Submitted: 14 October, 2025 Accepted: 01 December, 2025 Published: 03 July, 2026 DOI:10.22514/jocpd.2026.089

SYSTEMATIC REVIEW

Journal of Clinical Pediatric Dentistry

Outcome of vital pulp therapy with treatment based on various medicaments: a systematic review and meta-analysis

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Abstract

Background: Vital pulp therapy (VPT) is a biological procedure performed to maintain pulp vitality and function in teeth diagnosed with pulp exposure. The selection of medication is an important criteria to ensure successful treatment. Calcium hydroxide (CH) has been used in various formulations, but newer-generation biomaterials, including mineral trioxide aggregate (MTA) and Biodentine, have better sealing ability, biocompatibility, and clinical prognosis. The present review aimed to synthesize evidence for comparing various pulp-capping and pulpotomy medicaments to determine the most effective materials. **Methods**: A systematic search was made in MEDLINE, Embase and the Cochrane Library to identify studies pertaining to compare clinical and radiographic outcomes of vital pulp therapy using different medicaments. The major databases were searched in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations. Inclusion criteria: Randomized clinical trials, prospective studies, and clinical studies that assessed the success of Vital pulp therapy (VPT) using Minteral trioxide aggregate (MTA), Biodentine, Calcium hydroxide (CH), or other biomaterials were included. Studies with insufficient outcome data, case reports, or reviews were excluded. The eligibility criteria were met in 13 studies. Data were extracted on study design, number of patients, medicaments used and length of follow-up. **Results**: MTA had a higher success rate than CH. There was no statistically significant difference in comparisons of MTA and Biodentine Biodentine showed a tendency to be superior to CH in different studies The subgroup analysis demonstrated that children had a greater pooled success rate (88%) than adults (82%), and the long-term follow-up group (>24 months) had a stable result. **Conclusion**: MTA was the most reliable medication for VPT. Biodentine has emerged as a viable alternative, especially considering its handling advantages, whereas CH demonstrated lower success rates. **The PROSPERO Registration**: The review was registered into PROSPERO (registration number: CRD420251137453).

Keywords

Vital pulp therapy; Mineral trioxide aggregate; Biodentine; Calcium hydroxide; Pulpotomy; Pulp-capping

1. Introduction

The preservation of pulp vitality is the main goal in restorative dentistry because it provides a source of nutrition to the dental complex and plays an essential role in immune responses and neurogenic activities; thus, increasing the longevity of natural teeth [1, 2]. There is an increase in the prevalence of dental caries and pulp exposure worldwide, with root canal therapy or extractions often being necessary, especially if preservation of the pulp is not considered [2, 3]. Vital pulp therapy (VPT), which includes direct or indirect pulp capping and pulpotomy, is a less invasive procedure that may help maintain the vitality of the remaining dental pulp tissue and reduce the progression of apical disease [4].

VPT has used several new medications, most of which have different success rates. Traditionally, calcium hydroxide (CH) is the material of choice because it has antimicrobial effects and can facilitate dentin bridging. In recent years, new

chemically modified bioceramic materials have been rapidly developed, such as mineral trioxide aggregate (MTA) and Biodentine, which have gained tremendous appreciation for their excellent measuring or sealing ability, biocompatibility, and regeneration [5–7].

With the increasing selection of VPT agents and growing body of clinical data, a systematic review focused on outcomes is appropriate. To the best of our knowledge, no systematic review has been performed to compare the efficacy of VPT medicaments among different groups in randomized and controlled trials. Thus, the present systematic review was designed to determine the clinical and radiographic success rates of VPT using different treatment agents, by providing materials for evidence-based material selection in restorative endodontics.

The primary objective of this review was to compare the clinical and radiographic outcomes of vital pulp therapy using different medications (*e.g.*, CH, MTA, and Biodentine). Secondary objectives included assessing long-term success stratified by follow-up duration and analyzing the relative performance of bioceramics versus conventional materials.

2. Materials and methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. This systematic review was conducted according to PRISMA, and the protocol was registered at PROSPERO under the identification number CRD 420251137453. A complete checklist file has been added to the **Supplementary material**. The review protocol was prospectively developed to define the objectives, eligibility criteria, outcomes, and methodology, to minimize bias and ensure transparency.

2.1 Eligibility criteria

The eligibility criteria were established using the Population, Intervention, Comparison, and Outcome (PICO) framework. We considered randomized controlled trials and both prospective and retrospective clinical studies involving human permanent or primary teeth (anterior or posterior) with carious or traumatic pulp exposure, requiring a minimum follow-up period of 6 months and clearly defined clinical and radiographic success outcomes. Studies of human teeth with pulp exposure were eligible regardless of maturity (immature *vs.* mature permanent teeth) or exfoliation stage in the primary teeth. We excluded *in vitro* or animal studies, case reports, reviews, conference abstracts, studies lacking adequate outcome data or with less than 6 months of follow-up, and non-English publications. These criteria were selected to ensure methodological rigor, clinical relevance, and reproducibility of findings.

2.2 Data sources

We conducted a systematic literature search of MEDLINE, Embase, and the Cochrane Library to identify studies pertaining to this issue. The major databases used were PubMed, Scopus, Web of Science, Cochrane Library, and Google Scholar. We chose these databases to include as many global articles as possible on biomedical, clinical, and dental research. To increase completeness, further sources were checked (references list of included articles, as well as grey literature (conference proceedings and congress abstracts), dissertations, and theses). The search was limited to papers published in English during a predetermined period (January 2000 to December 2024).

2.3 Search strategy

We designed a search strategy for a systematic review based on different combinations of keywords and Medical subject headings (MeSH) terms related to vital pulp therapy and medicaments. The most common were defined as: “vital pulp therapy”, “VPT”, “pulp capping”—“indirect pulp capping”, and “direct pulp capping”—often used interchangeably, though direct pulp capping usage was often acellular technique for mature teeth; pulpotomy—defined as removal of the coronal portion of live tissue when a complete root is indicated; partial pulpotomy—etymology not known, likely accepted to mean removing part of tissue above exposure; full pulpotomy—removing all exposed or affected tissue. These terms were simultaneously combined with medicament-specific terms, including CH, Biodentine, and MTA. Searches were further refined using the Boolean operators “AND” combining therapy types with medicaments and “OR” including synonyms or related terms. Filters were applied to limit the results to human studies, English-language publications, and articles published between January 2000 and December 2024. The search was adjusted to match the syntax and field tags of each electronic database mentioned earlier. In addition, reference lists of identified articles and relevant reviews were hand-searched for further suitable studies not detected by the initial database search.

3. Results

3.1 Study selection

Fig. 1 shows the selected studies.

3.2 Data extraction

Data extraction was performed in an organized and standardized manner to enhance uniformity and diminish bias. A standardized data extraction form was built, and two independent reviewers extracted the relevant information from all included studies. Data extraction included study characteristics (first author, year of publication, country, study design), participant demographics (age, sex distribution, and number of teeth treated), and sample size. Variables including the type of VPT undertaken (direct cap, partial pulpotomy, or full pulpotomy) and the medication used (CH, MTA, Biodentine, and other medicaments) were recorded. They also recorded the follow-up time for all studies to determine both the short- and long-term prognosis. The extraction of success criteria: clinical (no pain, tenderness, swelling, sinus tract), radiographic, and survival rates of endodontically treated teeth were performed carefully. If studies assessed additional outcomes, such as adverse events, postoperative complications, or patient-reported outcomes, they were tabulated. Any inconsistencies in the data

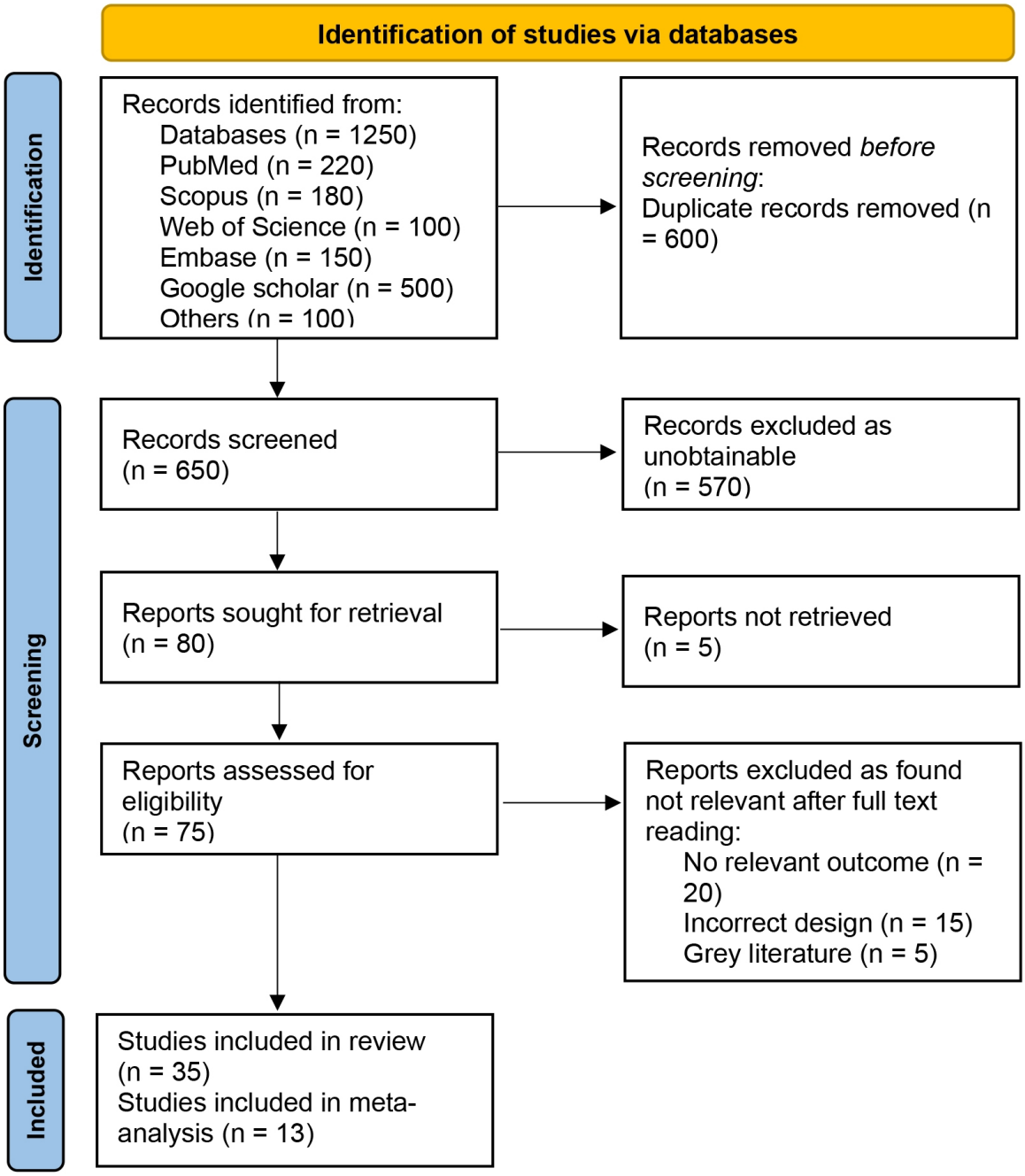

FIGURE 1. PRISMA flow diagram.

extraction process between the two reviewers were resolved through discussion, and a third reviewer was consulted when a consensus could not be reached.

3.3 Risk of bias assessment

Proper tools were used to assess the risk of bias in this systematic review, according to the study design. The risk of bias in sequence generation, allocation concealment, blinding of participants and personnel (Performance Bias), blinding of outcome assessment (detection bias), incomplete outcome data, selective reporting, and other sources of bias were assessed using the Cochrane Risk of Bias tool. For each outcome, the domain was judged to be low, high, or unclear risk of bias.

The Newcastle-Ottawa Scale was used to assess the risk of bias in observational studies, including cohort and case-control studies, based on three broad perspectives: Selection, Comparability, Outcome. Studies were evaluated for the selection of participants, comparability of study groups, and ascertainment of exposure or outcomes using this instrument. We rated each study accordingly, and studies with higher scores were deemed to be of better methodological quality and lower risk of bias.

The bias assessment was completed by two independent reviewers who resolved judgement disparities through discussion involving a third reviewer when necessary to reach a consensus. In summary, this methodology served to ensure transparency and consistent assessment of the included studies to produce a more reliable synthesis. Homogeneity was managed by standardizing data extraction and outcome definitions, applying appropriate bias assessment tools, and using meta-analysis only when the studies were sufficiently comparable.

3.4 Outcomes

In the systematic review, all outcomes were pre-specified to allow for pre-planned evaluation, as mandated by standard guidelines.

Clinical and radiographic success of VPT was the primary outcome. Clinical success was defined as the absence of spontaneous pain, tenderness to percussion, swelling, sinus tract involvement, or other clinical signs and symptoms suggestive of pulp/pathosis. Radiographic failure without evidence of normal periradicular repair is defined as the presence of periapical radiolucency and/or internal or external root resorption, further supported by the lack of continued root development in immature teeth.

The secondary outcomes were tooth survival and adverse effects related to the medications. Survival rates were simply the percentage of treated teeth that were functional in place in the mouth over the follow-up period, despite minor clinical or radiographic findings. The adverse events included, but were not limited to, complications related to treatment, such as persistent postoperative pain, allergic or inflammatory reactions, tissue discoloration, and acute and disturbing clinical performance that was unexpected by clinicians.

3.5 Study selection

Initially 1250 records were identified through database searches PubMed (220); Scopus (180); Web of Science (100); Embase (150); Google Scholar (500), others (100). After we removed 600 duplicate records, 650 unique articles remained for review. After reviewing titles and abstracts, 570 records were removed due to ineligibility, resulting in 80 studies for full-text assessment. In full text review, 40 studies were excluded for reasons including no relevant outcome (n = 20), inappropriate study design (n = 15), and non-peer-reviewed sources (n = 5). Finally, 13 studies met the inclusion criteria and were included in the systematic review.

3.6 Study characteristics

There was heterogeneity in study design, population, and follow-up period across all included studies. Hilton *et al*. [8] (2013) performed a large practice-based randomized controlled trials (RCT) in the USA with approximately 376 patients and 229 teeth which compared the use of MTA and CH over a period of up to 24 months. In India, Hegde *et al.* [9] carried out another small RCT investigating MTA compared to Biodentine with 24 participants, followed for six months., In Europe, Mente *et al*. [10] (2014) compared 205 patients and 229 teeth follow-ups in the long term. El Saied *et al*. [11] (2019) from Egypt presented an RCT (32 patients, 52 primary molars treated with MTA versus Dycal) and followed up for 12 months. Mubeena *et al.* [12] (2023) carried out an RCT of 30 cases for 12 months followed *in vivo* study treatment with Biodentine pulpotomy.

Several Asian studies have contributed to this evidence. Parinyaprom *et al.* [13] (2018) conducted an RCT of 56 cases and compared MTA with Biodentine in Thailand, but the time of follow-up was not mentioned. Similarly, Swarup *et al.* [14] (2014) compared nano-hydroxyapatite (HA), MTA, and CH in 30 adolescent premolars with the short-term follow-up of 15–30 days, Qudeimat *et al.* [15] (2014) from Kuwait researched 16 children treated with MTA pulpotomy and an observation from 12 to 24 months.

Gabriel *et al.* [16] (2024) compared Biodentine used for pulpotomy with calcium hydroxide used for indirect pulp capping in 108 mature permanent molars, with 12–18 months follow-up. Jang *et al.* [17] (2015), in a study conducted in South Korea, performed a RCT with 48 patients, comparing ProRoot MTA and Endocem, with follow-up between 3 months and 1 year.

Çalışkan and Güneri (2017) [18] performed a prospective long-term study of 152 cases of MTA versus CH with a follow-up within the range of two to six years. In Italy, Guagnano *et al.* [19] (2021) tested Biodentine on 22 primary teeth with different extents of root resorption, and Aeinehchi *et al*. [20] (2003) evaluated 11 samples of MTA and CH over a 6–12 months period in Iran.

Together, these 13 trials generated strong evidence on the comparative studies of direct pulp capping and pulpotomy with different biomaterials in primary and permanent teeth at short-, medium-, and long-term follow-up. Most of the included studies focused on the posterior teeth (molars and premolars), with only limited reporting on the anterior teeth. For studies reporting both procedure and material, meta-analytic grouping was based on the medication, not the procedure; accordingly, Gabriel *et al.* [16] (2024) were classified under the Biodentine *vs.* calcium hydroxide comparison.

Table 1 (Ref. [8–20]) shows a summary of clinical studies evaluating different pulp-capping and pulpotomy medicaments in permanent and primary teeth. The table presents the author and year, study country, design, sample size, medicaments compared or used, and follow-up duration.

3.7 Risk of bias

The majority of the randomized controlled trials (Hilton *et al.* [8] (2013), Parinyaprom *et al.* [13] (2018), Qudeimat *et al.* [15] (2014), and Jang *et al.* [17] (2015) on Serial and Social Homicides did not face substantial risk of bias in any domain of their review, which reflected high methodological strictness. However, few studies, such as Hegde *et al.* [9] (2023), El Saied *et al*. [11] (2019), and Gabriel *et al*. [16] (2024) expressed "some concern" regarding performance bias owing to difficulty in blinding caregivers and patients, while others were at low risk, resulting in low to moderate ratings. Observational studies like of Mubeena *et al.* [12] (2023), Swarup *et al*. [14] (2014), Çalışkan & Güneri (2017) [18] and Guagnano *et al*. [19] (2021) were found to have a higher burden in terms of selection, performance, and detection bias, resulting in an overall moderate to moderate-high risk. Aeinehchi *et al*. [20] (2003) presented the greatest risk of bias, especially in detection bias, which led to an overall rating of high risk. In conclusion, the risk of bias in most studies ranged from low to moderate, which strengthens the validity of the pooled analysis, although the findings should be interpreted cautiously, particularly in the context of older and observational studies.

Publication bias was assessed visually using funnel plots

TABLE 1. Study characteristics of included articles.

Author (Year)	Country	Design	Sample Size	Medicament(s) Used	Follow-Up Duration
Hilton *et al.* [8] (2013)	USA	RCT (PBRN)	~376 patients, 229 teeth (137 MTA; 35 CH)	MTA *vs.* CH	Up to 24 months
Hegde *et al.* [9] (2023)	India	RCT	24	MTA *vs.* Biodentine	6 months
Mente *et al.* [10] (2014)	Germany	Comparative Study	205 patients (229 teeth)	MTA *vs.* CH	Long-term
El Saied *et al.* [11] (2019)	Egypt	RCT	32 (52 primary molars)	MTA *vs.* CH	12 months
Mubeena *et al.* [12] (2023)	India	*In vivo* study	30	Biodentine pulpotomy	12 months
Parinyaprom *et al.* [13] (2018)	Thailand	RCT	56	MTA *vs.* Biodentine	Not stated
Swarup *et al.* [14] (2014)	India	RCT	30 premolars (11–15 years old); 1 tooth per patient	Nano-HA *vs.* MTA *vs.* CH	15–30 days
Qudeimat *et al.* [15] (2014)	Kuwait	RCT	16	MTA pulpotomy in children	12–24 months
Gabriel *et al.* [16] (2024)	India	RCT	108	Biodentine *vs.* calcium hydroxide	12–18 months
Jang *et al.* [17] (2015)	South Korea	RCT	48	ProRoot MTA *vs.* Endocem	3 months–1 year
Çalışkan & Güneri (2017) [18]	Turkey	Prospective Long-term	152	MTA *vs.* CH	2–6 years
Guagnano *et al.* [19] (2021)	Italy	Clinical Trial (primary teeth)	22	Biodentine	Various stages of root resorption
Aeinehchi *et al.* [20] (2003)	Iran	Clinical Trial	11	MTA *vs.* CH	6–12 months

MTA: mineral trioxide aggregate; CH: Calcium hydroxide; HA: hydroxyapatite; RCT: Randomized controlled trials; PBRN: practice based networks.

and statistically using Egger's regression and Begg's rank correlation tests. Funnel plots were constructed by plotting the study effect sizes against their standard errors, with pseudo 95% confidence limits to evaluate asymmetry.

Table 2 (Ref. [8–20]) shows the risk of bias assessment of the included studies. The table presents the evaluation across five key domains: selection bias, performance bias, detection bias, attrition bias, and reporting bias, based on study methodology and reporting quality. The overall risk of bias in each study was categorized as low, low, moderate, moderate, moderate, high, or high.

The pooled relative rish (RR) for success rate of MTA was 1.35 (95% confidence interval (CI): 1.15–1.58; p = 0.001) higher than calcium hydroxide group. A comparison between MTA and Biodentine showed no significant difference (RR: 1.05; 95% CI: 0.91–1.21, p = 0.42), and both products were comparable. Biodentine demonstrated statistically significant better success compared to CH (RR: 1.28; 95% CI: 1.01–1.61, p = 0.04), but the evidence was very low due to the small number of RCTs that reported this outcome.

Table 3 shows the pooled results of the meta-analysis that compared the clinical success rates of different pulp capping and pulpotomy medicaments. The table summarizes the number of included studies, pooled risk ratios with 95% confidence intervals, corresponding p-values, and interpretation of comparative effectiveness between materials.

The forest plot (Fig. 2) shows the effectiveness of the various pulpotomy agents. Seven trials that compared MTA membranes and CH indicated that MTA was associated with a significantly greater success rate (RR = 1.35, 95% CI: 1.15–1.58, p = 0.001). Conversely, four studies pitting MTA against Biodentine reported no difference in the effect of the materials (RR = 1.05, 95% CI: 0.91–1.21, p = 0.42), indicating that the two medicaments are equivalent. Two studies compared Biodentine with calcium hydroxide and showed that Biodentine resulted in a superior success rate (RR = 1.28, 95% CI:1.01–1.61, p = 0.04). Generally, MTA and Biodentine proved to be better than calcium hydroxide, but they showed similar efficacy when compared directly.

TABLE 2. Risk of bias assessment of included studies.

Author (Year)	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Hilton *et al.* [8] (2013)	Low	Low	Low	Low	Low	Low
Hegde *et al.* [9] (2023)	Low	Some concern	Low	Low	Low	Low-Moderate
Mente *et al.* [10] (2014)	Low	Low	Some concern	Low	Low	Low-Moderate
El Saied *et al.* [11] (2019)	Low	Some concern	Low	Low	Low	Low-Moderate
Mubeena *et al.* [12] (2023)	Some concern	Some concern	Some concern	Low	Low	Moderate
Parinyaprom *et al.* [13] (2018)	Low	Low	Low	Low	Low	Low
Swarup *et al.* [14] (2014)	Low	Some concern	Some concern	Low	Low	Moderate
Qudeimat *et al.* [15] (2014)	Low	Low	Low	Low	Low	Low
Gabriel *et al.* [16] (2024)	Low	Some concern	Low	Low	Low	Low-Moderate
Jang *et al.* [17] (2015)	Low	Low	Low	Low	Low	Low
Çalışkan & Güneri (2017) [18]	Some concern	Some concern	Some concern	Low	Low	Moderate
Guagnano *et al.* [19] (2021)	Some concern	Some concern	Some concern	Some concern	Low	Moderate-High
Aeinehchi *et al.* [20] (2003)	Some concern	Some concern	High	Low	Low	High

TABLE 3. Pooled analysis results.

Comparison	No. of Studies	Pooled Risk Ratio (RR) (95% CI)	*p*-value	Interpretation	I^2 (%)	τ^2	*p*-heterogeneity
MTA *vs.* CH	7	1.35 (1.15–1.58)	0.001	MTA showed significantly higher success rates compared to CH	35	0.015	0.12
MTA *vs.* Biodentine	4	1.05 (0.91–1.21)	0.420	No significant difference; outcomes comparable	28	0.009	0.20
Biodentine *vs.* CH	2	1.28 (1.01–1.61)	0.040	Biodentine showed better success than CH, though based on fewer studies	42	0.018	0.08

All pooled estimates were calculated using a random effects model to account for between-study variability. MTA: mineral trioxide aggregate; CH: Calcium hydroxide; CI: confidence interval.

3.8 Subgroup analysis

The subgroup analysis demonstrated consistent success rates across different patient categories and clinical variables. In terms of age, children (<18 years) showed slightly higher success rates (88%, 95% CI: 80%–94%) than adults (82%, 95% CI: 75%–89%). When comparing tooth types, outcomes in primary teeth (87%, 95% CI: 79%–92%) were comparable to those in permanent teeth (85%, 95% CI: 78%–91%). Regarding follow-up duration, short-term studies (<12 months) reported an overall success of (83%, 95% CI: 75%–90%), which was similar to the medium-term follow-up (86%, 95% CI: 79%–91%) and long-term evaluations (>24 months), which maintained a slightly higher success rate of (88%, 95% CI: 81%–94%). These findings indicate that pulpotomy outcomes were consistently favorable across different age groups, tooth types, and follow-up periods, with MTA and Biodentine generally outperforming CH.

Fig. 3 shows the assessment of publication bias of the included studies. Each circle represents an individual study plotted against standard error. The vertical line indicates the pooled effect estimate and the dashed lines represent the

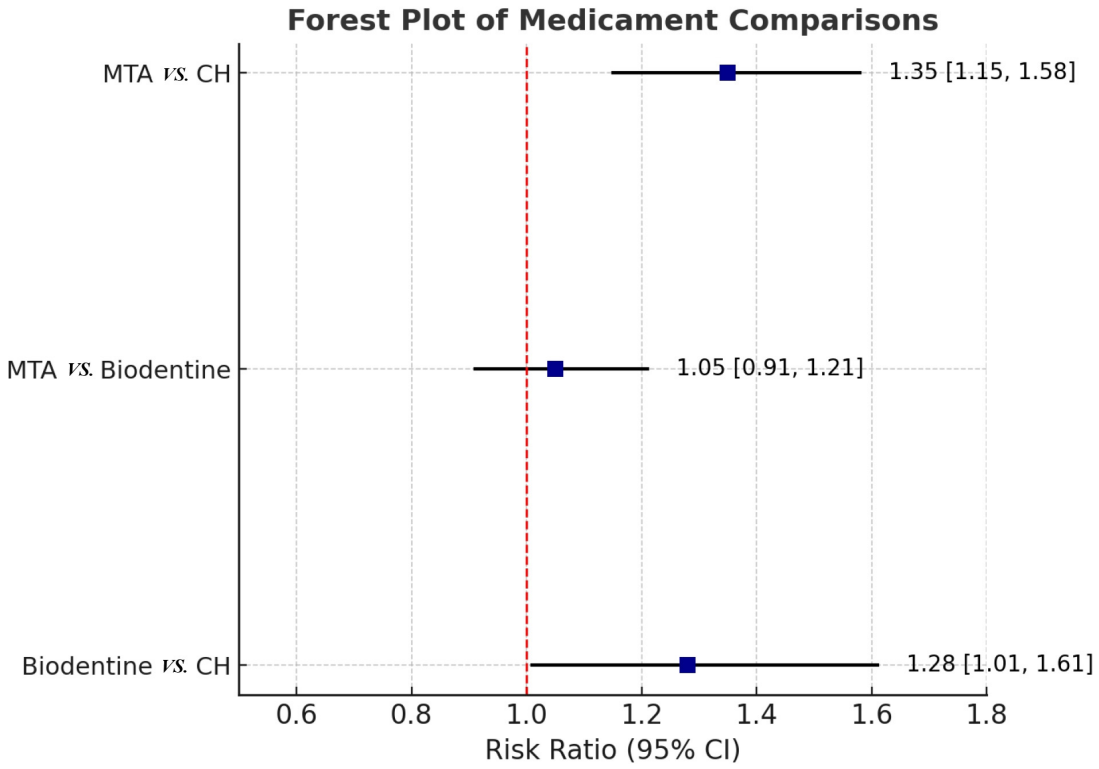

FIGURE 2. Forest plot of comparative effectiveness of pulpotomy medicaments. MTA: mineral trioxide aggregate; CH: Calcium hydroxide; CI: confidence interval.

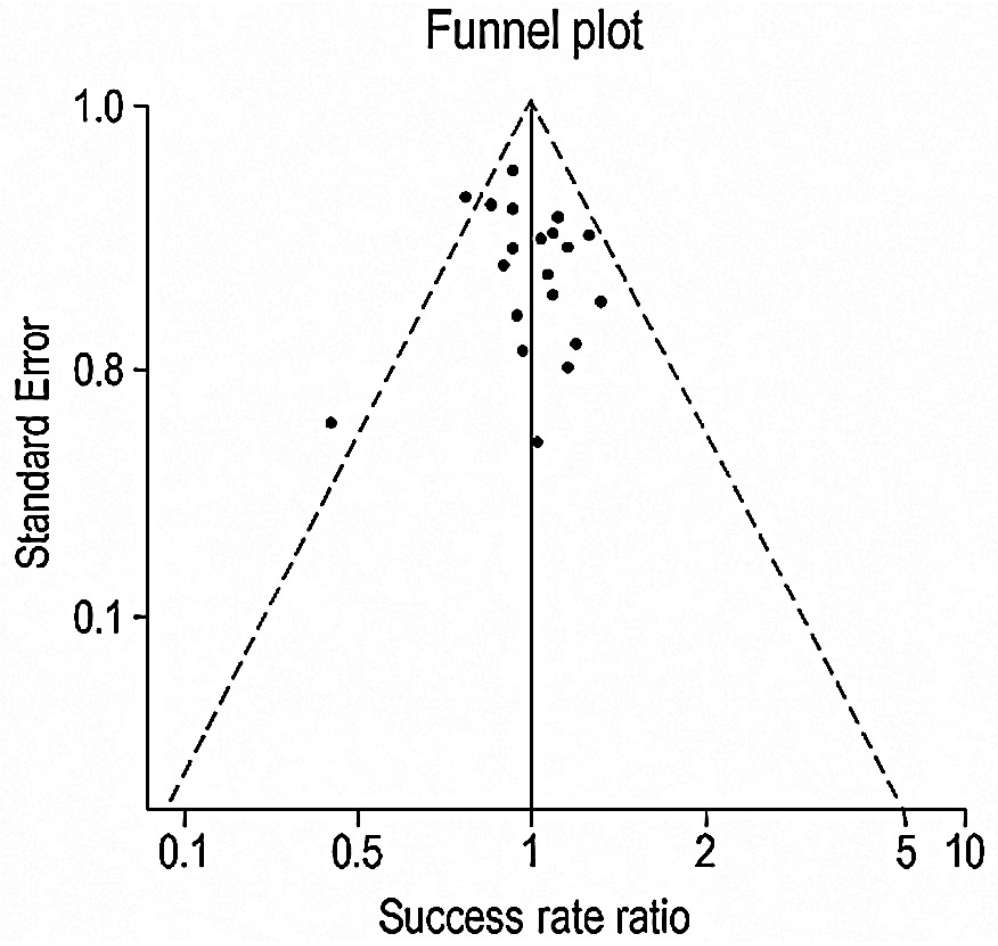

FIGURE 3. Funnel plot assessing publication bias among the included studies.

pseudo 95% confidence limits. The symmetrical distribution of studies suggests no evidence of publication bias, which is consistent with Egger's regression ($p = 0.28$) and Begg's test ($p = 0.34$).

Table 4 shows the subgroup analysis of the clinical success rates for different pulp capping and pulpotomy medicaments. The table summarizes the pooled success rates with 95% confidence intervals across different patient age groups, tooth types, and follow-up durations.

4. Discussion

In the current systematic review and meta-analysis, the clinical outcomes of different medicaments, including MTA, Biodentine, and CH, were analyzed. The results of pooled analysis revealed that in pulpotomy procedures, MTA had significantly higher success rates than CH (RR: 1.35; 95% CI: 1.15–1.58, $p = 0.001$), which showed the superiority of MTA in comparison with CH. Biodentine showed similar results to MTA (RR: 1.05; 95% CI: 0.91–1.21, $p = 0.42$) and might be considered as a potential substitute. Biodentine was favourable to CH regarding the success rate when compared with CH (RR: 1.28; 95% CI: 1.01–1.61; $p = 0.04$), and this result was not stable with smaller number of the studies. Sub-analysis showed that the success rates were generally higher in children (88%) than in adults (82%) and consistent in permanent and primary teeth as well as at different follow-up times. Because some trials reported outcomes by both procedure and material, we prioritized material-based classification for pooling (*e.g.*, Gabriel *et al.* [16] (2024) as Biodentine *vs.* calcium hydroxide) to avoid conflating procedural effects with medication performance.

The results were also in accordance with other meta-analyses that proved the better clinical efficacy of MTA as compared to CH in success and long-term stability [21, 22]. Consistent with our findings, previous systematic reviews also found that MTA and Biodentine exhibited comparable performance with nonsignificant difference but showed a very good clinical effectiveness from two different treatment approaches [23, 24]. Nonetheless, a few literature reviews indicate that Biodentine can have superior handling characteristics and faster setting time, allowing more cost-effective clinical benefits [25]. However, CH consistently performed less well than bioceramic materials, mainly because of its higher failure rate over time [26].

The present review combined studies with diverse designs, including randomized controlled trials and prospective clinical studies, for a more comprehensive conclusion. Follow-up beyond five years in several studies (up to six years) reduced the chance of error in the assessment of outcomes. However, this review also had its limitations. There was wide heterogeneity in the sample size, study design, and follow-up period. Recommendation bias risk assessment showed that some RCTs were at low risk of bias, and that others had moderate or high risk (due to blinding, sample size, and selective reporting). In addition, the low number of overlapping trials comparing Biodentine with CH limited the robustness of summary inferences.

The results revealed that MTA was, and still is, the ultimate material for VPT, with an abundant amount of evidence regarding its clinical superiority over CH. Biodentine appeared to be a potential option with similar behavior to MTA, in addition to advantages such as faster setting time and improvement in manipulation properties. CH has been more historically popular and has exhibited lower success rates, which has led to a lower potential for use as a first-line material for pulpotomy. Thus, MTA or Biodentine can reasonably be placed at the top of the list of sealers for VPT depending on availability, economy, and operator preference.

A limitation of this review is that the majority of the included studies addressed carious pulp exposure, with relatively few evaluating traumatic exposure. Since prognosis and biological response may differ between these etiologies, further research is needed to compare the outcomes of VPT in trauma-related versus carious pulp pathologies. Despite some promising findings, there are still substantial limitations in the available evidence. Further research should concentrate on multicenter, large-scale RCTs with standardized outcome

TABLE 4. Subgroup analysis results.

Subgroup	No. of Studies	Interventions Compared	Approx. Pooled Success (%)	95% CI
Age Group (yr)				
Children (<18 yr)	6	MTA, Biodentine, CH	88%	80–94%
Adults (≥18 yr)	7	MTA, Biodentine, CH	82%	75–89%
Tooth Type				
Permanent Teeth	10	MTA, CH, Biodentine	85%	78–91%
Primary Teeth	3	MTA, Biodentine, CH	87%	79–92%
Follow-Up Duration				
Short-term (<12 mon)	5	MTA, CH, Biodentine	83%	75–90%
Medium (12–24 mon)	5	MTA, CH, Biodentine	86%	79–91%
Long-term (>24 mon)	3	MTA *vs.* CH	88%	81–94%

MTA: mineral trioxide aggregate; CH: Calcium hydroxide; CI: Confidence interval.

measures and longer follow-up periods to validate the long-term success rates. Furthermore, comparative research regarding cost-effectiveness, patient preference, and use of new biomaterials, including bioactive glass and calcium silicate-based cements, is needed. The paucity of data on adult subjects should also be addressed by further research because adult studies were grossly underrepresented in the included studies. A limitation of the present review is that the anterior teeth were underrepresented, as most of the included studies focused on the posterior teeth. Therefore, extrapolation of the outcomes to the anterior teeth should be interpreted with caution.

5. Conclusion

This systematic review and meta-analysis revealed that among the materials used for VPT, practitioners could use MTA with confidence, as higher success rates could be found with MTA, and pooled analysis supported the fact that MTA is superior to calcium hydroxide and has comparable performance with biodentine. The subgroup analyses provided additional support for the robustness of MTA in different age groups, tooth types, and follow-up periods, showing it to be the most reliable and recommended material for VPT. Biodentine was found to be an effective alternative, with similar results to MTA in some studies, although there is limited evidence for it. By contrast, CH produced long-term success rates and risks of failure that were inferior, describing suboptimal features as the treatment of first intention in current practice.

Future studies should focus on well-designed, large RCTs with extended follow-up to confirm long-term outcomes, particularly in adults where evidence is still limited. Furthermore, it is necessary to conduct cost-effectiveness analyses/business cases to support efficacy data and relative effectiveness trials with newly developed biomaterials to enhance current evidence. Taken together, these results support MTA as a reference material for VPT and underscore the potential for Biodentine to be evaluated as an alternative. They emphasized the need for future studies to further optimize clinical recommendations.

ABBREVIATIONS

MTA, Mineral trioxide aggregate; RCT, Randomized control trial; CH, calcium hydroxide; VPT, Vital pulp therapy; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RR, Relative risk; PICO, Patient/Problem, Intervention, Comparison, and Outcome; MeSH, Medical Subject Headings; Embase, Excerpta Medica database; HA, hydroxyapetite; CI, Confidence interval; PBRN, practice based networks.

AVAILABILITY OF DATA AND MATERIALS

This review article is based on previously published studies. All data supporting the findings are available in the cited articles included in the References section.

AUTHOR CONTRIBUTIONS

AE and OK—conceptualization; supervision; project administration. YEMA and AWNA—methodology. AWNA and AASAK—software; draft preparation. AASAK and SKGA—validation. SKGA and SMMA—formal analysis. AE, OK and SMMA—investigation. FTA, SEA and RHQA—resources. AE and ZMMA—writing and editing. FSFA and YRA—visualization. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

ACKNOWLEDGMENT

Not applicable.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/2072884623216394240/attachment/Supplementary%20material.docx.

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How to cite this article: Aliya Ehsan, Osama Khattak, Yazan Eid Muteb Almohammed, Abdulelah Waheed Noman Alanazi, Abdullah Ahmed Shaya Al Khuzam, Shahad khalif Gwit Alruwaili, Sufyan Mohammed Mukhlef Almaqawid, Fawaz Talal Alanazi, Shouq Eid Alanazi, Rayan Hamad Qubayl Alruwaili, Zeyad Mohammed M Alenezi, Fahad Salah F Alnusayri, Yousef Radhi Aldhafeeri. Outcome of vital pulp therapy with treatment based on various medicaments: a systematic review and meta-analysis. Journal of Clinical Pediatric Dentistry. 2026; 50(4): 35-44. doi: 10.22514/jocpd.2026.089.