EFFICACY OF VARIOUS VITAL PULP TREATMENT PROCEDURES IN MANAGING CARIOUS PULP EXPOSURE IN PERMANENT TEETH WITH IRREVERSIBLE PULPITIS: A SYSTEMATIC REVIEW

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ABSTRACT

This systematic review aimed to evaluate the outcomes of vital pulp treatments, including direct pulp capping, partial pulpotomy, and full pulpotomy in permanent teeth with irreversible pulpitis. A comprehensive literature search was performed using PubMed, the Cochrane database, and Scopus, complemented by a manual search. The risk of bias was assessed. The pooled success rates were calculated for each vital pulp treatment procedure. Overall, among thirteen included studies, full pulpotomy showed more effective than the other vital pulp treatment procedure. Prior to the clinical recommendation, randomized clinical trials with long-term follow-up comparing the outcomes of different vital pulp treatments on teeth with carious pulp exposure is needed. Additionally, calcium silicate-based cement demonstrated greater success than calcium hydroxide in vital pulp treatment.

Keywords:

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INTRODUCTION

Historically, root canal treatment was recommended for vital permanent teeth with carious pulp exposure or teeth diagnosed as irreversible pulpitis. However, histological studies have shown that dental caries do not invariably lead to complete pulp necrosis. The extent and severity of pulpal inflammation are influenced by the degree of carious progression and severity (Ricucci et al., 2014). Localized pulpal inflammation and partial pulp necrosis have occasionally been observed beneath the site of pulp exposure (Ricucci et al., 2014). Consequently, by removing pulp irritants and the severely inflamed pulp, it is often possible to preserve the remaining pulp tissue, which can retain its vitality and function (Dunchan, 2022).

Vital pulp treatments for teeth with carious pulp exposure including direct pulp capping, partial pulpotomy, and full pulpotomy, each involving different extents of pulp tissue removal. However, the literature remains inconclusive regarding which of these vital pulp treatment techniques provides the most effective outcomes for managing carious pulp exposure in vital permanent teeth (Jakovljevic et al., 2023).

The success of vital pulp treatment is influenced by the choice of pulp-dressing materials. Calcium hydroxide has long been used in vital pulp therapy, but its use has been associated with several drawbacks, including high solubility in oral fluids, the formation of tunnel defects in tertiary dentine, and inadequate adhesion, which can potentially lead to treatment failure (Hanna et al., 2020). In the early 1990s, calcium silicate-based cements were introduced as alternative pulp-dressing material for vital pulp treatment, and numerous clinical studies have reported promising outcomes with these materials (Davaie et al., 2021). Nonetheless, further clarification is needed regarding which material provides the most favorable results for vital pulp treatment.

Clinical decision-making should be based on the best available evidence (Kranke, 2010). Systematic reviews, which compile studies and data in a systematic and unbiased manner and evaluate them using appropriate statistical methods, represent the highest level of evidence (Higgins et al., 2022). To date, many systematic reviews have assessed the outcomes of vital pulp treatment by comparing different pulp-dressing materials, but few have compared the effectiveness of various vital pulp treatment procedures (Sabeti et al., 2021; Sila et al., 2023; Alsubait et al., 2021; Cushley et al., 2021; Chen et al., 2019). Recently, Jakovljevic and colleagues conducted a qualitative synthesis of the effectiveness of vital pulp treatments for teeth with carious pulp exposure and showed that no conclusion could be drawn on which treatment procedure yields the most successful outcomes (Jakovljevic et al., 2023).

The purpose of this study was to conduct a systematic review to evaluate the success rates of vital pulp treatments—namely direct pulp capping, partial pulpotomy, and full pulpotomy—in vital permanent teeth with carious pulp exposure diagnosed as irreversible pulpitis.

RESEARCH METHODOLOGY

Protocol and Registration

The protocol of this systematic review was registered with the PROSPERO database (CRD42023445319) and the review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

PICO Question

The focused research question was formulated according to the PICO (Population, Intervention, Comparison, Outcome) principle: "For vital permanent teeth with carious pulp exposure diagnosed as irreversible pulpitis (P), which vital pulp treatment procedure namely pulpotomy (partial/full) (I) and direct pulp capping (C) provides the highest success rate (O)?"

Literature Search

The search strategy was developed based on the PICO principle and adapted for each database as follows: (irreversible OR pulpitis OR pulp disease OR dental caries OR deep caries OR deep

carious lesion) AND (permanent teeth OR permanent tooth OR molar OR premolar OR posterior OR anterior) AND (vital pulp therapy OR treatment OR VPT OR direct OR pulpotomy OR pulp capping) AND (outcome OR prognosis OR success rate OR survival rate OR effectiveness) NOT (primary teeth OR primary tooth OR deciduous OR animal)
Three authors conducted independent searches for studies across PubMed, the Cochrane Database, and Scopus. Additionally, manual searches were performed by examining reference lists from the included studies and other related research. No restrictions were applied regarding language or publication date. The search was conducted up to August 2023.

Study Selection and Data collection

Three authors independently screened studies by reviewing titles, abstracts, and full texts according to the inclusion criteria. Studies that did not meet these criteria were excluded. Any discrepancies were resolved through discussion among the authors.
Inclusion criteria
1) Original clinical studies evaluating vital pulp treatment procedures, including direct pulp capping, partial pulpotomy, and full pulpotomy, in human permanent teeth with carious pulp exposure diagnosed as irreversible pulpitis.
2) Treatment outcomes were assessed through both clinical and radiographic examinations.
3) Success rates were reported or could be calculated from the provided raw data.
4) A minimum follow-up period of 3 months was required.
The authors systematically collected and recorded data from the included studies, including the following details: authorship, title, publication year, eligibility criteria, participant characteristics, sample size, intervention and control groups, type of pulp-dressing material used, methods of outcome evaluation, follow-up period, and success rates.

Quality assessment and Risk of bias

The Cochrane risk of bias tool for randomized trials (RoB 2) was employed to assess the risk of bias in randomized controlled trials. This tool evaluates studies across seven domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases. Each domain was rated as high, unclear, or low risk. An overall high risk of bias was assigned if at least one domain was rated as high risk. An overall unclear risk of bias was assigned if at least one domain was rated as unclear risk without any high-risk domains. An overall low risk of bias was assigned if all domains were rated as low risk (Higgins et al., 2011).
The risk of bias in non-randomized studies of interventions (ROBINS-I) tool was used to evaluate the risk of bias in non-randomized studies. This tool assesses seven domains: bias due to confounding, bias in the selection of participants into the study, bias in classification of interventions, bias due to deviations from intended interventions, bias due to missing data, bias in measurement of outcomes, and bias in the selection of reported results. Each domain was rated as critical, serious, moderate, low risk, or no information. An overall risk of bias was categorized as critical if at least one domain was rated as critical risk, serious if at least one domain was rated as serious risk without any critical risk, moderate if all domains were rated as moderate or low risk, and low if all domains were rated as low risk (Sterne et al., 2016; McGuinness et al., 2020). Any discrepancies in the assessment were resolved through discussion.

Data synthesis and analysis

The pooled success rates and 95% confidence intervals (CIs) for each treatment—direct pulp capping, partial pulpotomy, and full pulpotomy—were calculated across three follow-up periods: less than 1 year, 1-2 years, and 3-5 years, using the DerSimonian-Laird method. Additionally, the pooled success rates and 95% CIs for each pulp-dressing material—calcium hydroxide, Mineral Trioxide Aggregate (MTA), Biodentine, calcium-enriched mixture (CEM), and TotalFill—were calculated. Statistical analyses were performed using R version 4.3.2.

RESEARCH RESULTS

The electronic and additional hand searches identified a total of 1,626 studies. Of these, 17 studies met the inclusion criteria comprising 13 randomized controlled trials and 4 clinical studies and were included in the subsequent analysis. The study selection process is illustrated in Figure 1. A summary of the included studies is presented in Tables 1. The total number of teeth analyzed was 1,798 teeth. The treatments comprised 96 teeth with direct pulp capping, 269 with partial pulpotomy, and 1,433 with full pulpotomy. The follow-up period was extended up to 5 years. Patient ages ranged from 6 to 75 years.

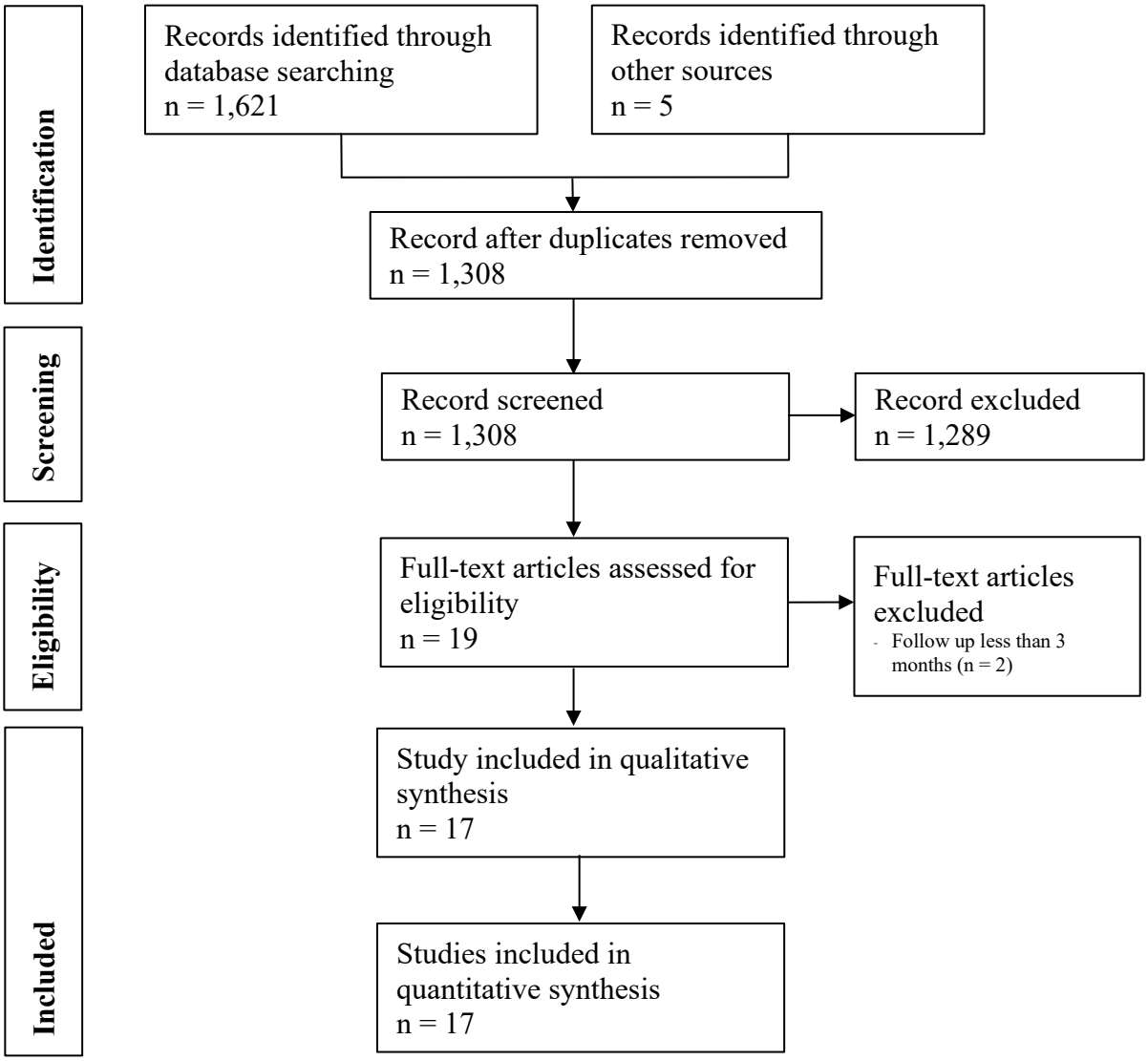

Figure 1 Study selection flowchart

Table 1 Characteristics of the included studies

Studies	Study design	Age range (years)	Sample (n)	Treatment	Material	Follow-up (months)
Asgary S, 2010	Randomized controlled trials	9-65	178	Full pulpotomy	CEM	6
			184	Root canal treatment	Root canal filling material	
Asgary S, 2013	Randomized controlled trials	9-65	167	Full pulpotomy	CEM	12
			179	Full pulpotomy	MTA	
Asgary S, 2013	Randomized controlled trials	9-65	167	Full pulpotomy	CEM	6, 12
			175	Root canal treatment	Root canal filling material	
Asgary S, 2014	Randomized controlled trials	9-65	166	Full pulpotomy	CEM	24
			166	Root canal treatment	Root canal filling material	
Asgary S, 2015	Randomized controlled trials	9-65	137	Full pulpotomy	CEM	60
			134	Root canal treatment	Root canal filling material	
Qudeimat MA, 2017	Prospective, Single arm	7.6-13.6	23	Full pulpotomy	MTA	3, 6, 12
Taha NA, 2017	Prospective, Single arm	10-59	52	Full pulpotomy	MTA	3, 6, 12, 24, 36
Taha NA, 2017	Randomized controlled trials	20-59	26	Partial pulpotomy	MTA	6, 12, 24
			23	Partial pulpotomy	CH	
Taha NA, 2018	Prospective, Single arm	19-69	64	Full pulpotomy	Biodentine	6, 12
Taha NA, 2018	Prospective, Single arm	9-17	20	Full pulpotomy	Biodentine	6, 12
Asgary S, 2018	Randomized controlled trials	12-75	73	Direct Pulp capping	CEM	3, 12
			76	Partial Pulpotomy	CEM	
			69	Full pulpotomy	CEM	
Parinyaprom N, 2018	Randomized controlled trials	6-18	11	Direct pulp capping	Biodentine	6-56
			12	Direct pulp capping	MTA	

Studies	Study design	Age range (years)	Sample (n)	Treatment	Material	Follow-up (months)
Uesrichai N, 2019	Randomized controlled trials	6-18	37	Partial pulpotomy	MTA	36
			30	Partial pulpotomy	Biodentine	
Asgary S, 2021	Randomized controlled trials	14-60	51	Full pulpotomy	MTA	12
			47	Full pulpotomy	CEM	
Ramani A, 2022	Randomized controlled trials	18-40	49	Full pulpotomy	MTA	6, 12
			52	Partial pulpotomy	MTA	
Sharaan M, 2022	Randomized controlled trials	7-14	20	Full pulpotomy	CEM	3, 6, 12
			20	Full pulpotomy	MTA	
Jassal A, 2023	Randomized controlled trials	19.8-29.8	24	Full pulpotomy	Biodentine	12
			25	Partial pulpotomy	Biodentine	

The results of the quality and risk of bias assessments for the included studies are presented in Figures 2 and Figure 3. Among the 13 randomized controlled trials, 4 studies were classified as low risk of bias (Asgary et al.,2013; Asgary et al.,2014; Asgary et al.,2015; Asgary et al.,2013), 6 studies were classified as unclear risk (Asgary et al., 2010; Asgary et al., 2022; Parinyaprom et al. 2018; Ramani et al., 2022; Asgary et al., 2018; Taha et al., 2017), and 3 studies were classified as high risk (Jassal et al., 2023; Sharaan et al., 2022; Uesrichai et al., 2019). For the 4 non-randomized studies, all were rated as moderate risk of bias (Taha et al., 2017; Qudeimat et al., 2017; Taha et al., 2018; Taha et al., 2018).

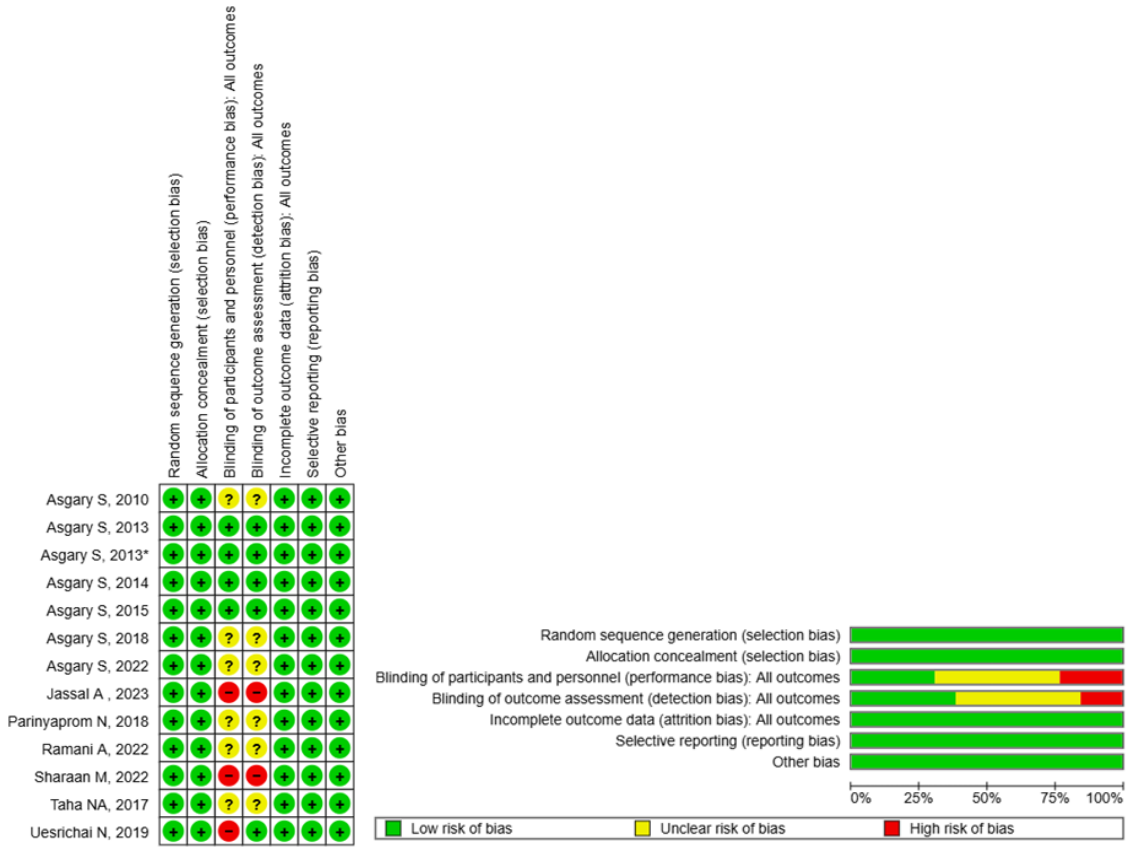

Figure 2 Risk of bias summary and graph for the randomized controlled trials studies.

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Taha NA, 2017	Low	Moderate	No information	Low	Low	Moderate	Low	Moderate
Qudeimat MA, 2017	Low	Moderate	No information	Low	Low	Low	Low	Moderate
Taha NA, 2018	Low	Moderate	No information	Low	Low	Low	Low	Moderate
Taha NA, 2018*	Low	Moderate	No information	Low	Low	Low	Low	Moderate

Figure 3 Risk of bias summary for the non-randomized studies.

The pooled success rates for each treatment are detailed in Table 2. The overall pooled success rates for each treatment ranged from 79.0% to 90.6%, with full pulpotomy demonstrating the highest success rate.

Table 2 Pooled success rate of the various vital pulp treatment procedures.

Follow-up period	**Less than 1 year**		**1-2 years**		**3-5 years**		**Total**	
Treatment	**Success rate (%)**	**95% CI**	**Success rate (%)**	**95% CI**	**Success rate (%)**	**95% CI**	**Success rate (%)**	**95% CI**
Direct Pulp capping	88.5	82.1-94.9	79.2^{G}	71.1-87.3	95.7	87.4-100.0	87.8	80.2-94.1
Partial Pulpotomy	78.5^{F}	71.3-85.7	68.8^{H}	63.1-74.5	89.8	82.5-97.0	79.0^{I}	72.3-85.8
Full pulpotomy	94.9^{F}	93.2-96.7	94.9^{GH}	93.6-96.1	82.1	76.7-87.6	90.6^{I}	87.8-93.5
Total	**87.3**	**82.2-92.4**	**81.0**	**75.9-86.0**	**89.2**	**82.2-94.9**	**85.8**	**80.1-91.1**

The same subscript letters in the same columns indicate a significant difference in the success rate between treatment procedures.

The pooled success rates for various pulp-dressing materials used in vital pulp treatment ranged from 55.5% to 96.0%, as shown in Table 3. Regardless of the treatment procedures, calcium hydroxide was associated with lower success rates compared to calcium silicate-based cements.

Table 3 Pooled success rate of the various materials used in vital pulp treatment procedures

Material	Success rate (%)	95% CI
CH	55.5^{ABC}	38.4-72.6
MTA	92.3^{A}	84.5-98.4
Biodentine	96.0^{BD}	91.7-99.9
CEM	80.2^{CD}	73.2-87.3

The same subscript letters in the same columns indicate a significant difference in the success rate between treatment procedures.

DISCUSSION & CONCLUSION

Current systematic reviews on vital pulp treatment primarily focus on comparing the outcomes of different pulp-dressing materials for direct pulp capping, partial pulpotomy, and full pulpotomy in carious-exposed permanent teeth [8-12] (Sebeti et al., 2021; Silva et al., 2023; Alsubait et al., 2021; Cushley et al., 2021; Chen et al.,2019). Recently, a systematic review with qualitative data synthesis investigating the effectiveness of various vital pulp treatments in permanent teeth with carious pulp exposure showed that there was no conclusion on which procedure providing the most successful outcomes (Jakovljevic et al., 2023). To address this gap, our study collected data from published clinical studies and conducted quantitative analyses to determine which treatment procedure provides the most successful outcomes for teeth with irreversible pulpitis.

The pulpal diagnosis in the included studies was based on the diagnostic terminology recommended by the American Association of Endodontists (Bjørndal et al., 2010). Teeth with irreversible pulpitis typically presented with prolonged and spontaneous pain (Bjørndal et al., 2010). Only studies that included both clinical and radiographic examinations in their evaluation process were considered for analysis. Clinical success was defined as functional teeth with no clinical symptoms, whereas teeth that developed or exhibited persistent apical radiographic pathology were classified as failures. Only those teeth that demonstrated both clinical and radiographic success were categorized as successful. Conversely, teeth showing any clinical or radiographic failures were classified as failures. Studies using different evaluation criteria were excluded; for instance, using pulp vitality and hemostasis ability as success criteria (Bjørndal et al., 2010).

The quality assessment of the included studies, conducted using the Cochrane risk of bias tool for randomized trials (RoB 2) (Chen et al., 2019) and the Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) tool (Sterne et al., 2016; McGuinness et al., 2020), revealed the following risk classifications: 4 studies were identified as low risk (Asgary et al., 2013; Asgary et al., 2014; Asgary et al., 2015; Asgary et al., 2013), 4 studies as moderate risk (Taha et al., 2017; Qudeimat et al., 2017; Taha et al., 2018; Taha et al., 2018), 6 studies as unclear risk (Asgary et al., 2010; Asgary et al., 2022; Parinyaprom et al., 2018; Ramani et al., 2022; Asgary et al., 2018; Taha et al., 2017), and 3 studies as high risk (Jassal et al., 2023; Sharaan et al., 2022; Uesrichai et al., 2019). High risk of bias was assigned to studies where the treatment process could not be blinded to participants or the outcome assessment could not be blinded to researchers (Jassal et al., 2023; Sharaan et al., 2022; Uesrichai et al., 2019). Studies with unclear processes in blinding participants and outcome assessment were categorized as unclear risk (Asgary et al., 2010; Asgary et al., 2022; Parinyaprom et al., 2018;

Ramani et al., 2022; Asgary et al., 2018; Taha et al., 2017). All non-randomized studies were classified as moderate risk (Taha et al., 2017; Qudeimat et al., 2017; Taha et al., 2018; Taha et al., 2018). The available studies with low risk of bias that met the inclusion criteria were limited. Although the included studies may be subject to some risks of bias, such as the inability to blind the researcher, operators who performed the treatment due to each procedure was different in steps of treatment, and differences among the participants involved, moreover, the studies included in this analysis still represent the best available evidence. This underscores the need for more rigorously designed research to strengthen the evidence base in this field.

The pooled success rates for each treatment procedure in irreversible pulpitis teeth were 79.0% to 90.6%. These high success rates suggest that vital pulp treatment for vital permanent teeth with carious exposure should be considered a viable alternative to root canal treatment, as supported by the recommendations of the American Association of Endodontists and the European Society of Endodontology (Duncan et al., 2022; AAE, 2009).

Pulpal healing is achievable if the source of infection is addressed and the remaining pulp tissue is in a condition conducive to recovery. Overall, full pulpotomy demonstrated a higher success rate compared to partial pulpotomy in irreversible pulpitis teeth. Partial pulpotomy involves removing 1-3 mm of inflamed pulp tissue beneath the exposure site to reach healthy pulp. However, inflammation can sometimes extend beyond the area removed. In contrast, full pulpotomy, which involves the complete removal of coronal pulp tissue, offers a more predictable outcome by ensuring the thorough removal of inflamed pulp.

The success of vital pulp treatment is closely related to the accurate diagnosis of pulpal health. Histological studies have shown that teeth with clinical signs and symptoms of irreversible pulpitis may exhibit a range of conditions, including pulp necrosis, severely inflamed pulp, mildly infllamed pulp, and healthy pulp (Ricucci et al., 2014). Currently, there is no diagnostic tool available to precisely determine the status of the pulp, making it challenging to decide the extent of pulp tissue removal. In response to pulpitis, the pulp releases inflammatory mediators such as tumor necrosis factor-alpha (TNF-α) and various interleukins (e.g., IL-1β, IL-8, IL-4, IL-10) (Bjørndal et al., 2019). The quantity of these mediators correlates with the severity of the inflammation (Bjørndal et al., 2019). Certain biomarkers have shown potential in differentiating between healthy and inflamed pulp (El karim et al., 2021). Accurate identification of the relationship between these mediators and pulpal health could lead to the development of chairside diagnostic tools, facilitating immediate assessment of pulpal status.

Pulpal inflammation is crucial for pulpal healing. Low-grade and controlled inflammation can promote healing, whereas severe and uncontrolled inflammation often leads to pulp necrosis (Karrar et al., 2023). In dentistry, various materials are used to manage inflammation, including fluocinolone acetonide, glucocorticoids, and corticosteroids. These materials can reduce the accumulation of inflammatory cells at the site, inhibit inflammatory mediators such as tumor necrosis factor-alpha (TNF-α) and interleukins (IL-1, IL-2, IL-6, IL-12) (Shukla et al., 2019; Czock et al., 2005), and stimulate the formation of reparative dentin (Louwakul et al., 2021). In vital pulp treatment, applying corticosteroids to severely inflamed pulp may reduce inflammation and enhance the pulp's ability to heal (Shukla et al., 2019; Czock et al., 2005).

The optimal materials for vital pulp treatment have yet to be fully determined. This systematic review found that calcium silicate-based cements yielded significantly higher success rates compared to calcium hydroxide. Despite its widespread use as a pulp dressing material, calcium hydroxide has notable disadvantages, including tunnel defects in tertiary dentin, high solubility in oral fluids, and inadequate adhesion, which can contribute to treatment failure (Hanna et al., 2020). Calcium silicate-based cements have been developed to address these issues, offering enhanced physical and biological properties such as chemical stability, non-corrosiveness, alkaline pH, antimicrobial effects, and superior sealing ability (Davaie et al., 2021). Additionally, clinical studies have demonstrated that calcium silicate-based cements facilitate

more predictable dentin bridge formation compared to calcium hydroxide [54, 56] (Soliman et al., 2023; Leye et al., 2012). Consequently, calcium silicate-based cements should be considered the preferred pulp dressing materials for vital pulp treatment.

This systematic review has several limitations. There are limited randomized clinical trials comparing the outcomes of different vital pulp treatments for teeth with the same diagnosis. Most of the studies included in this review primarily focused on comparing different pulp dressing materials within the same treatment procedure, rather than assessing the efficacy of various treatment procedures against each other. Additionally, the data available across studies exhibited considerable heterogeneity such as materials used in treatment procedure, follow-up period, which precluded the performance of a meta-analysis to compare success rates among different vital pulp treatment procedures. Consequently, the reported pooled success rates are derived from the available data without direct comparisons of different treatments. Although a minimum 3-month follow-up was utilized in this study, longer-term follow-up data would greatly enhance the reliability of the success rate findings. However, conducting studies with extended follow-up is challenging due to many factors such as the lengthy duration required or participant loss to follow-up, which can limit data availability and result in fewer studies reporting long-term success outcomes. This should be emphasized as a limitation of this systematic review. To address these gaps, future research should include randomized controlled trials comparing different vital pulp treatment procedures for teeth with similar diagnoses, along with long-term follow-up, to provide more definitive conclusions.

In conclusion, vital pulp treatments, including direct pulp capping, partial pulpotomy, and full pulpotomy, should be considered as treatment for carious pulp exposure in vital permanent teeth with irreversible pulpitis. Calcium silicate-based cement is preferable to calcium hydroxide due to its superior properties and higher success rates. Prior to the clinical recommendation, randomized controlled trials studies with long term follow-up comparing the outcomes of different vital pulp treatments on irreversible pulpitis teeth with carious pulp exposure is needed.

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