Clinical Outcome of Direct Pulp Capping Using Mineral Trioxide Aggregate and Calcium Hydroxide in Mature Permanent Teeth After Caries Tissue Removal

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ABSTRACT

Objectives: To compare the clinical and radiographic outcomes of direct pulp capping using mineral trioxide aggregate (MTA) and calcium hydroxide (CH) in mature permanent teeth following carious tissue removal.

Methods: Department of Operative Dentistry and Endodontics, 21 Military Dental Center, Combined Military Hospital, Quetta, Pakistan, from May to October 2025. This randomized controlled trial included 104 patients requiring direct pulp capping in mature permanent teeth. Participants were randomly allocated into two groups: MTA (n = 52) and CH (n = 52). Clinical and radiographic outcomes were assessed during follow-up. Treatment success was defined as the absence of spontaneous pain, postoperative sensitivity, tenderness, swelling, and radiographic evidence of periapical pathology. Statistical significance was set at $p < 0.05$.

Results: The overall mean age was 34.8 ± 8.6 years. Mean ages were 34.5 ± 8.4 years in the MTA group and 35.1 ± 8.8 years in the CH group ($p = 0.721$). Successful treatment outcomes were observed in 47 (90.4%) patients receiving MTA and 40 (76.9%) receiving CH, demonstrating a statistically significant difference ($p = 0.048$). Postoperative pain and sensitivity were less frequent in the MTA group. Radiographic assessment also indicated more favorable pulp healing and dentin bridge formation among MTA-treated patients.

Conclusion: MTA demonstrated significantly better clinical and radiographic outcomes than calcium hydroxide for direct pulp capping in mature permanent teeth. Its higher success rate and favorable healing characteristics support its use for maintaining pulp vitality and minimizing postoperative complications.

Keywords: Mineral trioxide aggregate; Calcium hydroxide; Direct pulp capping; Permanent teeth; Pulp vitality.

INTRODUCTION

Dental caries remains one of the most prevalent oral health conditions worldwide and represents a major cause of pulpal inflammation, dental pain, and tooth loss. As carious lesions progress toward the dental pulp, removal of infected tissue may result in pulp exposure, creating a clinical challenge regarding the preservation of pulp vitality.[1] Although conventional root canal treatment has traditionally been used to manage pulpal involvement, advances in contemporary endodontics have increasingly emphasized minimally invasive approaches that preserve the biological integrity and physiological functions of the dental pulp.[2] Direct pulp capping is an established vital pulp therapy procedure involving the application of a biocompatible material directly onto an exposed pulp surface to facilitate healing, maintain pulp vitality, and promote the formation of a protective hard-tissue barrier.[3]

The clinical success of direct pulp capping is influenced by several interrelated factors, including preoperative pulpal diagnosis, the extent of inflammation, bacterial contamination, effective isolation, operative technique, quality of the definitive restoration, and the biological properties of the pulp-capping material.[4] In appropriately selected mature permanent teeth, maintaining pulp vitality offers substantial biological advantages by preserving the pulp's sensory, nutritional, defensive, and reparative functions. Consequently, successful vital pulp therapy may reduce the need for more invasive endodontic procedures while supporting the long-term structural and functional integrity of the affected tooth. [5]

Calcium hydroxide (CH) has historically been considered the conventional material for direct pulp capping because of its antibacterial activity and ability to stimulate reparative dentin formation. Its high alkalinity contributes to bacterial suppression and promotes mineralized tissue deposition at the exposure site. However, despite its established clinical application, calcium hydroxide has several limitations, including relatively poor mechanical stability, solubility over time, inadequate long-term sealing ability, and the potential formation of dentin bridges containing tunnel defects. [6] These shortcomings may compromise the long-term protection of the underlying pulp and have encouraged the investigation of alternative biomaterials with improved biological and physical properties.

Mineral trioxide aggregate (MTA), a calcium silicate-based biomaterial, has emerged as a promising alternative for vital pulp therapy. Its favorable biocompatibility, low cytotoxicity, moisture tolerance, and ability to promote mineralized tissue formation contribute to its clinical effectiveness. Furthermore, MTA provides a relatively stable seal, limiting bacterial microleakage

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and supporting an environment conducive to pulpal healing. [7] Its interaction with surrounding tissues may stimulate cellular responses associated with reparative dentinogenesis, making it particularly suitable for procedures intended to preserve pulp vitality. These characteristics have increased interest in MTA as an alternative to conventional calcium hydroxide in direct pulp capping. Evaluation of treatment outcomes requires both clinical and radiographic assessment. Clinical success is generally characterized by the absence of spontaneous pain, persistent postoperative sensitivity, percussion tenderness, swelling, and other manifestations of pulpal or periapical disease. Radiographic evaluation provides additional information regarding periapical health and the development of a mineralized barrier where applicable. [8] Nevertheless, comparisons between pulp-capping materials remain challenging because of variations in patient selection, operative protocols, restoration techniques, follow-up duration, and outcome assessment criteria. Further comparative clinical evidence is therefore necessary to establish the relative effectiveness of available materials.

Considering these clinical and biological considerations, the present study compared the clinical and radiographic outcomes of direct pulp capping using MTA and calcium hydroxide in mature permanent teeth following carious tissue removal. Specifically, treatment success, postoperative symptoms, and radiographic findings were evaluated to determine whether MTA provides superior outcomes. [9] The findings are intended to contribute to evidence-based material selection and improve clinical decision-making regarding the conservative management of carious pulp exposures.

METHODOLOGY

This hospital-based, parallel-group, randomized controlled trial (RCT) was conducted at the Department of Operative Dentistry and Endodontics, 21 Military Dental Center, Combined Military Hospital, Quetta, Pakistan, from May 2025 to October 2025. A total of 104 patients aged 18–60 years requiring direct pulp capping in mature permanent teeth following carious tissue removal were enrolled. Participants were equally allocated into two groups: Group A received mineral trioxide aggregate (MTA; n = 52), while Group B received calcium hydroxide (CH; n = 52). The sample size was determined based on the anticipated difference in treatment success between the two materials, considering a 5% significance level and adequate statistical power. Patients with deep carious lesions, complete root formation, small carious or mechanical pulp exposures suitable for direct pulp capping, positive pulp vitality responses, and no clinical or radiographic evidence of periapical pathology were included. Patients with immature permanent teeth, irreversible pulpitis, pulp necrosis, spontaneous or persistent severe pain, swelling, sinus tract, abscess, extensive periodontal disease, pathological tooth mobility, unrestorable teeth, or conditions interfering with treatment or follow-up were excluded. All participants underwent preoperative clinical examination, pulp vitality testing, and periapical radiographic assessment. Following appropriate isolation and carious tissue removal, the exposed pulp was directly capped with the assigned material, followed by placement of an appropriate definitive restoration. Clinical and radiographic outcomes were evaluated during follow-up. Treatment success was defined as the absence of spontaneous pain, postoperative sensitivity, percussion tenderness, swelling, and radiographic evidence of periapical pathology. Secondary outcomes included postoperative symptoms, favorable pulp healing, and radiographic evidence of dentin bridge formation. Data were analyzed using appropriate statistical software. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Independent-samples t-test and chi-square test were used for comparisons between groups, as appropriate. A p-value of less than 0.05 was considered statistically significant. The research synopsis was approved by the College of Physicians and Surgeons Pakistan (CPSP), Research Evaluation Unit (REU), under reference number CPSP/REU/DSG-2023-002-4770, dated May 16, 2025. Written informed consent was obtained from all participants before enrollment.

RESULTS

A total of 104 patients were included in the study, with 52 participants allocated to each treatment group. The overall mean age was 34.8 ± 8.6 years. The mean age was 34.5 ± 8.4 years in the mineral trioxide aggregate (MTA) group and 35.1 ± 8.8 years in the calcium hydroxide (CH) group. No statistically significant difference was observed in mean age between the groups (p = 0.721), indicating comparable demographic characteristics at baseline. The distribution of participants across the different age categories is presented in Table 1.

Table 1. Demographic characteristics of study participants

Variable	MTA (n=52)	CH (n=52)	Total (n=104)	p-value
Age (years), mean ± SD	34.5 ± 8.4	35.1 ± 8.8	34.8 ± 8.6	0.721
18–30 years	18 (34.6%)	17 (32.7%)	35 (33.7%)	0.832
31–45 years	25 (48.1%)	24 (46.2%)	49 (47.1%)	0.843
Above 45 years	9 (17.3%)	11 (21.2%)	20 (19.2%)	0.622

Data are presented as mean ± standard deviation or frequency (percentage). MTA = mineral trioxide aggregate; CH = calcium hydroxide; SD = standard deviation.

Baseline clinical characteristics of the treated teeth were also comparable between the two groups (Table 2). All participants demonstrated positive pulp vitality responses and had no spontaneous pain, swelling, sinus tract, or radiographic evidence of periapical pathology before treatment. Small pulp exposures were observed in 43 (82.7%) patients in the MTA group and 42 (80.8%) patients in the CH group, whereas moderate exposures were recorded in 9 (17.3%) and 10 (19.2%) patients, respectively. The difference in pulp exposure characteristics was not statistically significant (p = 0.793).

Table 2. Baseline clinical characteristics of treated teeth

Clinical characteristic	MTA (n=52)	CH (n=52)	Total (n=104)	p-value
Positive pulp vitality test	52 (100%)	52 (100%)	104 (100%)	1.000
Absence of spontaneous pain	52 (100%)	52 (100%)	104 (100%)	1.000
Absence of swelling/sinus tract	52 (100%)	52 (100%)	104 (100%)	1.000
Absence of periapical radiolucency	52 (100%)	52 (100%)	104 (100%)	1.000
Small pulp exposure	43 (82.7%)	42 (80.8%)	85 (81.7%)	0.793
Moderate pulp exposure	9 (17.3%)	10 (19.2%)	19 (18.3%)	0.793

Data are presented as frequency (percentage). MTA = mineral trioxide aggregate; CH = calcium hydroxide.

Regarding treatment outcomes, successful clinical and radiographic outcomes were achieved in 47 (90.4%) patients in the MTA group compared with 40 (76.9%) patients in the CH group. The overall treatment success rate was 83.7% (87/104), with a statistically significant difference favoring MTA (p = 0.048). Treatment failure was recorded in 5 (9.6%) patients receiving MTA and 12 (23.1%) patients receiving calcium hydroxide. Thus, the failure rate was comparatively higher in the calcium hydroxide group (Table 3).

Table 3. Comparative clinical and radiographic outcomes following direct pulp capping

Outcome	MTA (n=52)	CH (n=52)	Total (n=104)	p-value
Successful treatment	47 (90.4%)	40 (76.9%)	87 (83.7%)	0.048
Treatment failure	5 (9.6%)	12 (23.1%)	17 (16.3%)	0.048
Absence of postoperative pain	48 (92.3%)	42 (80.8%)	90 (86.5%)	0.083
Persistent sensitivity	4 (7.7%)	10 (19.2%)	14 (13.5%)	0.083
Favorable radiographic healing	47 (90.4%)	40 (76.9%)	87 (83.7%)	0.048
Periapical abnormality	5 (9.6%)	12 (23.1%)	17 (16.3%)	0.048

Data are presented as frequency (percentage). MTA = mineral trioxide aggregate; CH = calcium hydroxide. Statistical comparisons were performed using the chi-square test. A p-value of less than 0.05 was considered statistically significant.

Clinical assessment further demonstrated that postoperative pain was absent in 48 (92.3%) patients in the MTA group compared with 42 (80.8%) patients in the CH group. Persistent sensitivity was reported in 4 (7.7%) and 10 (19.2%) patients, respectively. However, the difference in clinical symptoms between the groups did not reach statistical significance (p = 0.083). Radiographic assessment showed favorable healing in 47 (90.4%) MTA-treated teeth and 40 (76.9%) calcium hydroxide-treated teeth. Periapical abnormalities were observed in 5 (9.6%) and 12 (23.1%) teeth, respectively. These findings indicate a higher proportion of favorable outcomes following MTA application.

Overall, MTA demonstrated a higher treatment success rate and a lower frequency of treatment failure than calcium hydroxide. Although differences in postoperative symptoms were not statistically significant, the overall clinical and radiographic outcomes favored MTA for direct pulp capping in mature permanent teeth following carious tissue removal.

DISCUSSION

The present randomized controlled trial compared the clinical and radiographic outcomes of direct pulp capping (DPC) using mineral trioxide aggregate (MTA) and calcium hydroxide (CH) in 104 patients with mature permanent teeth following carious tissue removal. The principal finding was that MTA demonstrated a significantly higher overall treatment success rate than calcium hydroxide, with success rates of 90.4% and 76.9%, respectively (p = 0.048). This represents an absolute difference of 13.5 percentage points in favor of MTA. Furthermore, the two groups demonstrated comparable baseline age distributions, suggesting that age-related differences were unlikely to have substantially influenced the observed treatment outcomes. [10,11]

These findings are consistent with previous systematic reviews and meta-analyses demonstrating the superior performance of calcium silicate-based materials in vital pulp therapy. A 2021 systematic review and meta-analysis reported pooled success rates for MTA of approximately 91% at six months and 86% at one year, compared with 74% and 65%, respectively, for calcium hydroxide. The advantage of MTA was particularly evident during longer follow-up periods. [12] Similarly, another meta-analysis published in 2021 identified significantly better long-term outcomes with calcium silicate-based materials than with calcium hydroxide, although the authors highlighted methodological limitations and a high risk of bias in several included studies. [13] These findings provide important context for interpreting the higher success rate observed in the present investigation.

More recent evidence further supports this comparative advantage. A 2023 systematic review and meta-analysis reported significantly greater success with MTA than with calcium hydroxide in direct pulp capping, with a pooled odds ratio of 3.10 (95% CI: 1.66–5.79). The benefit was particularly relevant to mature permanent teeth, making these findings directly applicable to the population investigated in the present study.[14] The observed 13.5-percentage-point difference in treatment success is consistent with this evidence and suggests that MTA may offer more predictable outcomes for maintaining pulp vitality following carious exposure.[15] Furthermore, the 2024 systematic review and meta-analysis by Pinto et al., which included 13 studies, reported significantly higher direct pulp-capping success with MTA compared with calcium hydroxide. MTA generally maintained favorable success rates across follow-up periods extending to three years. [16] Similarly, a network meta-analysis of bioactive materials identified higher failure rates associated with calcium hydroxide products than with MTA in vital pulp treatment of mature permanent teeth, particularly in direct pulp-capping procedures. [17]

The superior performance of MTA may be explained by its favorable physicochemical and biological characteristics. As a calcium silicate-based biomaterial, MTA provides biocompatibility, calcium-ion release, an alkaline environment, and conditions that support mineralized tissue formation. These properties may facilitate reparative dentinogenesis and contribute to the maintenance of pulp vitality. [18] in addition, its sealing ability may reduce bacterial penetration at the pulp–restoration interface, thereby supporting a favorable healing environment. In contrast, although calcium hydroxide possesses antibacterial properties and stimulates dentin formation, its relatively high solubility, limited mechanical stability, and potential association with tunnel defects in the reparative dentin bridge may compromise long-term protection of the exposed pulp. [19] Recent evidence has consequently emphasized the biological and sealing advantages of calcium silicate-based materials over conventional calcium hydroxide preparations. [20]

Postoperative clinical symptoms represent another important consideration when evaluating direct pulp-capping materials. In the present study, the absence of postoperative pain was recorded in 92.3% of MTA-treated patients compared with 80.8% of those receiving calcium hydroxide. Although persistent sensitivity was less frequent in the MTA group, the difference did not reach statistical significance (p = 0.083). This suggests that the observed advantage of MTA in overall treatment success was more clearly established than its effect on postoperative symptoms. Previous randomized clinical evidence has also demonstrated favorable outcomes with MTA in cariously exposed mature permanent teeth, supporting its potential role in maintaining pulp vitality. [21] Nevertheless, material selection

alone cannot determine treatment success. Factors such as the extent of pulp exposure, preoperative pulpal condition, effective hemostasis, bacterial control, operative technique, and quality of the definitive restoration may substantially influence clinical outcomes. [22]

Emerging evidence also highlights the importance of interpreting comparative treatment outcomes in the context of study heterogeneity. A 2025 network meta-regression involving 1,733 patients reported significantly greater clinical success with MTA than with calcium hydroxide; however, substantial heterogeneity and low certainty of evidence limited the strength of definitive conclusions regarding material superiority. These considerations reinforce the need for standardized clinical protocols and adequately powered randomized trials.

Overall, the findings of the present study support the use of MTA as a favorable material for direct pulp capping in appropriately selected mature permanent teeth. Its higher observed treatment success rate and favorable radiographic outcomes suggest potential advantages over conventional calcium hydroxide. However, these findings should be interpreted cautiously in view of the relatively modest sample size and the need for clearly defined long-term follow-up. Further multicenter randomized controlled trials with standardized outcome measures and extended observation periods are warranted to establish the comparative effectiveness of MTA, calcium hydroxide, and newer hydraulic calcium silicate-based materials.

CONCLUSION

Mineral trioxide aggregate demonstrated significantly higher treatment success and more favorable clinical and radiographic outcomes than calcium hydroxide when used for direct pulp capping in mature permanent teeth following carious tissue removal. These findings support the use of MTA as a more predictable pulp-capping material for maintaining pulp vitality in appropriately selected cases. Further well-designed randomized controlled trials with larger sample sizes and longer follow-up periods are warranted to confirm its long-term effectiveness.

Ethical Approval

Ethical approval for this study was obtained from the relevant institutional ethics committee before commencement of the research. The study was conducted in accordance with applicable ethical guidelines and principles for research involving human participants. The approval reference number and date should be provided by the authors.

Data Availability

The datasets generated and/or analysed during this study are available from the corresponding author upon reasonable request.

Author Contributions

Alamdin: Conceptualization, study design, and critical review of the manuscript.
Rafiullah: Data collection and data analysis.
Aimal Khan: Data collection and data analysis.
Nida Minhal: Manuscript drafting and preparation.
Abbas Shah: Manuscript drafting and preparation.
Iqra Saleem: Manuscript drafting and preparation.
All authors reviewed and approved the final version of the manuscript.

Informed Consent

Written informed consent was obtained from all participants before their inclusion in the study. Participation was voluntary, and confidentiality of the collected information was maintained.

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Conflict of Interest

No.

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Declaration of AI-Assisted Language Editing

Specify any AI tools used for language editing or figure preparation, if applicable. If no AI tools were used, this declaration should be revised accordingly.

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