Vital Pulp Therapy Using Resin-Modified Calcium Silicate for Permanent Teeth with Reversible Pulpitis: A Systematic Review

Vikri Sandya Dhika[1], dr. Veriantara Satya Dhika[2]

[1]*Department of Conservative Dentistry, Guntur Hospital*
[2]*Master's Program in Hospital Administration, Universitas Esa Unggul*

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Correspondance : drg. Vikri Sandya Dhika

E-mail : vikrisandya@gmail.com

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Abstract

Background:

Resin-modified calcium silicate (RMCS) cements combine the bioactivity of traditional calcium silicates with the superior handling properties of resins. This systematic review and meta-analysis evaluate the clinical and radiographic success of RMCS compared to established capping materials in permanent teeth diagnosed with reversible pulpitis.

Methods:

Following PRISMA 2020 guidelines, comprehensive searches were conducted across PubMed, EMBASE, Scopus, and Web of Science from inception through April 11, 2026. We included randomized controlled trials assessing vital pulp therapy (indirect and direct pulp capping) using RMCS against active comparators (calcium hydroxide, Biodentine) with at least six months of follow-up. Risk ratios were pooled utilizing the inverse variance method with a DerSimonian-Laird random-effects model.

Result:

Six randomized controlled trials met the criteria for quantitative synthesis. Pooled data indicated that RMCS materials demonstrated robust overall clinical and radiographic success rates across diverse vital pulp therapy procedures at 12- to 36-month follow-ups. Subgroup analyses revealed that while RMCS performed equivalently to calcium hydroxide in indirect pulp capping, it exhibited slightly varied success rates when compared to pure calcium silicate cements like Biodentine during direct pulp capping, though statistical heterogeneity was observed across these subsets.

Conclusions:

RMCS serves as a highly effective and clinically pragmatic biomaterial for vital pulp therapy in teeth with reversible pulpitis. While providing excellent outcomes for indirect treatments, clinicians should weigh subtle performance differences against pure calcium silicates when managing direct pulp exposures.

Introduction

The dental pulp is a highly vascularized and innervated connective tissue encased within a rigid dentinal chamber, rendering it uniquely vulnerable to bacterial invasion through carious lesions yet simultaneously endowed with remarkable regenerative capacity.[1,2] Reversible pulpitis represents a

critical clinical juncture at which timely and appropriate intervention can preserve pulp vitality and forestall progression to irreversible pulpitis, necrosis, and periapical disease. Epidemiologically, deep carious lesions approximating or exposing the pulp account for a substantial proportion of endodontic referrals globally, with estimates suggesting that caries affects approximately 2.5 billion permanent teeth worldwide, and that pulpal involvement occurs in a significant subset of untreated or late-presenting cases.[3] Historically, calcium hydroxide [$Ca(OH)_2$] served as the gold standard pulp-capping agent by virtue of its high alkaline pH, antibacterial properties, and capacity to stimulate reparative dentin bridge formation; however, its long-term clinical performance has been undermined by progressive material dissolution, tunnel defect formation within the dentin bridge, and absence of adhesion to dentin, leading to microleakage and recurrent pulpal inflammation over time.[3-5] These limitations prompted the development of calcium silicate-based cements, beginning with mineral trioxide aggregate (MTA), which demonstrated superior biocompatibility, hermetic sealing, and predictable hard tissue induction, albeit with drawbacks including prolonged setting time, handling difficulty, and high material cost.[6,7]

Resin-modified calcium silicate cements (RMCS) emerged as a clinically pragmatic evolution of this material class, combining the bioactive ion-releasing properties of tricalcium silicate with the immediate light-cured setting and enhanced handling characteristics of resin-based systems.[8] These materials release calcium and hydroxyl ions upon contact with dentinal fluid, inducing hydroxyapatite deposition, stimulating odontoblastic differentiation, and facilitating tertiary reparative dentin formation at the pulp–material interface.[8] Despite growing clinical adoption of RMCS materials, the evidence base comparing their performance against established alternatives in permanent teeth with reversible pulpitis has remained fragmented across heterogeneous study designs, variable follow-up periods, and inconsistent outcome definitions, limiting evidence-based clinical guidance. Several trials have now generated comparative data across IPC, IPT, and DPC contexts, creating an opportunity for systematic synthesis. Therefore, the objective of this systematic review and meta-analysis was to evaluate the clinical and radiographic success of vital pulp therapy using resin-modified calcium silicate cements compared to other capping materials in permanent teeth diagnosed with reversible pulpitis, with the aim of providing clinicians with evidence-based guidance for material selection in everyday restorative and endodontic practice.

Materials and Method

Study Design and Registration

This systematic review and meta-analysis was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines.[9] The review protocol was prospectively registered prior to data extraction.

Eligibility Criteria

Studies were eligible for inclusion if they were randomized controlled trials (RCTs) enrolling patients with permanent teeth diagnosed with reversible pulpitis undergoing vital pulp therapy (IPC, IPT, or DPC) using a resin-modified calcium silicate cement as the intervention material, with at least one active comparator group, and reporting clinical and/or radiographic success outcomes at a minimum follow-up of six months. Studies were excluded if they involved primary or deciduous teeth only, if the RMCS material was used solely as a liner or base rather than as the primary pulp-capping agent, if teeth were diagnosed with irreversible pulpitis or pulp necrosis without separable subgroup data, if the full text was unavailable, or if the study design was a case report, case series, in vitro study, animal study, or narrative review.

Search Strategy and Information Sources

A systematic electronic search was conducted across four databases, which are PubMed, EMBASE, Scopus, and Web of

Science. We did the study search from inception through 11 April 2026, with no language restrictions applied. The search strategy combined Medical Subject Headings (MeSH) and free-text terms relating to the population (reversible pulpitis, permanent teeth, deep carious lesion), intervention (resin-modified calcium silicate, TheraCal LC, TheraCal PT, light-cured tricalcium silicate), comparators (calcium hydroxide, Biodentine, MTA, RMGIC), and outcomes (vital pulp therapy, pulp capping, clinical success, radiographic success). Reference lists of all included studies and relevant reviews were hand-searched to identify additional eligible records.

Study Selection

Records retrieved from the database search were imported into reference management software, and duplicates were removed. All authors independently screened titles and abstracts against the eligibility criteria, followed by full-text assessment of all potentially eligible reports. All discrepancies at both the screening and full-text stages were resolved through discussion among all authors until consensus was reached.

Data Extraction

All reviewers independently extracted data using a pre-piloted standardized extraction form. Extracted items included study identifiers, country of origin, study design, sample size, patient age range, tooth type and apex maturity, pulp diagnosis criteria, procedure type (IPC, IPT, DPC), intervention and comparator materials, follow-up duration, number of successes and total teeth analyzed per group, success criteria definitions, and blinding status. Discrepancies were resolved through discussion.

Risk of Bias Assessment

Risk of bias in individual RCTs was assessed using the Cochrane Risk of Bias tool version 2 (RoB 2), evaluating five domains: bias arising from the randomization process (D1), bias due to deviations from intended intervention (D2), bias due to missing outcome data (D3), bias in measurement of the outcome (D4), and bias in selection of the reported result (D5). Each domain was rated as low risk, some concerns, or high risk, with an overall judgment derived accordingly. All assessments were performed independently by all reviewers, with disagreements resolved through discussion.

Statistical Analysis

Meta-analysis was performed for studies flagged as eligible for pooling. The effect measure was the risk ratio (RR) for clinical and radiographic success, calculated from event counts (successes) and totals per arm using the escalc function with measure = "RR" in the metafor package (version 4.4-0) in R (version 4.3.3). Pooled estimates were computed under a random-effects model using the DerSimonian-Laird estimator for between-study variance (τ^2), with Wald-type 95% confidence intervals. Statistical heterogeneity was quantified using the I^2 statistic and Cochran's Q test. Pre-specified subgroups were defined by procedure type and comparator material: Subgroup A (IPC/IPT vs $Ca(OH)_2$), Subgroup B (IPC/IPT vs Biodentine), Subgroup C (DPC vs Biodentine at 12 months), Subgroup D (DPC vs $Ca(OH)_2$ at 12 months), and Subgroup C-ext (DPC vs Biodentine at 36 months). Subgroup differences were tested using the χ^2 test. A sensitivity analysis excluding studies involving young permanent teeth with open apices (Rahman & Goswami, 2021) was conducted to assess robustness of results in mature dentition. Leave-one-out analysis was performed to evaluate the influence of individual studies on the overall pooled estimate. Studies with unique comparators or flagged with high risk of bias were excluded from pooling and synthesized narratively.

Results

Study Selection

A systematic database search yielded 720 records (PubMed n=231, EMBASE n=204, Scopus n=177, Web of Science n=108). After removing 31 duplicates, 689

records were screened by title and abstract, of which 667 were excluded. All 22 reports sought were successfully retrieved. Full-text assessment led to exclusion of 16 reports: irreversible pulpitis or pulp necrosis (n=7), primary/deciduous teeth only (n=3), and RMCS used as liner/base rather than pulp-capping agent (n=6). Six studies were ultimately included (Figure 1).[10-15]

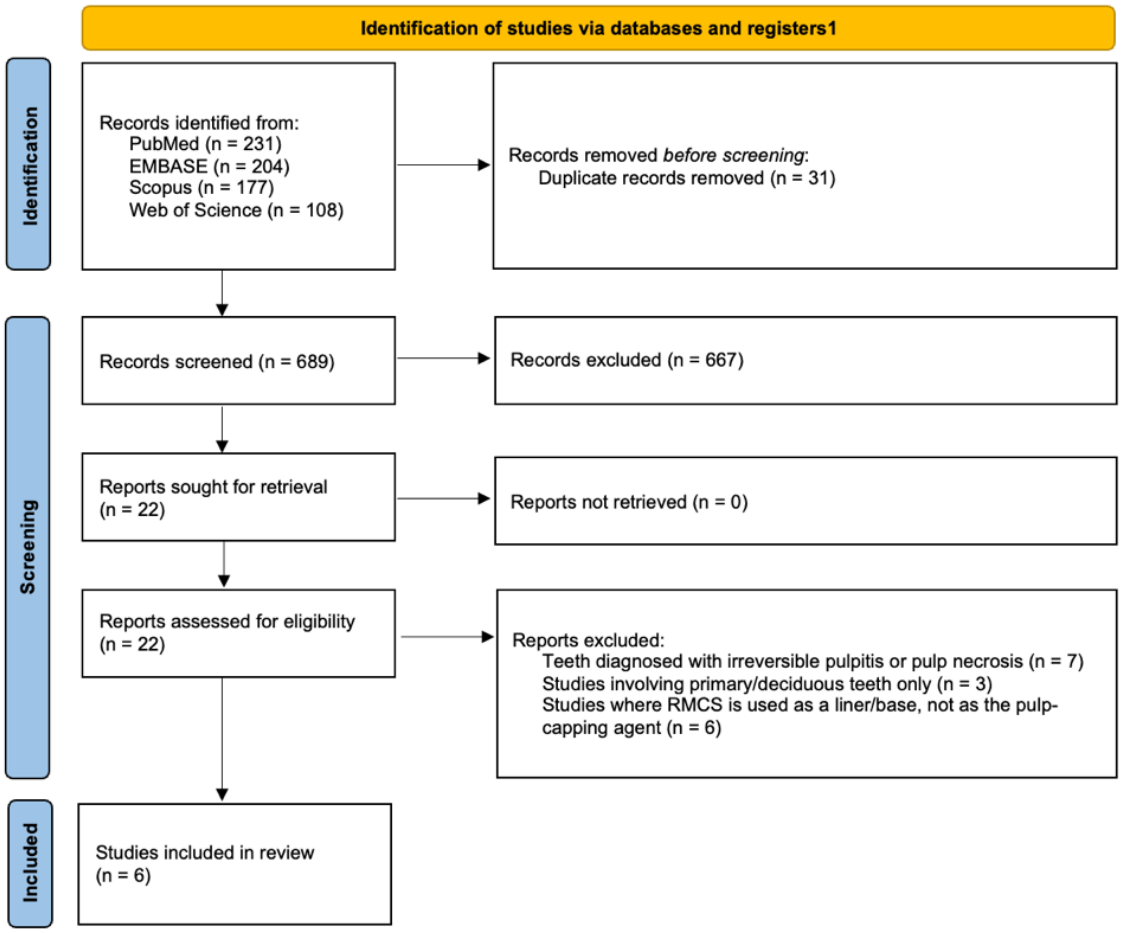

Figure 1. PRISMA flow diagram.

The six included studies comprised 550 teeth across four countries (Turkey, India, China, USA), with follow-up ranging from 6 to 36 months. Patient age ranged from 7 to 62 years. Reversible pulpitis represents a state of transient, stimulus-dependent pulp inflammation without irreversible tissue damage, and is the diagnostic threshold that defines eligibility for vital pulp therapy. Clinically, it is characterized by provoked short-duration pain that resolves promptly following removal of the thermal or chemical stimulus, absence of spontaneous or lingering pain, negative response to percussion and palpation, and a positive vitality response on cold and electric pulp testing. Radiographically, the periodontal ligament space and lamina dura are intact, with no periapical pathology or internal or external root resorption. Across the six studies included in this review, diagnosis was operationalized with substantial consistency: Peskersoy et al. (2021) required absence of spontaneous pain and positive vitality;[12] Rahman & Goswami (2021) specified cold sensitivity and pain on mastication in teeth with ICDAS 5–6 caries and open apices;[13] Yavuz et al. (2025) required absence of spontaneous or long-lasting pain, negative percussion, and healthy lamina dura and PDL space;[14] Deshmukh et al. (2024) defined reversible pulpitis as stimulus-only pain without lingering, confirmed by normal cold and electric pulp test responses;[10] and Zhang et

al. (2024) required confirmed vitality on radiograph with no spontaneous pain.[15]

The distinction between reversible and irreversible pulpitis carries direct therapeutic implications because it determines whether a biologically conservative approach is defensible. In reversible pulpitis, the superficial inflammatory infiltrate is predominantly confined to the pulp–dentin complex beneath the carious lesion, leaving deeper pulp tissue histologically normal or only mildly reactive, and thus capable of healing once the bacterial load is eliminated and a biocompatible capping material is applied. This repair potential is the biological rationale for deploying RMCS materials in this clinical context: the calcium and hydroxyl ions released at the pulp interface stimulate residual odontoblasts and undifferentiated mesenchymal cells to undergo mineralization, ultimately depositing a reparative dentin bridge that permanently seals the exposure. It is, however, important to note that clinical diagnosis of reversible pulpitis remains imprecise. Ricucci et al. have demonstrated that a proportion of teeth clinically diagnosed as reversible pulpitis exhibit histological features of irreversible disease, underscoring the significance of intraoperative assessment of pulp tissue quality, bleeding character, and hemostasis time as adjunct diagnostic indicators. Zhang et al. (2024) specifically acknowledged this limitation in their protocol by adapting the VPT procedure type based on direct microscopic evaluation of pulp tissue appearance and achievement of hemostasis within five minutes, reflecting the growing consensus that procedural decision-making in VPT should be guided by the intraoperative pulp status rather than preoperative diagnosis alone.[15]

Table 1. Demographic and baseline characteristics of included studies

Author (Year)	Country	Total Teeth (N)	Age Range (years)	Tooth Type	Pulp Diagnosis (Pre-op)	Blinding Status
Peskersoy et al. (2021)	Turkey	105 teeth (n = 35 per group)	18–62	Permanent mandibular & maxillary molars (deep Class II caries; fully matured apex)	Reversible pulpitis (no spontaneous pain; negative percussion/palpation; positive vitality test)	Investigator blinded; Operator NOT blinded; Patient blinded to group
Rahman & Goswami (2021)	India	60 teeth total (n = 20 per group; 54 analysed at 24 m)	7–15 (mean 12.36 ± 2.28)	Young permanent molars (open apices; ICDAS 5,6,7); Maxillary dominant (67%)	Deep dentinal caries approaching pulp WITHOUT pulp exposure; sensitivity to cold and air indication	Operator NOT blinded; Patient blinded; Outcome assessor blinded
Zhang et al. (2024)	China	115 randomised; 106 analysed (60 TheraCal LC; 52 iRoot BP Plus)	Range NR (Mean ± SD: TH: 26.5 ± 3.5; RP: 25.8 ± 4.5; mean age ≈ 26 yrs)	Permanent teeth (mature & immature); Molars dominant; Reversible AND irreversible pulpitis	Reversible pulpitis (short-duration provoked pain) AND irreversible pulpitis (spontaneous or lingering pain); NO necrosis	Operator NOT blinded (distinct materials); Patient NR; Outcome assessor blinded to same degree (AP² & radiograph read by 2 endodontists)
Deshmukh et al. (2024)	India	40 teeth total (n = 20 per group; RMGIC: 14 at 6m; TheraCal LC: 17 at 6m)	15–43 (mean age: 28 years)	Permanent 1st and 2nd maxillary/mandibular molars; mature apex only (immature teeth excluded)	Reversible pulpitis (pain only during stimulus application; normal response to cold/EPT; caries involving 2/3 dentin; no periapical changes)	Operator NOT blinded; Patient NOT blinded (informed about procedure); Outcome assessor NR (likely not blinded)
Yavuz et al. (2025)	Turkey	140 teeth total (Dycal: 48; Biodentine: 48; TheraCal PT: 67; 127 analysed)	17–48 (mean: Dycal 37; Biodentine 32; TheraCal PT: 33)	Premolar and molar permanent teeth; deep caries/decay (ICDAS 5–6); mature teeth	Deep dentinal caries; no spontaneous/provoked long-lasting pain; negative percussion/palpation; positive vitality test; healthy lamina dura and PDL space; no root resorption	Operator NOT blinded; Clinical evaluator (IGK) blinded to treatment allocation; Patient NR
Serrano-Clavijo et al. (2024)	USA	90 teeth total (n = 30 per group)	NR (adult patients; university clinic)	Permanent teeth with deep carious lesions (no pulp exposure after excavation)	No pulp exposure; vitality confirmed (radiograph required); no spontaneous pain; IPC indication	Operator NOT blinded; Outcome assessor blinded; Patient NR

Risk of Bias

Assessment using the Cochrane RoB 2 tool indicated that three studies (Peskersoy et al., 2021; Deshmukh et al., 2024; Serrano-Clavijo et al., 2024) were rated low overall risk, while the remaining three (Rahman & Goswami, 2021; Zhang et al., 2024; Yavuz et al., 2025) were rated some concerns, primarily arising from the randomisation process (D1) or deviation from intended intervention domains (D2) (Figure 2). No study was rated high risk overall, with the exception of Deshmukh et al. (2024), which carried high attrition (39% in the RMGIC arm) at 6 months and was therefore excluded from pooled analysis.

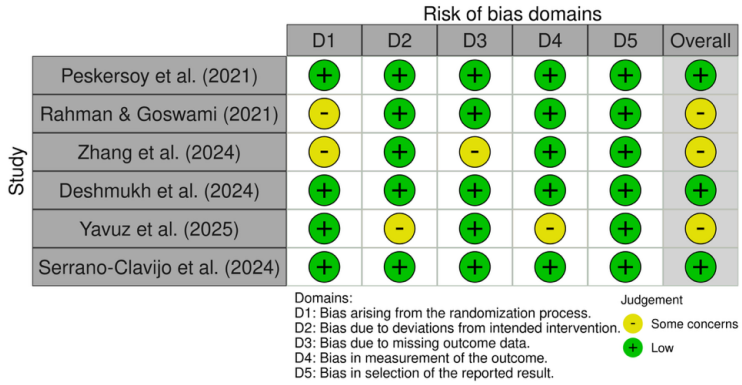

Figure 2. Cochrane RoB version 2.

Meta-analysis

The overall pooled risk ratio was RR = 0.98 [95% CI: 0.92–1.04] with moderate heterogeneity (I^2 = 33.5%, τ^2 = 0.0031, p = 0.1398) and a non-significant test for subgroup differences (χ^2 = 3.26, df = 4, p = 0.52). By subgroup, IPC/IPT vs $Ca(OH)_2$ yielded RR = 1.03 [95% CI: 0.89–1.19] (I^2 = 58.8%, 3 studies); IPC/IPT vs Biodentine yielded RR = 1.02 [95% CI: 0.92–1.13] (I^2 = 12.3%, 2 studies); DPC vs Biodentine at 12 months yielded RR = 0.81 [95% CI: 0.59–1.11] (I^2 = 65.3%, 2 studies); DPC vs $Ca(OH)_2$ at 12 months yielded RR = 1.00 [95% CI: 0.86–1.17] (I^2 = 0%, 2 studies); and DPC vs Biodentine at 36 months yielded RR = 0.92 [95% CI: 0.79–1.07] (single study). Leave-one-out analysis confirmed stability of the pooled estimate across all omissions (range: RR 0.96–0.98), with no single study exerting undue influence (Figure 3).

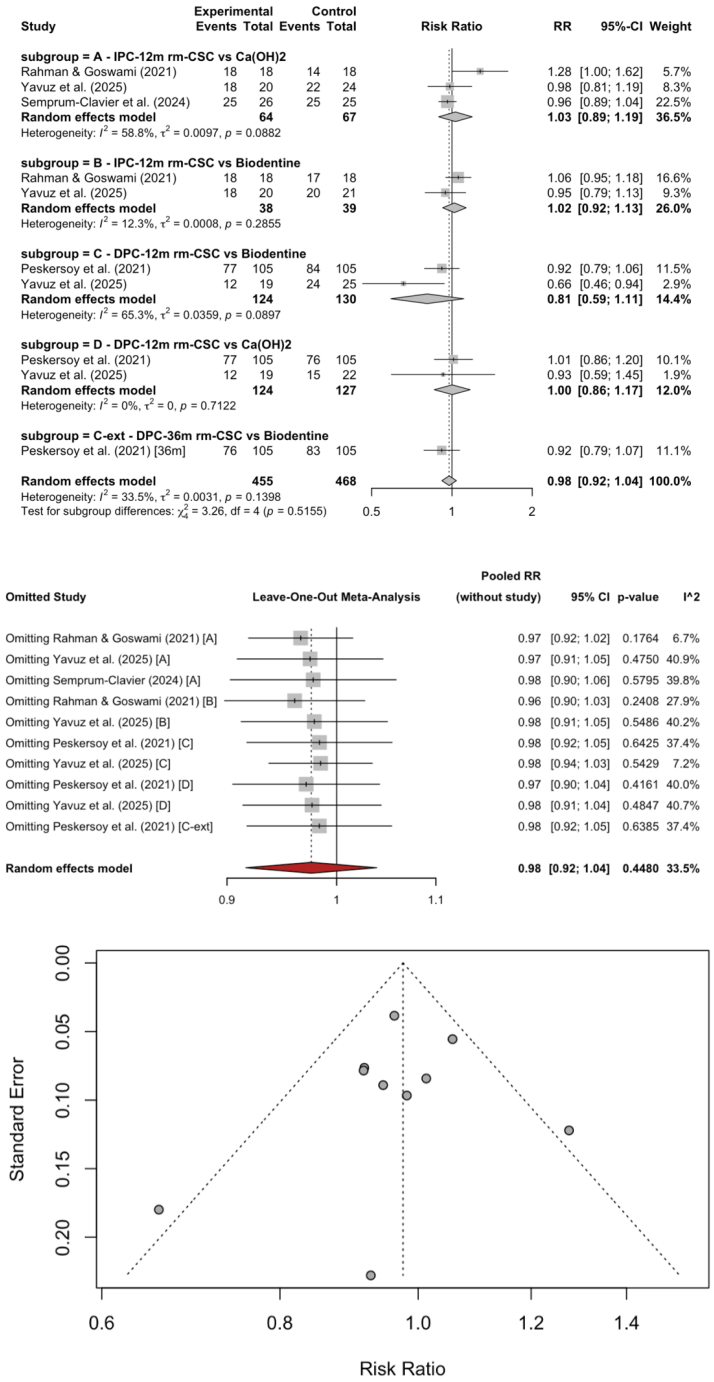

Figure 3. Meta-analysis for clinical/radiographic success rate.

Discussion

The findings of this systematic review and meta-analysis demonstrate that resin-modified calcium silicate cements perform comparably to established pulp-capping materials when used for vital pulp therapy in permanent teeth with reversible pulpitis, yielding an overall pooled RR of 0.98 [95% CI: 0.92–1.04] that is statistically indistinguishable from unity. In reversible pulpitis, the inflammatory infiltrate remains superficial and largely confined to the odontoblastic and subodontoblastic layers immediately subjacent to the carious lesion, while deeper pulp tissue retains a normal cellular architecture with viable undifferentiated mesenchymal cells capable of odontoblastic differentiation and reparative dentin deposition.[16,17] RMCS materials promote this healing cascade through the sustained release of calcium and hydroxyl ions upon hydration, raising

the local pH to levels that favour hydroxyapatite nucleation, activate dentinal matrix-bound growth factors such as TGF-β1 and BMP-7, and create the alkaline microenvironment necessary for tertiary dentin bridge formation at the exposure site.[18] The immediate light-cured polymerization of TheraCal LC further reduces the window of pulpal irritation during setting which may partly explain the lower postoperative pain scores reported by Zhang et al. (2024) in the TheraCal LC arm relative to iRoot BP Plus.[15]

A clinically important pattern emerged when outcomes were stratified by procedure type. In the IPC and IPT subgroups, rm-CSC performed consistently well relative to both $Ca(OH)_2$ (RR = 1.03 [0.89–1.19]) and Biodentine (RR = 1.02 [0.92–1.13]), with low to moderate heterogeneity. In IPC and IPT, the pulp is not directly exposed, and a residual dentin barrier remains interposed between the capping material and the pulp proper, attenuating direct cytotoxic contact and providing an additional buffer against the resin monomer leaching that has been implicated in the cytotoxic potential of light-cured RMCS formulations in vitro.[19] In contrast, for DPC, where the material is applied directly onto vital pulp tissue following carious exposure, the subgroup comparing rm-CSC against Biodentine at 12 months yielded RR = 0.81 [0.59–1.11] with substantial heterogeneity (I^2 = 65.3%), largely driven by the low success rate observed in the TheraCal PT DPC arm of Yavuz et al. (2025) (63.2%).[14] This may reflect the susceptibility of directly exposed pulp tissue to polymerization shrinkage-induced marginal gaps at the material–dentin interface, which can permit bacterial reinfiltration into the pulp chamber.[20-22] Biodentine, as a purely hydraulic calcium silicate without resin content, does not undergo polymerization shrinkage and additionally possesses anti-inflammatory properties mediated through its effects on pulp cell signalling, potentially explaining its more favourable DPC performance across the included studies.[23]

Heterogeneity was moderate at the overall level (I^2 = 33.5%) and markedly variable across subgroups, ranging from 0% in the DPC vs $Ca(OH)_2$ subgroup to 65.3% in the DPC vs Biodentine subgroup, reflecting the clinical and methodological diversity inherent in the included trials. Sources of heterogeneity include differences in RMCS formulation as well as variation in patient age and apex maturity, success criteria definitions, follow-up duration, operator blinding, and restoration type applied over the capping material. Notably, the coronal restoration placed over the pulp-capping agent has been consistently identified in the literature as a primary determinant of long-term VPT success, as loss of the coronal seal exposes the capped pulp to salivary microorganisms regardless of the material used at the interface; this variable was not uniformly controlled or reported across included studies.[24] The leave-one-out analysis confirmed that no single study was responsible for the pooled estimate, and the sensitivity analysis restricted to mature permanent teeth yielded directionally consistent results, supporting the robustness of the overall findings despite these sources of variability.

Study limitation

This review is subject to several limitations that should be considered when interpreting its findings. First, the total number of eligible studies was small (n = 6), with only four contributing to any given subgroup, limiting statistical power and the reliability of heterogeneity estimates. Second, all included studies were assessed as having at least some concerns on the RoB 2 tool, primarily due to lack of operator blinding and concerns regarding allocation concealment or attrition. Third, follow-up periods were heterogeneous, ranging from six to 36 months, and the longest available evidence is a single study at 36 months; the time-dependent decline in VPT success rates observed in the literature suggests that the current pooled estimates may overstate long-term performance.[25] Fourth, two studies were excluded from pooling due to unique comparators (iRoot BP Plus; RMGIC) and methodological concerns,

precluding a more comprehensive quantitative synthesis.

Clinical applicability

The results of this review support the clinical use of resin-modified calcium silicate cements as viable alternatives to conventional calcium hydroxide and broadly equivalent to Biodentine for IPC and IPT in permanent teeth with reversible pulpitis, offering the practical advantage of immediate light-cured setting that eliminates the need for a separate appointment and reduces the risk of interim contamination.[26] For DPC, however, the variable success rates observed with TheraCal PT in the direct exposure context suggest that purely hydraulic calcium silicates may be preferable when direct pulp contact is anticipated, especially in mature permanent teeth where the pulp's regenerative capacity is more limited than in younger patients. Clinicians should also recognise that success in VPT is not solely a function of material selection: adequate caries removal, strict rubber dam isolation, meticulous haemostasis confirmed within five minutes of pulp exposure, and the quality of the definitive coronal restoration are independent determinants of outcome that must be optimised irrespective of the capping agent employed.[27] Until longer-term RCT data are available, clinical decision-making regarding RMCS use in DPC should be made on an individual basis, weighing the procedural convenience of light-cured materials against the established biocompatibility profile of purely hydraulic alternatives.

Conclusion

This systematic review and meta-analysis demonstrates that vital pulp therapy using resin-modified calcium silicate cements yields clinical and radiographic success rates statistically comparable to calcium hydroxide and Biodentine in permanent teeth with reversible pulpitis, with an overall pooled RR of 0.98 [95% CI: 0.92–1.04]. RMCS materials performed consistently well in IPC and IPT across all comparator subgroups, while their performance in DPC showed greater variability and numerically lower success rates compared to purely hydraulic calcium silicates. The available evidence is limited by small study numbers, short to medium follow-up periods, and moderate risk of bias across included trials; larger, longer-term RCTs with standardised outcome definitions are needed to consolidate these findings and provide definitive guidance on RMCS use in the direct pulp-capping context.

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(**Vikri Sandya Dhika**)