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Introduction

Regenerative endodontic procedures (REPs) are biologically based therapies that aim to restore the pulp–dentin complex. Contemporary REP protocols integrate three core components disinfection, a scaffold, and biologic signaling to establish a

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Removal Efficiency of Mineral Trioxide Aggregate: A narrative Review of Retrieval Techniques

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Abstract

*Regenerative endodontic procedures are designed to eliminate clinical symptoms, promote periapical healing, and restore a functional pulp–dentin complex with continued root development. However, treatment failure may occur and require retreatment. In such situations, the removal of mineral trioxide aggregate (MTA) poses a significant clinical and technical challenge. This narrative review critically appraises recent advances in MTA removal techniques following failed regenerative endodontic therapy, with particular emphasis on removal efficiency, effects on radicular dentin, and subsequent management considerations. A systematic electronic search of PubMed and Google Scholar was conducted to identify English-language articles published between 2017 and 2025 using keywords related to regenerative endodontics, MTA retrieval, chemical solvents, and assessment methods. From an initial yield of 70 articles, 10 studies met the inclusion criteria based on relevance, methodology, and scientific merit. The available evidence indicates that complete removal of set MTA from the root canal system cannot be achieved using a single technique. Mechanical methods showed limited effectiveness, while ultrasonic activation enhanced MTA retrieval but consistently left residual material. Chemical agents, particularly acidic solutions, demonstrated superior MTA softening and removal potential. However, their application was associated with reduced dentin microhardness and signs of dentinal erosion, as confirmed by micro-CT and SEM analyses. **In conclusion**, the findings highlight the absence of a standardized and clinically optimal protocol for MTA removal and emphasize the need for further well-designed studies to establish safe exposure times, effective concentrations, and evidence-based guidelines that balance removal efficiency with preservation of radicular dentin integrity. **Keywords:** Mineral trioxide aggregate (MTA), regenerative endodontics, orthograde retreatment, citric acid, glycolic ac*



microenvironment that supports tissue regeneration and continued root maturation in immature necrotic teeth. Unlike apexification, which constructs an apical barrier without promoting further root development, REPs can increase root length and wall thickness, thereby reducing the tooth's susceptibility to fracture.(1–3).

Although clinical outcomes are generally favorable, treatment failure may be indicated by symptoms such as persistent pain, swelling, fistula formation, or increased tooth mobility. In such cases, complete removal of the coronal barrier material followed by orthograde retreatment is considered a conservative and effective management approach. However, residual barrier material may adversely affect subsequent bonding and the quality of the coronal seal (4). Mineral trioxide aggregate (MTA) is the principal coronal barrier material used in regenerative endodontic procedures because it promotes tissue regeneration, provides an effective bioactive seal (5). MTA attains substantial mechanical strength in a moist environment reported compressive strengths increase from approximately 40.0 MPa at 1 day to 67.3 MPa at 21 days making purely mechanical retrieval difficult and often necessitating prior chemical softening (6). With a microhardness of about 69.9 HV, MTA can be rendered more amenable to removal by exposure to solvents such as sodium hypochlorite, citric acid, or hydrofluoric acid, the latter producing the greatest softening effect in vitro (7). Clinical failures due to persistent infection, insufficient root maturation, compromised coronal sealing, or canal obstruction by displaced MTA or calcific deposits highlight the importance of dependable and effective retrieval techniques (8,9). Incomplete removal adversely affects obturation quality, bonding, and the potential success of secondary regenerative attempts (4,10).

The composition of MTA, which consists of tricalcium silicate, tricalcium aluminate, tricalcium oxide, silicate oxide, and other mineral oxides, is responsible for its superior marginal adaptation. These elements work together to form a hydrophilic powder that solidifies when it comes into contact with water (11). Mineral trioxide aggregate (MTA) is an additional therapeutic option for immature necrotic teeth. MTA contained calcium oxide, which could react with tissue fluid to produce calcium hydroxide, even though it did not contain calcium hydroxide (12). Chemical, mechanical, and ultrasonic approaches have been investigated to address these issues. By demineralizing the matrix, decreasing Portlandite, and increasing porosity, acidic agents such as EDTA, citric acid, glycolic acid, hydrochloric acid, carbonic acid, CHX, and NaOCl aid in dissolution (6,10,13). MTA can be quickly softened by strong acids like 37% HCl, but there is a chance that dentin will deteriorate(7,14). A balance between dissolution effectiveness and dentin microstructure preservation is required because most solvents decrease dentin microhardness and may increase fracture susceptibility (13,15). Organic dentin components are broken down by NaOCl. (16), Although ideal values are yet unknown, lower concentrations, like 7.5% HCl, may provide regulated softening with less dentin injury (13,15). Lower concentrations, such as 7.5% HCl, may offer controlled softening with reduced dentin damage, though optimal parameters remain undetermined(17).

Micro-CT and SEM studies, which consistently demonstrate that chemical agents and ultrasonics reduce MTA volume and expose dentinal tubules but rarely achieve complete canal clearance, particularly apically, provide crucial evidence on MTA removal methods (9,15). SEM also reveals dentinal erosion and collagen loss after acid exposure, underscoring the need for cautious clinical use (14,15).

Overall, current evidence supports a combined approach of chemical softening with acidic agents followed by ultrasonic activation as the most effective strategy for the retreatment of failed REPs (15). Current in-vitro and ex-vivo evidence shows that no existing technique reliably achieves complete removal of MTA or other calcium-silicate



cements during regenerative endodontic retreatment, with the apical third consistently retaining the most residual material. Variations in material type, canal anatomy, and methodology limit direct clinical extrapolation, indicating that current approaches are suitable for bulk reduction but not predictable complete elimination. Standardized protocols, anatomically realistic models, volumetric assessment, and dentin-safety evaluation are needed to guide clinical application. (18). The effects of various solvents and acids on long-term dentin integrity are still poorly known. There is less evidence on eliminating MTA elements from REPs. Consequently, this narrative review intends to clarify current findings and guide future research towards safer and more predictable retreatment strategies by synthesizing information from previous studies and providing a summary of those findings. (15).

Methodology

This narrative review was conducted to critically evaluate the available evidence regarding techniques for the removal of mineral trioxide aggregate (MTA) following failed regenerative endodontic procedures. A systematic electronic search strategy was applied to identify relevant literature, while the overall synthesis and interpretation followed a narrative review framework. PubMed and Google Scholar databases were searched for English-language articles published between 2017 and 2025 using combinations of the following keywords: “mineral trioxide aggregate,” “regenerative endodontics,” “orthograde retreatment,” “MTA removal,” “citric acid,” “glycolic acid,” “micro-CT,” “SEM,” and “RetroMTA.”

The inclusion criteria comprised *in vitro*, *ex vivo*, and experimental studies that specifically evaluated techniques or materials used for MTA removal from the root canal system in the context of regenerative endodontic treatment failure, as well as studies assessing the impact of these techniques on radicular dentin. Review articles, case reports, studies not addressing MTA retrieval, non-English publications, and articles lacking sufficient methodological detail were excluded.

The initial search yielded 70 records, which were screened based on titles and abstracts for relevance to the study aim. Following full-text assessment, 10 studies met the inclusion criteria and were selected for qualitative synthesis. Data extraction focused on the type of MTA, removal technique employed, assessment method, and reported effects on dentin structure. Given the heterogeneity of study designs, materials, and outcome measures, a quantitative meta-analysis was not feasible, and findings were therefore analyzed descriptively and comparatively.

Search strategy

A comprehensive literature search was conducted to identify studies evaluating the removal of mineral trioxide aggregate (MTA) following failed regenerative endodontic procedures. Electronic searches were performed in PubMed/MEDLINE and Google Scholar to retrieve English-language articles published between 2017 and 2025. The search strategy combined controlled vocabulary and free-text terms related to MTA, regenerative endodontics, and retrieval techniques. The primary keywords included “mineral trioxide aggregate,” “regenerative endodontics,” “regenerative endodontic procedures,” “orthograde retreatment,” “MTA removal,” and “retrieval techniques.” These were combined using Boolean operators with technique- and outcome-specific

terms such as “citric acid,” “glycolic acid,” “EDTA,” “hydrochloric acid,” “sodium hypochlorite,” “ultrasonics,” “laser,” “XP-Endo Finisher,” “micro-CT,” “SEM,” and “dentin microhardness.” Seventy (70) articles were identified. Screening for duplicates of the selected articles was performed. Hand-searching for the reference list of the selected articles was performed to identify further relevant sources. Articles were excluded if they were review articles or editorial letters, only 10 articles were selected that met the scope of this review (Figure. 1).

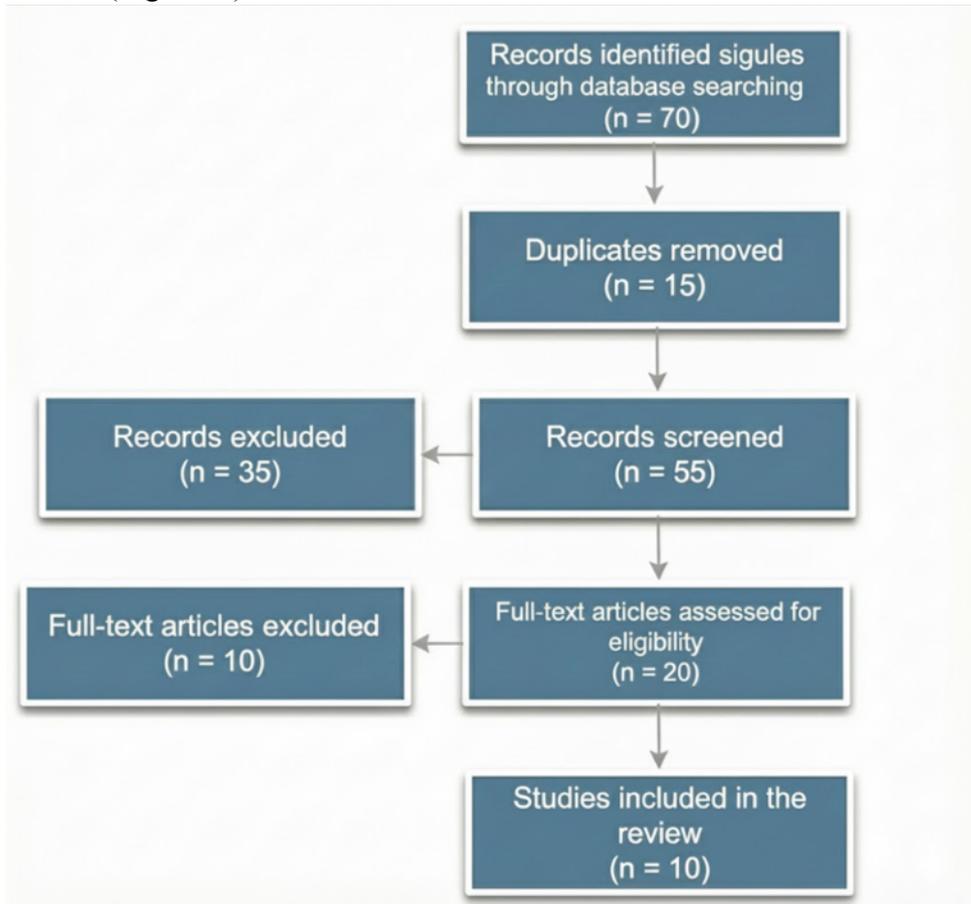


Figure. 1: Shows a PRISMA search flow chart that used in this review

Selected articles

The selected articles included in this review were summarized, including authors, key focus, and main findings of studies investigating the MTA removal techniques, as listed in Table. 1.

Clinical Relevance in Regenerative Endodontic Treatment (RET)

Although regenerative endodontic treatment (RET) has a high success rate, persistent clinical symptoms including as pain, percussion sensitivity, fistula formation, tooth movement, and swelling are clear indicators of failure (4) . In such circumstances, thorough removal of the coronal barrier material followed by orthograde retreatment is a conservative and preferable strategy that offers better chances of tooth survival than surgical alternatives (4).However, fragments of the removed material may persist on the

dentinal walls, affecting the bonding of successive obturation materials (4). Therefore, along from achieving a good seal, the ability to completely remove coronal barrier materials in cases of failed RET is of essential clinical value (4).

Table. 1: Summary of the selected articles, including authors, key focus, and main findings of selected studies

	Author(s), Year	Key Focus	Main Findings
1	Almutairi W et al. (2019)	Systematic analysis of failed regenerative endodontic cases	Synthesizes reasons for REP failure and clinical consequences, describes when removal/replacement of intracanal materials (including MTA) is indicated, and summarizes retreatment options establishes clinical rationale for studying MTA retrieval methods.
2	Butt N & Talwar S (2013)	In-vitro evaluation of solvents for retrieval of MTA and effect on dentin microhardness	Tested several solvents and reported that some acidic/chelating solutions facilitate MTA softening/removal but can reduce dentin microhardness; highlights trade-off between removal efficacy and dentin alteration.
3	Boutsioukis C, Noula G, Lambrianidis T (2008)	Ex-vivo comparison of two removal techniques for MTA used as root-filling	Compared two mechanical/technique approaches and found measurable differences in remaining MTA volumes and practical limitations of each technique underscores incomplete removal with mechanical methods alone.
4	Bhandare RS & Mattigatti SB (2024)	Microhardness of MTA and Biodentine after removal using different solvents (in vitro)	Showed that chosen solvents alter the microhardness of retrieved materials and that retrieval method affects residual material properties; provides recent experimental data on solvent effect magnitude.
5	Chan S & Abbott PV (2025)	Laboratory investigation of different acids for removing MTA from simulated canals	Compared acid solutions as aids to MTA removal; reported acids can facilitate disintegration/softening of set MTA but emphasize potential effects on dentin and need for concentration/time optimization.
6	Chhabra N & Parolia A (2023)	Effectiveness of various acidic solutions in removing OrthoMTA-based root-canal filling (in vitro)	Demonstrated that certain acids improved retrieval of OrthoMTA compared with controls and discussed practical implications and dentin safety concerns.
7	Oh S et al. (2016)	Effect of acidic solutions on microhardness of dentin and set OrthoMTA and cytotoxicity	Reported that acidic agents reduce microhardness of both dentin and set MTA to varying degrees and evaluated cytotoxicity on murine macrophages important safety data when considering acid-based removal protocols.
8	Pérez-Heredia M et al. (2008)	Decalcifying effects of 15% EDTA, 15% citric acid, 5% phosphoric acid, 2.5% NaOCl on root canal dentine	Quantified decalcifying action of common irrigants/acidic solutions on dentine; shows that some agents cause significant mineral loss essential for balancing MTA removal vs dentin preservation.

9	Gharechahi M et al. (2023)	Effect of hydrochloric acid at different concentrations on MTA plug and dentin	Investigated concentration-dependent effects of HCl on MTA softening and dentin; results indicate higher concentrations increase MTA dissolution but also raise concerns about dentin damage.
10	Cebeci GY et al. (2023)	Removal efficiency of capping materials used in pulp revascularization (in vitro)	Compared retrieval efficiency of different capping/coronal repair materials used in REPs (including MTA variants); documents which materials leave more residuals and which methods improved removal directly applicable to failed REP management.

Challenges of MTA retrieval

Mineral Trioxide Aggregate (MTA) is well-known in endodontics for its exceptional sealing capacity, which adds greatly to its clinical appeal (19). Effective sealing is required to avoid microleakage of bacteria and their byproducts, which is known to jeopardize treatment success (20). Despite its numerous benefits, one of MTA's key drawbacks is its difficult retrieval once implanted in the root canal system. With compressive strength values rising from 40.0 MPa at one day to 67.3 MPa after 21 days of damp conditions, MTA has a strong mechanical endurance (6). This slow increase in strength makes mechanical removal very challenging in the restricted root canal environment, requiring the use of chemical solvents during retreatment (22). According to microhardness tests evaluations, MTA has an average score of 69.9 HV(21). Chemical agents such as NAOCL, citric acid, and HF acid considerably lower MTA's microhardness, with HF acid having the strongest effect, followed by citric acid and sodium hypochlorite (21). Because of the acidic pH, the solubility of MTA material may increase as pH decreases, potentially affecting sealing ability.(22).

Techniques for MTA removal

The material experiences continuous maturation, which leads to a gradual increase in hardness over time, making the removal of MTA challenging. In moist conditions, compressive strength rises to over 67 MPa by 21 days from about 40 MPa after 24 hours (3). Microhardness values of set MTA are around 69.9 HV, showing the material's durability once it is fully set (7). Additionally, MTA shows significant intratubular penetration, with reported depths from 352 µm to more than 1800 µm depending on the root level (23). Due to these challenges, several studies were conducted to remove the hard-setting material, including:

⌘ Conventional hand instrumentation

This can assist initial penetration into coronal and mid-root MTA, but it is highly operator-dependent, slow, and by itself generally insufficient for predictable complete removal, particularly in the apical third where substantial residues commonly persist (24). Ex-vivo data from Boutsoukis et al. corroborate that hand files often fail to penetrate or disrupt set MTA, indicating that mechanical filling alone rarely achieves full clearance. However, the clinical relevance of these findings is limited by study design. Many supporting reports are laboratory or ex-vivo studies with small samples and simplified canal geometries that do not reproduce intracanal anatomical complexity, remaining

MTA age, or in-vivo constraints (e.g., limited tip reach, patient factors) (10). The weight of evidence suggests that hand instrumentation serves mainly for bulk reduction and initial access, but is inadequate as a standalone strategy for complete MTA retrieval. Clinically applicable protocols should therefore combine mechanical approaches with adjuncts for example, solvent or chemical softening and controlled ultrasonic activation while prioritizing methods that minimize iatrogenic dentin loss. Future studies must standardize materials, setting protocols and outcome metrics (preferably using high-resolution micro-CT and simulated clinical models) to resolve current contradictions and allow evidence-based clinical recommendations.(10,24)

⌘ Ultrasonic tips

Ultrasonic activation delivers concentrated mechanical energy to the canal and can enhance agitation of irrigants, producing greater reduction of set MTA mass than manual filing alone in many laboratory reports(25). Several studies frequently using high-resolution outcome measures such as micro-CT report improved bulk removal when ultrasonics are used, particularly for coronal and mid-root material. However, these benefits are highly conditional on multiple methodological factors (tip design and size, power setting, activation protocol, ability to reach working length, and the age/formulation of the MTA), which vary widely between studies and help explain inconsistent findings in the literature. In immature or thin-walled roots the technique is of particular concern, even at low power and with careful technique, ultrasonics can concentrate stress and generate heat or excessive dentin removal that may weaken the root or risk iatrogenic perforation(25). Moreover, many supporting studies are in-vitro or ex-vivo and use simplified canal geometries that do not capture the complexity of clinical cases or quantify long-term dentin effects (for example, microhardness reduction or fracture resistance). Thus, while ultrasonics commonly outperform hand instrumentation for MTA bulk reduction, neither approach reliably achieves complete material elimination, and the clinical translation of reported efficacy remains limited without concurrent strategies (e.g., controlled chemical softening, optimized tip designs, or protocols validated in simulated immature-tooth models)(18). Future research should standardize device parameters and outcome metrics (preferably micro-CT and validated mechanical testing) and explicitly measure collateral dentin damage to permit evidence-based clinical recommendations(18,25).

Ultrasonic activation, particularly with the Ultra-X system, demonstrated superior efficiency in removing MTA remnants compared with conventional needle irrigation, achieving significantly greater reduction of debris in the middle and apical thirds of the canal (18).

⌘ Rotary NiTi retreatment systems

Rotary NiTi retreatment systems provide rapid, standardized bulk reduction of root filling materials but were engineered primarily for gutta-percha and thermoplastic sealers rather than for rigid, set calcium-silicate cements such as MTA (25). Consequently, their cutting mechanics and flute geometry are not optimized to fracture or dislodge the stiffer MTA matrix, which helps explain inconsistent clearance and the frequent presence of residual material after retreatment. Mechanically driven instrumentation transmits concentrated stresses to canal walls; several laboratory reports have linked rotary preparation to dentinal microcracks and altered mechanical properties, implying that



aggressive rotary MTA removal could similarly compromise radicular dentin integrity and microhardness if excessive force or inappropriate file sequences are used (26). Importantly, the evidence base contains substantial methodological heterogeneity studies differ in the material tested (gutta-percha vs set MTA), sample selection (straight versus curved or immature canals), outcome metrics (stereomicroscopy, SEM, weight loss, micro-CT), and operational parameters (file system, torque/speed, operator experience) which limits direct comparison and contributes to apparent contradictions. Across multiple ex-vivo and in-vitro investigations, no currently tested rotary or ultrasonic protocol reliably achieves complete MTA elimination. The residual material on canal walls remains the rule rather than the exception(10,25). Therefore, while rotary NiTi systems are valuable for bulk removal and standardization, they should not be relied upon as sole agents for MTA retrieval; instead, clinicians should adopt combined strategies (controlled rotary bulk reduction followed by adjunctive approaches such as ultrasonic activation, chemical softening, and careful irrigation) while minimizing force application particularly in immature teeth until robust clinical data clarify safety and efficacy(10) .

⌘ Reciprocating systems

Reciprocating NiTi systems frequently show equal or superior capacity to dislodge calcium-silicate-based materials in ex-vivo models (27), but this apparent advantage is highly conditional. The performance is varies with reciprocation angles, file geometry, and operator protocol. Additionally, several studies reported longer instrumentation times compared with rotary systems(28). Heterogeneity across trials including differences in the tested material type and age, canal anatomy models (standardized straight vs. curved or immature canals), outcome measures (stereomicroscopy, SEM, weight loss, micro-CT), and inconsistent use of adjuncts (ultrasonics, solvents, irrigation activation) largely explains contradictory results. Crucially, the evidence is almost entirely laboratory-based and rarely quantifies collateral effects on dentin microhardness, fracture resistance, or long-term root integrity, limiting direct clinical translation. Therefore, reciprocating files are best characterized as an effective option for controlled bulk reduction of MTA-type materials but not as a solitary solution for complete retrieval; optimal clinical protocols should combine reciprocation with validated adjuncts while prioritizing conservative dentin preservation(27,28).

⌘ Finishing instruments

The XP Endo Finisher is a flexible, shape-adaptive finishing instrument designed to improve access to canal irregularities while preserving dentin (9). Micro-CT-based studies indicate that, when used adjunctively after rotary or reciprocating instrumentation, it significantly reduces residual volumes of bioceramic and MTA-based materials; however, complete removal is not consistently achieved (9,29). Reported efficacy varies according to canal anatomy, prior bulk-removal strategy, and the physical properties and setting time of the calcium-silicate material, which explains inconsistent outcomes across studies. As most available evidence is derived from in-vitro or ex-vivo models with simplified canal geometries, direct clinical extrapolation remains limited. Overall, the XP Endo Finisher should be regarded as a supplementary finishing step that enhances canal cleanliness rather than a standalone solution for MTA retrieval, particularly in immature or thin-walled roots (9,29).



⌘ Laser-assisted approaches

Hard-tissue lasers (Er, Cr: YSGG, Er: YAG) and photoacoustic approaches such as PIPS produce micro-explosive and photoacoustic effects that can dislodge set root-filling materials and enhance irrigants activation; several micro-CT based laboratory studies report improved reduction of residual material compared with conventional instrumentation(30). However, these advantages are highly parameter-dependent (wavelength/pulse energy, pulse duration, tip design and position, irrigants type, and operator technique), and existing evidence is predominantly in-vitro or ex-vivo using simplified canal models and small samples. Consequently, results are heterogeneous and not yet directly clinically translatable. Importantly, potential harms thermal injury to periapical tissues, excessive dentin erosion, and altered dentin microstructure are poorly quantified in current reports, mandating cautious interpretation. At present laser-assisted retrieval should be considered experimental adjunctive therapy. Its use in practice requires standardized parameter reporting, safety data, and validation in anatomically realistic and immature-tooth models before routine clinical adoption (30).

⌘ Chemical solvents and acids solution

Chemical adjuncts can materially facilitate MTA retrieval by reducing the material's surface microhardness and increasing porosity, thereby lowering the mechanical energy required for disruption; several in-vitro studies report significant microhardness reductions after exposure to agents such as hydrofluoric acid, citric acid, glycolic acid, and sodium hypochlorite.(7,14,15) However, these beneficial effects are balanced by important safety and structural concerns. Chelating agents (e.g., 17% EDTA) demineralize dentin and, with prolonged exposure, cause erosion that may compromise radicular strength and sealing interfaces(31). Organic acids such as 10% citric acid and 5% glycolic acid have produced greater reductions in set-MTA microhardness than 17% EDTA in several laboratory comparisons and on limited cytotoxicity assays appear less injurious to surrounding cells than strong mineral acids, but results depend strongly on concentration, exposure time, and post-treatment neutralization (14,15). Hydrofluoric acid and other aggressive mineral acids are effective at softening MTA but pose significant clinical safety issues (tissue toxicity and handling risk) that currently limit their practical use (7). Crucially, chemical alteration of MTA or dentin may reduce MTA–dentin bond strength and thereby impair sealing capacity, an effect documented in laboratory leakage and bonding studies and with potential clinical consequences if retreatment is followed by re-obturations or perforation repairs (22). Given that most evidence derives from small-scale in-vitro models with heterogeneous protocols (different solvents, concentrations, exposure times, and outcome metrics), direct clinical extrapolation is premature; prudent practice favors limited, targeted solvent exposure (lowest effective concentration and shortest exposure), thorough irrigation/neutralization, and use of chemical adjuncts only as part of combined protocols (mechanical bulk reduction then solvent/acid softening and adjunctive agitation/ultrasonics) while monitoring for dentin compromise.(7,14,15,22,31)

⌘ Combination of acid solution with ultrasonic

Combination protocols using acidic solvents followed by ultrasonic activation show consistent synergy in laboratory models: pre-softening set OrthoMTA with organic acids



lowers surface microhardness and increases porosity, allowing low-power ultrasonics to dislodge material more effectively than either approach alone. In comparative ex-vitro work, Chhabra et al. reported the greatest efficiency for 10% glycolic acid + ultrasonic activation, followed by 5% glycolic acid and 10% citric acid(15) . Oh et al. corroborated that short exposures to 10% citric acid or 5% glycolic acid significantly reduce OrthoMTA microhardness and show lower cytotoxicity than EDTA in cell assays, but noted that a 5-minute application may be insufficient for predictable removal implying that longer exposure increases effectiveness but also raises safety concerns (14). Additional micro-CT and volumetric studies support improved bulk and residual-volume reduction when chemical softening precedes ultrasonic agitation(32).

Critically, these encouraging results are constrained by important methodological limitations that limit clinical translation: studies differ in MTA formulation, acid type and concentration, exposure time, ultrasonic power and tip positioning, and outcome metrics (microhardness vs volumetric residuals). Most data are in-vitro or ex-vivo using simplified canal anatomies and small samples, and few investigations quantify collateral effects such as dentin demineralization, loss of microhardness, reduction in bond/sealing capacity, thermal rise, or long-term fracture resistance. Thus, while acid and ultrasonic protocols are a promising adjunct for facilitating MTA retrieval under controlled conditions, their clinical adoption should be cautious and protocolized: use the lowest effective acid concentration for the shortest effective exposure, thoroughly irrigate/neutralize afterward, apply low-power ultrasonic activation with careful tip control, and avoid aggressive use in immature or thin-walled roots until safety and sealing outcomes are demonstrated in anatomically realistic and in-vivo models (14,15,32).

⌘ Impact of Retrieval Techniques on Root Dentin

Chemical agents used during MTA retrieval can significantly influence the microhardness of radicular dentin. In an ideal scenario, a solvent would soften the MTA sufficiently to allow its removal while preserving dentin integrity. However, many acidic and chelating agents reduce the microhardness of both MTA and dentin, raising concerns about potential weakening and structural compromise of the root (6). High-concentration citric acid has been shown to be especially effective in reducing the microhardness of MTA. However, it also causes a marked decrease in dentin hardness. Similarly, commonly used endodontic irrigants such as sodium hypochlorite (NaOCl), ethylenediaminetetraacetic acid (EDTA), and chlorhexidine (CHX) adversely affect the microhardness of both MTA and dentin. These findings highlight the importance of careful solvent selection to balance removal efficiency with preservation of dentin structure (6).

The decalcifying impact of these compounds is regulated by pH, concentration, exposure time, and baseline dentin hardness (33). Among the studied solutions, NaOCl reduced dentin microhardness the most, followed by carbonic, citric, and tartaric acids, most likely due to organic matrix degradation (13,16). Hydrochloric acid has been investigated as a potential MTA solvent, with evidence suggesting that 7.5% HCl represents a safe concentration capable of softening MTA without significant structural damage, aside from minor, reversible discoloration (17).

Dentinal abnormalities, such as dentinal fractures or craze lines, may develop in the root canal wall during and after chemomechanical root canal preparation using rotary instruments or ultrasonic tips. (34).

Studies employing the Vickers microhardness test have provided clearer insight into how various acid solutions, when combined with ultrasonic agitation, affect dentin and MTA.



Specimens treated with 5% or 10% glycolic acid under ultrasonic activation showed a significant reduction in dentin microhardness compared with untreated controls and those exposed to 10% citric acid or distilled water with ultrasonics ($p < 0.01$) (15). Although both concentrations of glycolic acid caused notable dentin softening, evidence indicates that 10% citric acid and 5% glycolic acid effectively reduced MTA microhardness while preserving dentin hardness more successfully than 17% EDTA (14). Across treatment groups, saline consistently resulted in the highest post-treatment dentin microhardness, followed by glycolic acid, citric acid, and EDTA, with EDTA producing the greatest dentin weakening (14). Collectively, these findings suggest that lower concentrations of citric and glycolic acids offer a favorable balance between effective MTA softening and conservation of dentin structure, supporting their consideration as preferred chemical adjuncts during clinical MTA retrieval procedures (14).

Limitation

- Most of the included studies were in vitro experiments, which do not fully replicate the complex conditions of the oral environment.
- No standardized risk-of-bias or evidence-quality evaluation was performed for the included studies.
- different MTA types/brands (e.g., OrthoMTA, RetroMTA, traditional MTA) and other calcium-silicate materials were included without consistent subgrouping, complicating interpretation of findings across products.
- acids/solvents, concentrations, exposure times, activation methods (ultrasonic power, laser settings), and instrumentation protocols varied widely among studies, making it difficult to recommend specific clinical parameters.
- only English-language articles were included; relevant studies published in other languages could have been omitted.
- Restricted literature search: Limiting the search to PubMed and Google Scholar may have excluded relevant studies from other major databases and gray literature
- many studies do not account for clinician/technician skill, instrumentation technique differences, or reproducibility across operators.

Conclusion

Current techniques for removing MTA after failed regenerative endodontic treatment are effective mainly for bulk reduction but do not reliably achieve complete elimination, particularly in the apical third where residual material commonly remains. Mechanical methods (hand, rotary, reciprocating, and finishing instruments) work best as part of combined protocols rather than as standalone strategies, while organic acids such as citric and glycolic acid, especially when followed by ultrasonic activation, can significantly soften and dislodge MTA but also risk reducing dentin microhardness and potentially weakening the root. A cautious, conservative approach that uses low-concentration acids for short, controlled exposure followed by low-power ultrasonics currently appears most reasonable, particularly when dentin preservation is critical and roots are immature or thin-walled, yet the predominance of heterogeneous, short-term in vitro studies means that robust, evidence-based clinical guidelines are still lacking and require standardized, long-term research focused on dentin integrity and fracture resistance



Declarations

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None

Ethics statement

The author approved that this research follows the journal's Attached Ethic Approval guidelines as appeared on the journal's author guidelines page.

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Competing interest's statement

The authors declare that they have no conflict of interest.

Author contributions

MAH and RHJ provided the concepts, data analysis, and writing of the manuscript; MAH and RHJ worked with data collection and analysis; RHJ revised the manuscript and analyzed the data.

References

1. Alothman FA, Hakami LS, Alnasser A, AlGhamdi FM, Alamri AA, Almutairii BM. Recent Advances in Regenerative Endodontics: A Review of Current Techniques and Future Directions. *Cureus* [Internet]. 2024 Nov 20 [cited 2025 Dec 14]; Available from: <https://www.cureus.com/articles/320328-recent-advances-in-regenerative-endodontics-a-review-of-current-techniques-and-future-directions>
2. Pendse G, Misra R, Mandke L, Maniar H, Khose A, Basmatkar N. Comparison of Revascularization and Apexification Using Mineral Trioxide Aggregate in Young Human Immature Nonvital Teeth: A Systematic Review and Meta-Analysis. *Cureus* [Internet]. 2025 July 25 [cited 2025 Dec 14]; Available from: <https://www.cureus.com/articles/371915-comparison-of-revascularization-and-apexification-using-mineral-trioxide-aggregate-in-young-human-immature-nonvital-teeth-a-systematic-review-and-meta-analysis>
3. Wei X, Yang M, Yue L, Huang D, Zhou X, Wang X, et al. Expert consensus on regenerative endodontic procedures. *Int J Oral Sci*. 2022 Dec;14(1):55.
4. Almutairi W, Yassen GH, Aminoshariae A, Williams KA, Mickel A. Regenerative Endodontics: A Systematic Analysis of the Failed Cases. *J Endod*. 2019 May;45(5):567–77.



5. Karunakaran S, Praveen N, Selvandran KE, Leburu A, Madhuran K, Kumar ARA. Effectiveness of mineral trioxide aggregate and its modifications in inducing dentin bridge formation during pulp capping: A systematic review. *J Conserv Dent Endod*. 2025 Mar;28(3):222–30.
6. Buyukcolpan G, Özden İ, Sazak Öveçoğlu H. Evaluation of the Effects of Different Irrigation Solutions on MTA and Dentin Microhardness. *Clin Exp Health Sci*. 2025 Sept 30;15(3):524–30.
7. Bhandare RS, Mattigatti SB. Re-evaluation of Microhardness of Mineral Trioxide Aggregate and Biodentine After Removal From Root Using Different Types of Solvents: An In Vitro Study. *Cureus* [Internet]. 2024 Sept 22 [cited 2025 Dec 14]; Available from: <https://www.cureus.com/articles/272299-re-evaluation-of-microhardness-of-mineral-trioxide-aggregate-and-biodentine-after-removal-from-root-using-different-types-of-solvents-an-in-vitro-study>.
8. Cheng G, Wu X, Li W, Lv Z. Comparative Outcomes of Apical Induction Versus Pulp Revascularization in Young Permanent Anterior Teeth with Traumatic Pulp Necrosis. *Ther Clin Risk Manag*. 2025;21:737–45.
9. Chan S, Abbott PV. A Laboratory Investigation of the Effectiveness of Different Acids in Removing Mineral Trioxide Aggregate From Simulated Root Canals. *Aust Endod J*. 2025 Aug;51(2):267–74.
10. Boutsoukis C, Noula G, Lambrianidis T. Ex Vivo Study of the Efficiency of Two Techniques for the Removal of Mineral Trioxide Aggregate Used as a Root Canal Filling Material. *J Endod*. 2008 Oct;34(10):1239–42.
11. Hamadhi F, M. Z. Evaluation the Marginal Adaptation for the Bio C Repair and Other Root end Filling Material by Using Scanning Electron Microscope (A Comparative In Vitro Study). *Cumhur Dent J*. 2023 Sept 29;26(3):261–7.
12. Al-Dahan ZAA, Khalaf MS, Al-Assadi AH. Apexification and Periapical Healing of Immature Teeth Using Mineral Trioxide Aggregate. *J Baghdad Coll Dent*. 2014 Sept;26(3):108–12.
13. Butt N, Talwar S. In-vitro evaluation of various solvents for retrieval of mineral trioxide aggregate and their effect on microhardness of dentin. *J Conserv Dent JCD*. 2013 May;16(3):199–202.
14. Oh S, Perinpanayagam H, Lee Y, Kum JW, Yoo YJ, Lim SM, et al. Effect of acidic solutions on the microhardness of dentin and set OrthoMTA and their cytotoxicity on murine macrophage. *Restor Dent Endod*. 2016;41(1):12.
15. Chhabra N, Parolia A. Effect of Various Acid Solutions as an Aid in Removing the OrthoMTA-Based Root Canal Filling. *Materials*. 2023 June 23;16(13):4535.

16. Pérez-Heredia M, Ferrer-Luque CM, González-Rodríguez MP, Martín-Peinado FJ, González-López S. Decalcifying effect of 15% EDTA, 15% citric acid, 5% phosphoric acid and 2.5% sodium hypochlorite on root canal dentine. *Int Endod J*. 2008 May;41(5):418–23.
17. Gharechahi M, Moradi S, Nasirnia S, Peighoun M. Investigation of the effect of hydrochloric acid with different concentrations on mineral trioxide aggregate plug and dentin. *Dent Res J*. 2023;20:61.
18. Dawod KM, Al-Hashimi RA. Assessing Volume of Two Sealers' Remnants after Reinstrumentation Using 3D Imaging Technology: An In Vitro Comparative Study. *J Contemp Dent Pract*. 2025 Oct 10;26(8):743–51.
19. Bates CF, Carnes DL, Del Rio CE. Longitudinal sealing ability of mineral trioxide aggregate as a root-end filling material. *J Endod*. 1996 Nov;22(11):575–8.
20. Torabinejad M, Watson TF, Pitt Ford TR. Sealing ability of a mineral trioxide aggregate when used as a root end filling material. *J Endod*. 1993 Dec;19(12):591–5.
21. Wikström A, Romani Vestman N, Rakhimova O, Lazaro Gimeno D, Tsilingaridis G, Brundin M. Microbiological assessment of success and failure in pulp revitalization: a randomized clinical trial using calcium hydroxide and chlorhexidine gluconate in traumatized immature necrotic teeth. *J Oral Microbiol*. 2024 Dec 31;16(1):2343518.
22. Al-Zubaidi AK, Al-Azzawi AKJ. The Effect of Various Endodontic Irrigants on the Sealing Ability of Biodentine and Other Root Perforation Repair Materials : In Vitro Study. *J Baghdad Coll Dent*. 2014 Sept;26(3):1–8.
23. Kim Y, Kim BS, Kim YM, Lee D, Kim SY. The Penetration Ability of Calcium Silicate Root Canal Sealers into Dentinal Tubules Compared to Conventional Resin-Based Sealer: A Confocal Laser Scanning Microscopy Study. *Materials*. 2019 Feb 11;12(3):531.
24. Alves FRF, Rôças IN, Provenzano JC, Siqueira JF. Removal of the Previous Root Canal Filling Material for Retreatment: Implications and Techniques. *Appl Sci*. 2022 Oct 11;12(20):10217.
25. Aksel H, Küçükaya Eren S, Askerbeyli Örs S, Serper A, Ocak M, Çelik HH. Micro-CT evaluation of the removal of root fillings using the ProTaper Universal Retreatment system supplemented by the XP-Endo Finisher file. *Int Endod J*. 2019 July;52(7):1070–6.
26. Abdul-Hamed S. A Stereomicroscopic Analysis of Dentinal Micro Cracks after Root Canal Preparation Using Four Different Rotary Instruments. *Indian J Forensic Med Toxicol* [Internet]. 2020 Jan 25 [cited 2025 Dec 14]; Available from: <http://medicopublication.com/index.php/ijfmt/article/view/78>

27. Madarati AA, Sammani AMN, Alnazzawi AA, Alrahlah A, Pedullà E. Efficiency of reciprocating systems reciprocated at different angles in removing root-canals fillings with an MTA-type sealer: an Ex-vivo study. *BMC Oral Health*. 2022 Aug 17;22(1):357.
28. Yoshpe M, Einy S, Ruparel N, Lin S, Kaufman AY. Regenerative Endodontics: A Potential Solution for External Root Resorption (Case Series). *J Endod*. 2020 Feb;46(2):192–9.
29. Tang H, Torabinejad M, Kettering J. Leakage Evaluation of Root End Filling Materials Using Endotoxin. *J Endod*. 2002 Jan;28(1):5–7.
30. Lee C, Song M. Failure of Regenerative Endodontic Procedures: Case Analysis and Subsequent Treatment Options. *J Endod*. 2022 Sept;48(9):1137–45.
31. Baruwa AO, Martins JNR, Maravic T, Mazzitelli C, Mazzoni A, Ginjeira A. Effect of Endodontic Irrigating Solutions on Radicular Dentine Structure and Matrix Metalloproteinases—A Comprehensive Review. *Dent J*. 2022 Nov 23;10(12):219.
32. Cebeci GY, Almaz ME, Orhan EO, Beklen A. Evaluation of removal efficiency of capping materials used in pulp revascularization in vitro. *BMC Oral Health*. 2023 Sept 6;23(1):646.
33. Ari H, Erdemir A. Effects of Endodontic Irrigation Solutions on Mineral Content of Root Canal Dentin Using ICP-AES Technique. *J Endod*. 2005 Mar;31(3):187–9.
34. Abdulameer ZM. A Comparative Study to Evaluate the Effect of Ultrasonic Agitation on Push - Out Bond Strength of Three Root-End Filling Materials: An In Vitro Study. *Indian J Forensic Med Toxicol* [Internet]. 2021 Jan 7 [cited 2025 Dec 14]; Available from: <http://medicopublication.com/index.php/ijfmt/article/view/13653>