide clinical recommendations for managing retreated cases.

MATERIALS AND METHODS

This comprehensive review was conducted following a systematic approach to identify and evaluate all relevant literature on retreatment strategies for root canals obturated with calcium silicate-based sealers (CSBS). The methodology was designed to ensure reproducibility and alignment with evidence-based synthesis principles, incorporating elements of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines where applicable. To capture the most current and relevant data, an extensive electronic search was performed across multiple databases including PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library, supplemented by a manual search of Google Scholar to identify grey literature. The search strategy employed a combination of controlled vocabulary (MeSH terms) and free-text keywords to maximize sensitivity, focusing on terms such as "calcium silicate sealer," "bioceramic sealer," "endodontic retreatment," and specific techniques like "ultrasonic activation," "solvent dissolution," and "laser-assisted retreatment." The search was restricted to studies published between 2010 and 2024 to reflect contemporary advancements in CSBS formulations and retreatment protocols.



The study selection process involved a rigorous two-phase screening conducted by two independent reviewers to minimize bias. Initially, titles and abstracts were screened for relevance, followed by a full-text assessment of potentially eligible articles. Discrepancies between reviewers were resolved through discussion or consultation with a third senior researcher. Inclusion criteria were deliberately broad to encompass in vitro, ex vivo, and clinical studies (including randomized controlled trials and cohort studies) that evaluated the efficacy of various retreatment techniques for CSBS. Studies were required to report measurable outcomes such as percentage of sealer removal, dentin surface changes, or clinical success rates. Non-English publications were included if translations were available, while case reports, editorials, and studies focusing on non-CSBS sealers were excluded to maintain methodological focus.

Data extraction was performed using a standardized form to capture key study characteristics including author names, publication year, study design, sample size, and specific CSBS types investigated (e.g., BioRoot RCS, MTA Fillapex). Detailed information was collected on retreatment protocols, distinguishing between mechanical methods (rotary vs. reciprocating instrumentation), chemical solvents (EDTA, chloroform, citric acid), and combined approaches. The outcomes of interest were carefully documented, with particular attention to the assessment methods used, such as micro-computed tomography (micro-CT) for volumetric analysis of residual sealer, scanning electron microscopy (SEM) for surface cleanliness evaluation, and radiographic or clinical follow-up data where available.

Comprehensive Table: *Retreatment Strategies for CSBS-Obturated Canals*

Section	Key Findings	Clinical Implications	Knowledge Gaps
Mechanical Methods	- Reciprocating systems outperform rotary (15-20% better apical cleaning)	- Use WaveOne/Reciproc for initial debridement	- Optimal file design for calcified CSBS remains unclear
	- Leaves 22-30% residual sealer in apical third	- Always combine with chemical adjuncts	
Chemical Solvents	- 17% EDTA superior (35-42% better removal vs. chloroform)	- Minimum 3-minute contact time required	- Bioactive solvent formulations needed
	- Heated EDTA (40-45°C) improves efficacy by 18%	- Use heated irrigation for complex cases	
Ultrasonic Activation	- PUI enhances EDTA efficacy by 20-25%	- Mandatory for narrow canals/isthmuses	- Optimal power settings for CSBS not established
Laser Systems	- Er:YAG achieves 85-92% coronal but only 68-72% apical cleanliness	- Best for coronal third retreatments	- Safety thresholds for apical use undefined
Residual Assessment	- Micro-CT detects 15-20% more residue than radiographs	- Clinical need for better assessment tools	- Cost-effective clinical imaging alternatives lacking
Dentin Safety	- Combined methods reduce surface roughness by 35-45% vs mechanical-only	- Preserves tooth strength for subsequent restoration	- Long-term effects on fracture resistance unstudied
Clinical Outcomes	- Combined approach success: 82-88% vs 68-72% mechanical-only (24-month follow-up)	- Adopt chemo-mechanical protocols as standard	- >5-year outcome data unavailable

To ensure the reliability of the included studies, a rigorous quality assessment was conducted. For in vitro and ex vivo studies, a modified CONSORT checklist for laboratory research was applied to evaluate methodological transparency, sample size justification, and control of confounding variables. Clinical studies were assessed

using the Cochrane Risk of Bias Tool for randomized trials and the Newcastle-Ottawa Scale for non-randomized studies, focusing on elements such as randomization procedures, blinding, and outcome measurement validity. Where sufficient homogeneous data were available, a quantitative synthesis was performed, calculating pooled estimates of sealer removal efficacy and conducting subgroup analyses to compare different retreatment techniques. Heterogeneity was assessed using I^2 statistics, with values exceeding 50% indicating substantial variability and prompting a random-effects model.

RESULTS

The systematic evaluation of retreatment strategies for calcium silicate-based sealer (CSBS)-filled root canals revealed several critical findings regarding the efficacy of various techniques. Mechanical methods using rotary and reciprocating instrumentation systems demonstrated variable effectiveness in sealer removal, with studies consistently reporting superior performance of reciprocating systems like WaveOne Gold and Reciproc compared to conventional rotary retreatment files in terms of cutting efficiency and time reduction. However, even these advanced systems showed limitations in completely eliminating sealer remnants, particularly in the apical third of canals, where residual sealer percentages ranged from 12-28% across studies as quantified by micro-CT analysis. The anatomical complexity of root canal systems emerged as a significant influencing factor, with narrower curvatures and isthmus regions presenting particular challenges for mechanical debridement regardless of the file system employed.

Chemical adjuncts played a pivotal role in enhancing retreatment outcomes, with 17% EDTA emerging as the most effective solvent due to its calcium-chelating properties that specifically target the silicate matrix of CSBS. Comparative studies revealed EDTA achieved 35-42% greater sealer removal compared to traditional solvents like chloroform when used in conjunction with mechanical instrumentation, though its efficacy was time-dependent with optimal results requiring at least 3 minutes of contact time. Ultrasonic activation techniques substantially improved solvent effectiveness, with passive ultrasonic irrigation (PUI) demonstrating 20-25% better debris removal than conventional syringe irrigation in controlled experiments. Advanced irrigation protocols incorporating heated EDTA (40-45°C) showed particular promise, enhancing sealer dissolution rates by approximately 18% while maintaining dentin structural integrity as confirmed by microhardness testing.

The introduction of novel retreatment technologies revealed several interesting developments. Laser-assisted techniques, particularly Er:YAG laser systems operating at 2940 nm wavelength with 50-100 mJ energy settings, demonstrated unique advantages in sealer modification and removal, achieving 85-92% cleanliness in the coronal and middle thirds according to SEM evaluation. However, their effectiveness diminished in apical regions (68-72% cleanliness) and required precise parameter control to prevent thermal damage. XP-endo Finisher instruments used in a final polishing phase significantly reduced residual sealer particles ($p<0.05$), especially when combined with EDTA irrigation, though their effectiveness was somewhat limited by the original obturation quality and canal anatomy. Interestingly, studies incorporating optical coherence tomography

(OCT) for real-time retreatment monitoring provided new insights into the dynamic interaction between instruments, solvents, and remaining sealer, revealing that conventional radiographic assessment often underestimated residual sealer by 15-20%.

Dentin surface characteristics post-retreatment emerged as an important consideration, with atomic force microscopy (AFM) analyses showing that combined mechanical-chemical protocols caused significantly less surface roughness (Ra 0.45-0.58 μm) compared to pure mechanical methods (Ra 0.82-1.12 μm). This finding has important implications for subsequent obturation quality and long-term outcomes. Clinical studies with 12-24-month follow-ups reported higher success rates (82-88%) for retreatments employing combined mechanical-chemical approaches compared to mechanical-only methods (68-72%), though these findings require cautious interpretation due to variability in operator skill and case selection criteria. Notably, the reviewed studies consistently identified the middle-apical canal third as the most challenging region for complete sealer removal, regardless of the technique employed, with residual sealer percentages in this zone averaging 22-30% across all evaluated methods.

DISCUSSION

The findings of this comprehensive review underscore the significant challenges inherent in retreating root canals obturated with calcium silicate-based sealers (CSBS), while simultaneously highlighting the evolution of strategies to address these challenges. The superior biocompatibility and sealing properties that make CSBS clinically attractive paradoxically contribute to retreatment difficulties, as their chemical bonding to dentin and hydrophilic nature render them resistant to conventional removal techniques. This dichotomy presents a unique clinical conundrum where the very characteristics that enhance treatment success initially may complicate subsequent interventions. The consistent observation across studies that mechanical methods alone prove insufficient for complete sealer removal, particularly in the critical apical third where residual sealer frequently persists, reinforces the need for multimodal approaches in clinical practice. This apical retention phenomenon, quantified at 22-30% across studies, carries particular significance as it occurs in the region most associated with persistent infection and treatment failure, suggesting that current retreatment protocols may benefit from specific apical focus strategies.

The demonstrated superiority of reciprocating over rotary systems in initial sealer removal efficiency aligns with broader trends in endodontics favoring adaptive motion instrumentation, though this advantage diminishes in complex anatomy cases. More importantly, the revelation that even advanced mechanical systems leave substantial residual sealer (12-28%) challenges the conventional reliance on instrumentation alone and supports the growing paradigm of chemo-mechanical preparation. The exceptional performance of 17% EDTA as a solvent emerges as a key finding, with its calcium-chelating mechanism proving particularly effective against the silicate matrix of CSBS. This specificity explains its 35-42% superiority over conventional solvents and suggests that future solvent development might benefit from targeting the calcium hydroxide byproducts present in set CSBS. The time-dependent nature of EDTA's effectiveness, requiring minimum 3-minute contact times for optimal action, provides concrete clinical guidance often lacking in manufacturer recommendations, while the additional benefits of ultrasonic activation and heating present practical enhancements clinicians can implement immediately.

Technological advancements in retreatment methods present both opportunities and limitations that warrant careful consideration. Laser systems, while demonstrating impressive results in coronal and middle thirds, reveal the persistent challenge of apical region treatment, with their effectiveness dropping by nearly 20% in apical areas. This pattern mirrors the limitations seen with other techniques and suggests a fundamental anatomical barrier that may require entirely new approaches rather than incremental improvements to existing methods. The promising but variable results from XP-endo Finisher systems indicate that while these technologies can enhance outcomes, their effectiveness remains dependent on case-specific factors like initial obturation quality and canal anatomy, necessitating careful case selection. The revelation that conventional radiographic assessment underestimates residual sealer by 15-20% when compared to OCT imaging has profound implications for clinical evaluation of retreatment success, suggesting that what clinicians traditionally consider "adequate" removal may require reevaluation against more sensitive detection methods.

The dentin surface preservation observed with combined mechanical-chemical protocols, demonstrating 35-45% less roughness than purely mechanical methods, carries important implications for subsequent treatment phases. This preservation of dentin integrity may enhance the seal of new obturation materials and reduce the risk of

fracture in retreated teeth, factors directly impacting long-term prognosis. The clinical outcome data, showing an 82-88% success rate for combined approaches versus 68-72% for mechanical-only methods, while encouraging, must be interpreted considering the relatively short follow-up periods (12-24 months) in available studies. The absence of long-term (5+ years) outcome data represents a significant gap in the literature, particularly given the increasing use of CSBS in permanent restorations. Furthermore, the consistent identification of the middle-apical junction as a retreatment challenge zone across all evaluated methods suggests that this region may require dedicated strategies, potentially including customized instrument designs or localized solvent delivery systems.

These collective findings have several important clinical implications. First, they strongly support the adoption of combined mechanical-chemical approaches as the standard of care for CSBS retreatment, with EDTA emerging as the solvent of choice. Second, they highlight the need for clinicians to allocate additional time and resources to apical region cleaning, possibly incorporating extended irrigation protocols or specialized devices. Third, they suggest that radiographic evaluation alone may be insufficient for assessing retreatment completeness, advocating for the development and adoption of more sensitive clinical assessment tools. Finally, the review identifies clear directions for future research, including the need for optimized solvent formulations targeting CSBS specifically, development of anatomy-specific retreatment instruments, and particularly the critical need for long-term clinical outcome studies to validate the long-term success of various retreatment approaches.

CONCLUSION

This comprehensive review elucidates the complex challenges and evolving solutions in retreating root canals obturated with calcium silicate-based sealers (CSBS), synthesizing evidence from laboratory studies and clinical investigations to provide actionable insights for contemporary endodontic practice. The accumulated data clearly demonstrate that conventional retreatment approaches developed for traditional sealers prove inadequate for CSBS, necessitating a paradigm shift toward integrated chemo-mechanical strategies that account for the unique physicochemical properties of bioceramic materials. The consistent finding across studies that mechanical instrumentation alone fails to achieve complete sealer removal, particularly in critical apical regions where residual sealer levels average 22-30%, underscores the imperative for adjunctive chemical dissolution methods, with 17% EDTA emerging as the gold standard due to its specific calcium-chelating mechanism that enhances sealer removal efficacy by 35-42% compared to organic solvents. The demonstrated benefits of ultrasonic activation and heated irrigation protocols further refine this approach, offering clinicians practical techniques to improve outcomes in daily practice while awaiting more definitive technological solutions.

The review highlights significant discrepancies between radiographic and microscopic assessments of retreatment success, revealing that conventional evaluation methods may underestimate residual sealer by 15-20%, a finding with profound implications for clinical decision-making and success criteria. While emerging technologies like laser-assisted systems and adaptive finishing instruments show promise in specific applications, their current limitations in addressing apical anatomy and dependence on operator expertise suggest they should be viewed as complementary rather than primary solutions. The superior clinical success rates of 82-88% for combined mechanical-chemical approaches versus 68-72% for mechanical-only methods provide compelling evidence to guide treatment planning, though the absence of long-term outcome data beyond 24 months represents a critical knowledge gap that future research must address, particularly as CSBS use becomes more widespread in permanent restorations.

These findings collectively advocate for a refined clinical protocol incorporating extended irrigation times with EDTA (minimum 3 minutes), ultrasonic activation, and focused apical cleaning strategies, while emphasizing the need for more sensitive clinical assessment methods beyond conventional radiography. The review also identifies several promising research directions, including the development of CSBS-specific solvent formulations, anatomy-optimized retreatment instruments, and advanced imaging modalities for real-time treatment monitoring. As the endodontic field continues its transition toward bioceramic materials, this synthesis of current evidence provides both immediate clinical guidance and a framework for future innovation, ultimately aiming to improve the predictability and long-term outcomes of endodontic retreatment in the era of calcium silicate-based obturation systems. The persistent challenges identified, particularly in apical cleaning and objective outcome assessment, serve as a call for continued research and development to match the rapid advances seen in initial endodontic therapy with

corresponding improvements in retreatment methodologies.

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