Review article

Coronal pulpotomy for cariously exposed permanent posterior teeth with closed apices: A systematic review and meta-analysis

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\section*{ABSTRACT}

\textbf{Objectives:} This systematic review was performed to evaluate the clinical outcome of coronal pulpotomy treatment to manage carious vital pulp exposure in permanent posterior teeth with closed root apices. \textbf{Data/Sources:} PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline was used. A search of articles published between 1960 January and 2015 July was conducted in PubMed, EMBASE, and CENTRAL databases.

\textbf{Study selection:} Only studies that performed full coronal pulpotomy for carious vital pulp exposure of permanent posterior teeth and had clinical and radiographic assessments during at least one-year follow-up were qualified for data analyses. The weighted mean success rate (WSR) was the primary outcome and estimated using DerSimonian-Laird random effects model. Out of 299 articles, six studies were included for the analysis of one-year WSR, and five studies were included in the analysis of two-year WSR. The one-year and two-year WSR were 94\% (95\% confidence interval [CI]: [90,99\%]) and 92\% (CI: [84,100\%]) respectively. Differences in pulp capping and restoration materials did not significantly affect success rates (Two-year WSR in the MTA and MTA-like products group vs. the calcium hydroxide group: 92\% (CI: [85,99\%]) vs. 88\% (CI: [76,100\%]); the amalgam group vs. the composite group: 92\% (CI: [81,100\%]) vs. 93\% (CI: [81,100\%]).

\textbf{Conclusions:} Generally, full coronal pulpotomy had a favorable success rate in treating carious vital pulp exposure of permanent mature teeth with closed root apices. More studies with control group of root canal treated teeth and longer follow-up periods are needed.

\textbf{Clinical significance:} Coronal pulpotomy treatment can be considered as an intermediate treatment option in managing carious vital pulp exposures of permanent teeth with closed root apices. This option may also serve as a substitute to extraction when root canal treatment cannot be performed for low income and uninsured patients or in underserved areas.

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1. \textbf{Introduction}

In the dental practice, when an adult patient is diagnosed with symptomatic or asymptomatic irreversible pulpitis secondary to deep carious pulp involvement, the routine treatment of choice is root canal treatment (RCT), which consists of pulpectomy, followed by root canal therapy and placement of a permanent restoration. If affordable, RCT is the preferred treatment option because of its superior success rate to other treatments\textsuperscript{[1,2,3]}. If the patient cannot afford RCT, tooth extraction is the only alternative option to resolve the symptoms\textsuperscript{[2,3]}. However, there is another potential option that can be used to treat carious exposure of teeth with vital pulps, which is coronal pulpotomy treatment (CPT). This treatment option involves removing the entire coronal pulp tissue and keeping the remaining pulp vital in the canals.

With the current improved understanding of pulp tissue regeneration and the advancement of new materials and technical use, attention was given to study partial pulp tissue regeneration to maintain pulp vitality using minimal invasive endodontic therapies\textsuperscript{[2,3]}. CPT has been considered as a definitive treatment to manage carious pulp exposure for primary teeth, young immature
permanent teeth [4–6] as well as in treating traumatic pulp exposure in mature teeth [7]. It has been shown that the cariously exposed vital pulp has the ability to repair and heal and retain vital after removing the inflamed pulp tissue [8–10]. Histological and clinical studies also have shown that CPT can be used successfully to treat carious vital pulp exposure in mature teeth with closed root apices [2,10,11]. Compared to RCT, CPT is a less technique sensitive that can be performed by general dental practitioners, particularly for treating posterior permanent teeth. Hence, CPT may increase patients’ access to dental care and more clinicians would be able to provide this affordable procedure when the patient’s finances prohibit RCT, leaving only extraction as a treatment option.

In recent years, there have been a growing number of studies assessing clinical outcomes of CPT [4,6,12–14]. These studies have generally demonstrated promising clinical results of treating permanent teeth and the results are similar to these of pulpotomy treatments for primary teeth and young permanent teeth [5,15]. However, there is lack of reviews that systematically demonstrate the clinical outcomes of coronal pulpotomy in treating carious pulp exposure of mature permanent teeth. A recent systematic review has assessed several different methods of vital pulp therapies for mature and immature teeth such as direct pulp capping, partial pulpotomy, and coronal pulpotomy [5]. However, in that review [5], the included studies had different treatment therapies, inconsistent definition of success rate, the follow-up periods were pooled, as well as several duplicate articles were included in the review. The objective of the present systematic review is to specifically assess the success rate of coronal pulpotomy in treating carious vital pulp exposure in permanent posterior teeth with closed root apices in order to evaluate a potential alternative when RCT cannot be performed.

2. Methods

This systematic review was conducted by following PRISMA guideline principles [15].

2.1. Focused question

The focused question was proposed by following the PICO principle. PICO is defined as the Population, the Intervention (or exposure), the appropriate Control or Comparator, and the Outcomes of interest. “What is the success rate of full coronal pulpotomy in treating mature permanent posterior teeth with carious vital pulp exposure and what is the success rate of coronal pulpotomy treatment compared to the success rate of root canal treatment?”

2.2. Selection criteria

Articles that met the following criteria were qualified for final selection:

- Complete coronal pulpotomy procedure was conducted in permanent posterior teeth, which were fully erupted with closed root apices.
- The teeth included in these studies had carious pulp exposure without pulp necrosis (only teeth with vital pulps).
- The selected studies could be prospective or retrospective studies having at least ten patients and had at least a one-year follow-up period. Case reports, expert opinions or reviews were excluded.
- Radiographic findings and clinical success rate were reported in the studies.
- The articles were published in English.
- Studies that performed other procedures, including apexogenesis, direct or indirect pulp capping, partial pulpotomy, were excluded. Cases of pulp exposure caused by trauma were not included in the analysis.

2.3. Literature search

Electronic databases (PubMed, EMBASE and Cochrane Central Register of Controlled Trials (CENTRAL)) were searched using a combination of key search terms relevant to the research topic (in Supplementary information). Articles published between January 1960 and July 2015 were included in the screening process. In addition, the reference lists of selected articles were screened to find studies that might qualify for this review.

2.4. Quality assessment

Two quality assessment methods were utilized based on different study designs of included studies. The randomized controlled trial was assessed by Cochrane Collaboration’s tool [16]. “High risk of bias”, “Low risk of bias”, or “Unclear risk of bias” was assigned to each assessment item. The prospective or retrospective cohort studies were assessed by Newcastle–Ottawa scale (NOS) [17]. The total score ranging from 0 to 9 was assigned to each study (in Supplementary information). Furthermore, the evidence level of the study was provided following Oxford Centre for Evidence-Based Medicine recommendation (http://www.cebm.net/oxford-centre-evidence-based-medicine-levels-evidence-march-2009/)

[18]. The assessments were performed by two examiners (C.L, S.B) independently, and the inter-examiner agreement was analyzed by kappa coefficient. Any discrepancy in quality assessment was resolved via discussion.

2.5. Data extraction and analysis

After the authors had independently screened the titles and abstracts of articles, the full texts of qualified articles were then read and selected. Any disagreement was solved by authors (C.L, S.B, H.A). Data were extracted independently by two authors (C.L, HA) with a specially designed data extraction form. The accuracy of the extracted data was confirmed by another author (S.B).

The primary outcome in the included studies was success rate of CPT. Success was defined as no radiographic abnormality or clinical symptoms, such as spontaneous pain, tenderness to percussion or palpation, resolution (decrease in size or elimination) of an existing radiographic periapical lesion, and no need for further pulpotomy and RCT of the treated teeth [19]. The success rate of each selected study was calculated using success cases divided by total treated cases at the specific follow-up period. The variance of success rate was estimated by using Greenwood’s formula [20].

The weighted mean success rate (WSR) was estimated by the DerSimonian–Laird random effects model. The random effects model was conducted because the included studies had significant heterogeneity ($P$-value derived from heterogeneity chi-square was <0.05) caused by different study designs, use of different capping and restoration materials, and other variables [16]. The heterogeneity between different studies was also analyzed by $P$ statistic. The criteria defining degree of heterogeneity was modified from Cochrane Handbook: $P$ < 30%: acceptable heterogeneity, $P$ = 30–60%: moderate heterogeneity, $P$ > 60%: substantial heterogeneity [16]. The robustness of the results from the meta-analysis was assessed by sensitivity analysis. A meta-regression analysis was conducted to assess the relationship between success rates
and different variables to evaluate the primary outcome in different clinical conditions. Publication bias was estimated by Egger’s test. Statistical analyses were conducted using STATA (Stata Statistical Software, Version 12, 2009, Stata Corp, College Station, TX, USA). P-value <0.05 was considered as statistically significant. Confidence interval (CI) was stated at 95% level. If the estimated upper limit of 95% confidence interval was over 1.0, the upper limit was defined as 1.0.

3. Results

3.1. Selected studies

Two hundred and ninety-nine articles were found during the search process (Fig. 1). After the preliminary screening of the titles and abstracts to exclude irrelevant articles, an in-depth full-text assessment of the 32 articles was done by the three investigators (C.L, H.A, S.B). Six articles were finally selected [4,12–14,21,22]; reasons for excluding the articles are summarized in Table 1, and the characteristics of each included article are summarized in Table 2.

3.2. Quality assessment of selected studies

The only randomized controlled trial selected in this review had seven out of nine “low risk of bias” evaluation items in the Cochrane Collaboration’s tool (in Supplementary information). The mean total score of five studies was 4.6 ± 0.5 using the Newcastle-Ottawa scale (NOS) (in Supplementary information). Most studies were ranked as Level 3b in the evidence level of CEBM. The only randomized clinical trial [12] ranked in the highest level of all included studies (Table 2). The kappa coefficients of the three assessments were 1.0, 0.92, and 1.0 respectively.

3.3. Success rate and sensitivity analysis

The success rate of coronal pulpotomy was calculated only if the study reported the number of failed cases at the specific follow-up period. Six studies were included in the analysis of one-year WSR [4,12–14,21,22] and five studies were included in the analysis of two years WSR [4,12–14,21]. Only two studies reported limited number of cases having follow-up period equal to or longer than three years [13,21], therefore, the estimated success rates equal or longer than three years were not calculated. Coronal pulpotomy

![Study Selection Process](image-url)
treatment had success rates over 90% in treating permanent posterior teeth within two-year follow-up (the one-year WSR: 94% (CI: [90,99]); two-year WSR: 92% (CI: [84,100])) (Fig. 2). The I² of weighted mean one-year and two-year success rates were 63.6% and 83.8% respectively indicating existing substantial heterogeneity among the included studies.

Sensitivity analysis was performed by excluding each data set one at a time, the lowest mean weight success rates of one-year and two-year follow-up were 92% (CI: [89,96]) and 88% (CI: [84,92]) while [14] was omitted, and the highest weight mean success rates of one-year and two-year follow-up were 95% (CI: [91,100]) and 96% (CI: [89,100]) while [12] was omitted. No study appeared to significantly affect the success rate.

### Table 1
Excluded articles.

<table>
<thead>
<tr>
<th>Cause of exclusion</th>
<th>Number of articles</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reviews</td>
<td>2</td>
<td>Miyashita et al., 2007 Yazdani et al., 2014 [25]</td>
</tr>
<tr>
<td>Teeth with open apices/apexogenesis</td>
<td>4</td>
<td>Ehrmann et al., 1981 Waly et al., 1994 Waly et al., 1995 El-Meligy et al., 2006 Witherspoon, 2006</td>
</tr>
<tr>
<td>Partial pulpotomy</td>
<td>2</td>
<td>Barrieshi et al., 2006 Qudeimat et al., 2007 [28]</td>
</tr>
<tr>
<td>Case reports</td>
<td>2</td>
<td>Chueh et al., 2010 [10] Solomon et al., 2015 [2]</td>
</tr>
<tr>
<td>Follow-up period &lt;1 year</td>
<td>3</td>
<td>Teixeira et al., 2000 Nyere et al., 2006 Eghbal et al., 2009 [11]</td>
</tr>
</tbody>
</table>

### Table 2
Summary of selected studies.

<table>
<thead>
<tr>
<th>Author Year</th>
<th>n</th>
<th>Age in years (mean)</th>
<th>Follow-up months (mean)</th>
<th>Pulp capping material</th>
<th>Restorative material</th>
<th>Clinical signs &amp; symptoms</th>
<th>LOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caliskan, 1995 [22]</td>
<td>25</td>
<td>10–24</td>
<td>16–72</td>
<td>Ca(OH)₂</td>
<td>Amalgam</td>
<td>Apical lesion, Pain with pressure</td>
<td>2b</td>
</tr>
<tr>
<td>DeRosa, 2006 [21]</td>
<td>22</td>
<td>14–70 (26.5)</td>
<td>14–88</td>
<td>Ca(OH)₂</td>
<td>Amalgam</td>
<td>Teeth indicated for RCT but patients can not afford RCT</td>
<td>2b</td>
</tr>
<tr>
<td>Barngkgei et al., 2013 [14]</td>
<td>10</td>
<td>17–54 (29)</td>
<td>24–42 (30.5)</td>
<td>MTA</td>
<td>Amalgam</td>
<td>Reversible pulpitis, Intense pain on sweets and/or cold food/drinks</td>
<td>3b</td>
</tr>
<tr>
<td>Simon et al., 2013 [14]</td>
<td>17</td>
<td>7–54 (37.2)</td>
<td>12–24</td>
<td>MTA</td>
<td>Composite</td>
<td>No apical lesion</td>
<td>3b</td>
</tr>
<tr>
<td>Asgary, 2014 [12]</td>
<td>166</td>
<td>9–65</td>
<td>24 (24.6)</td>
<td>CEM (MTA like products)</td>
<td>Amalgam</td>
<td>Apical lesion, Spontaneous pain Diagnosed with irreversible pulpitis</td>
<td>1b</td>
</tr>
</tbody>
</table>

* n: number of teeth treated in the study; MTA: mineral trioxide aggregate; CEM: calcium enriched mixture cement (MTA like products); Ca(OH)₂: calcium hydroxide; LOE: Oxford centre for evidence-based medicine-levels of evidence (March 2009).

* In the Barngkgei et al., 2013 study, an anterior mandibular tooth was excluded from the analysis because this systematic review included only posterior teeth.

* In the Simon et al., 2013 study, a case was excluded from the analysis because the tooth had open apices.

### 3.4. Subgroup analysis and meta-regression analysis

Subgroup analyses were conducted to assess the effect of different pulp capping materials or restoration materials on the success rate of CPT. The pulp capping materials included [1] MTA (mineral trioxide aggregate; Pro Root MTA, Dentsply, Tulsa Dental, etc.)
USA), and calcium enriched mixture (MTA-like products pulp capping materials; USPTO number: 7,942,961), and [2] calcium hydroxide material (mixture of powder and liquid).

The weighted mean success rate in one-year and two-year follow-up of MTA and MTA-like products group was 95% (CI: [90,100]) and 93% (CI: [84,100]) respectively. These success rates were higher than those of Calcium Hydroxide group (one-year WSR: 92% (CI: [85,99]); two-year WSR: 88% (CI: [76,100])). The MTA and MTA-like products group had substantial heterogeneity ($I^2 = 75.3\%$ and 86.6% in one-year and two-year follow-up respectively).

In the analysis of using different restoration materials, the amalgam group had higher weighted mean success rate than the composite group in the one-year follow-up (amalgam: 95% (CI: [90,100]); composite: 91% (CI: [78,100])), but lower weighted mean success rate in two-year follow-up (amalgam: 92% (CI: [81,100]); composite: 93% (CI: [81,100])). The degree of data heterogeneity in the amalgam group was higher than that in the composite group (one-year: 74.1% vs. 51.6%; two-year: 91.1% vs. 31.8%) (in Supplementary information).

3.5. Publication bias

There was no evidence of significant publication bias in the one-year and two-year weighted mean success rates of included studies (Egger’s test: $p$-value = 0.35 and 0.56 respectively). The funnel plot analyzing two-year WSR demonstrates a generally symmetric distribution (in Supplementary information).

![Fig. 2. Two-year weighted mean success rate of full pulpotomy treatment.](image)

4. Discussion

The results of the present review indicated favorable success rates of coronal pulpotomy in treating permanent posterior teeth with carious vital pulp exposure and closed root apices within two-year follow-up. The results were similar to the success rates of pulpotomy treatment for primary teeth [23], permanent teeth with open root apices and [26], root canal treatment over two years [5,24]. It has been suggested that a two-year follow-up without radiographic findings and free of patient symptoms is an adequate follow up time to predict success of endodontic treatment [24,25].

It was also suggested that vital pulp therapy’s failure might be due to bacterial leakage towards the remaining vital pulp in the canals through a defective restoration [25]. Recent studies have reported that the most important factors contributing to the success of CPT are the maximum sealing of the dental pulpal complex by using a well sealing pulp cap material and proper final restoration to ensure adequate seal and prevent bacterial leakage towards the remaining pulp in the canal [2,4,6,13]. This might explain the decline in the success rate of CPT over time (one-year WSR: 94% (CI: 90, 99); two-year WSR: 92% (CI: 84, 100), indicating the importance of the regular follow-up visits in order to evaluate and repair any defective restoration to ensure the integrity of the dental pulp.

The effect of pulp capping materials, restorative materials, and the radiographic periapical status of treated teeth on the success rate were evaluated by using meta-regression analysis. The cases of two studies had periapical involvement in the beginning [12,21], but other studies had cases without radiographic periapical lesions.
at the baseline. All three variables were not significantly related to success rates (in Supplementary information). Generally, the differences of success rates between different capping materials, between different restoration materials or between different periapical statuses were limited.

Studies have shown that MTA and MTA-like products as capping material have better clinical outcomes than the traditionally used calcium hydroxide in protecting the exposed pulp [27,28]. MTA and MTA-like products have excellent biocompatibility and great sealing ability that could create a strong barrier against future bacterial leakage towards the remaining pulp in canals [29–32]. In this review, different capping materials did not significantly affect the success rates of CPT. However, the limited number of the selected studies might bias the results.

It is recognized that the quality of coronal restoration is critical for the success of endodontic treatment [33,34]. According to the results of the present review, the type of permanent restoration over the pulp capping material was not significantly related to the success rate of CPT. However, a study of CPT [6] has reported that a prosthetic crown restoration showed the highest success rate after CPT followed by amalgam and the poorest performance was by composite restoration. Further longitudinal clinical studies are needed to confirm this finding.

Even though only studies that considered treating various pulpal exposures were included in this review, pretreatment diagnostic criteria were inconsistent among the included studies (Table 2). Studies showed that CPT could still provide favorable outcomes even when treating symptomatic teeth diagnosed with symptomatic irreversible pulpsitis [2,4,12]. There is no decisive definition in the literature that can clearly differentiate between reversible and irreversible pulpsitis that could relate diagnostic pulp status to the treatment outcomes [5,6]. Despite the inconsistent pretreatment diagnostic criteria, all the included studies in this review reported consistent success rate as well as consistent definition of the successful outcomes, which is absence of clinical symptoms with no radiographic pathology, indicating that coronal pulpotomy treatment appeared to be successful in treating permanent teeth with or without symptoms. However, there is a need for future studies to explicitly define the pretreatment diagnostic criteria for teeth indicated for CPT for better understanding of factors contributed to the success of CPT.

A younger dental pulp is more cellular and has better potential for healing and regeneration after removing the infected pulp tissue [13,35,36]. However, one study [6] found that age was not a risk factor for CPT after ten-year follow-up for patients whose ages ranged from 8 to 80 years old. Additionally, four studies of the present review have included patients up to 50-years-old and have reported high success rates of CPT [4,12,14,21] suggesting that CPT could work successfully in the elderly as in young patients.

The direct comparison of success rate between CPT group and RCT group could not be performed because only one included study reported the success rates of the two groups [12]. Other included studies are cohorts of coronal pulpotomy treatment.

It was found that the finance factor, particularly in challenging socioeconomic settings is the major significant barrier for receiving RCT [37]. As a result, many patients would opt for extraction as an alternative option [38], which could create an ethical conflict [39]. A previous review showed that the success rate of RCT was 85.2% [33]; which is comparable to the success rates of CPT found in the present review. However, the present review has only reported success rates for up to two years, whereas the review that evaluated RCT has included longer follow up time [33].

Moreover, a health technology assessment has been conducted to highlight the advantages of CPT over RCT in terms of pain relief, cost effectiveness, accessibility, and availability in long term [25]. This report has recommended the implementation of CPT in schools and health care centers as a viable treatment protocol, particularly in communities with limited funds [25].

5. Conclusion

Coronal pulpotomy treatment could increase tooth retention by providing a potential option particularly for low-income patients or in under served areas worldwide. However, more studies having longer follow-up, larger sample size and including a control group are needed to validate the possibility of performing CPT as an alternative to RCT.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j. jdent.2015.12.005.

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