SYSTEMATIC REVIEW AND META ANALYSIS

# Clinical and Radiographic Efficacy of Low-level Laser Therapy and Formocresol as Pulpotomy Agents in Primary Molars: A Systematic Review and Meta-analysis

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## Abstract

**Research question:** To evaluate the effectiveness of low-level laser therapy (LLLT) as a pulpotomy agent in primary molars.

**Research protocol:** This systematic review followed the recommendation of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline 2020.

**Literature search:** An electronic search of the databases was performed to find the effectiveness of LLLT over formocresol as a pulpotomy agent in primary molars in children aged between 3 and 10 years.

**Data extraction:** Authors independently extracted the data from the 14 included studies based on the inclusion criteria. The inclusion criteria comprised studies that compared the clinical and radiographical effectiveness of LLLT pulpotomy with formocresol pulpotomy in primary molars using randomized clinical trials (RCTs).

**Quality appraisal:** The risk of bias was assessed using a tool developed by the Cochrane Collaboration for RCT studies.

**Data analysis:** The meta-analyses were performed using the fixed-effects model. Heterogeneity was assessed by a Q test and quantified with $I^2$ statistics. Radiological and clinical success among the teeth treated with either formocresol or LLLT was considered the main outcome.

**Results and interpretation of results:** The search resulted in 390 published studies. After the removal of duplicate studies and analysis of full-text articles, 14 studies were selected for systematic review. Overall, the results demonstrated a high risk of selection and performance bias. No statistically significant difference was found between LLLT and formocresol as pulpotomy agents when compared clinically and radiographically at 6–9 and 12-month follow-up periods. LLLT is a good alternative method to be used as a pulpotomy agent in cases of reversible pulpitis.

**Key message:** Low-level laser therapy is an emerging and trending branch in dentistry because of its beneficial effects in various treatment approaches. It can be effectively used in the pulpotomy procedure due to its properties to reduce pulp inflammation, improve healing, and preserve dental pulp vitality.

**Keywords:** Diode laser, Formocresol, Low-level laser therapy, Photobiomodulation therapy, Pulpotomy.

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## Introduction

The most prevalent dental problem worldwide in children is dental caries. An increase in the severity of dental decay eventually leads to the early loss of deciduous teeth before their exfoliation time, which may interfere with the healthy eruption of permanent teeth, leading to malocclusion or impaction.[1] Vital pulp therapy is crucial for maintaining the health and functionality of primary teeth. One of the early treatment modalities used in cases of reversible pulpitis is pulpotomy. Pulpotomy is a procedure involving the removal of the infected or inflamed portion of the coronal pulp, followed by achieving hemostasis at canal orifices and placement of a suitable medicament to sustain the health and functionality of the remaining radicular pulp.[2]

Optimal materials for pulpotomy should facilitate healing and maintain the health of the remaining pulp tissue.[3] Different materials used for pulpotomy are formocresol, calcium hydroxide (CH), ferric sulfate, mineral trioxide aggregate (MTA), zinc oxide eugenol (ZOE), lasers, etc.[4,5] The most common and widely used pulpotomy agent for decades to date is formocresol.[6] Formocresol pulpotomy is considered a gold standard technique with a 70–97% clinical success rate.[4] Formocresol comes with many harmful properties, such as mutagenicity, carcinogenicity, and toxicity. Recently, efforts have been made to find a more effective and suitable alternative to formocresol.

Currently, one of the most innovative and popular advancements in dentistry is the application of lasers. Specifically, low-level laser therapy (LLLT) is considered one of the most effective and beneficial forms of laser treatment. The properties of LLLT, such as reduction in pain and inflammation, augmenting tissue repair and regeneration, promoting the healing of nerves and deeper tissues, while also preventing damage to surrounding tissues, offer

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significant benefits.[7] Various types of lasers, including $CO_2$, Er:YAG, Cr:YSGG, argon, and diode, each with different wavelengths and specifications, are utilized across diverse clinical settings and for various tooth types in patients of different ages. This variability has led to inconsistent and confusing evidence.[8–10] The use of LLLT in pulpotomy procedures has shown better results, mainly due to its hemostasis, antimicrobial, and cell-stimulating properties.[11]

According to the literature review, it is observed that various techniques and medicaments are used in the pulpotomy procedure. A recent study showed that the success rate of LLLT was significantly higher compared to formocresol pulpotomy.[12,13] Contradictory results were also observed, with a low success rate in the LLLT group.[14] The success rates of LLLT pulpotomy compared to formocresol pulpotomy remain uncertain due to inconsistent clinical, radiographic, and histopathological findings. Consequently, this systematic review aims to assess and compare the clinical and radiographic outcomes of low-level laser pulpotomy with those of traditional formocresol pulpotomy in the treatment of primary molars.

## Materials and Methods

### Protocol and Registration

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (http://www.prisma-statement.org). Additionally, the study protocol was registered with International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42022341087.

### Search Strategy

Three independent examiners conducted the search process. Searches were conducted using various electronic databases, such as Medline (accessed through PubMed), the Cochrane Library, Google Scholar, and EBSCO for articles published up to 31st December 2022, with no restriction on publication year but limited to English language. The search utilized the following terms: "LLLT," "diode laser," "photobiomodulation therapy," "formocresol," "Buckley's formocresol," and "pulpotomy." To formulate the search strategy, Boolean operators "AND" and "OR" were employed to combine the terms. The specific search strategies for each database are outlined in Table 1.

### Eligibility Criteria

Studies assessing the clinical and radiographic effectiveness of low-level laser pulpotomy and formocresol pulpotomy for deciduous molars were included. The inclusion criteria were established according to the population, intervention, comparison, outcome, study design (PICOS) framework (PRISMA-P 2020) as detailed in Table 2.

- Population (P): Primary molars (both maxillary and mandibular primary molars) in children in the 3–10-year age range.

**Table 1:** Search strategy in the database

| *Database* | *Search strategy* | *Findings* |
|---|---|---|
| PubMed | #1 Pulpotomy[Title/Abstract] | 1,327 |
| | #2 ((("low level laser therapy"[Title/Abstract]) OR ("diode laser"[Title/Abstract])) OR ("low level laser"[Title/Abstract])) OR ("low diode laser"[Title/Abstract]) | 10,846 |
| | #3 (("Buckley formocresol"[Title/Abstract]) OR ("Buckley's formocresol"[Title/Abstract])) OR (formocresol [Title/Abstract]) | 563 |
| | #1 AND #2 AND #3 | 11 |
| Cochrane | #1 (pulpotomy):ti,ab,kw (Word variations have been searched) | 655 |
| | #2 MeSH descriptor: [Pulpotomy] explode all trees | 190 |
| | #3 #1 OR #2 | 655 |
| | #4 (formocresol):ti,ab,kw OR ("buckley's formocresol"):ti,ab,kw (Word variations have been searched) | 167 |
| | #5 ("low level laser therapy"):ti,ab,kw OR ("diode laser"):ti,ab,kw OR ("laser photobiomodulation"):ti,ab,kw OR (LLLT):ti,ab,kw OR ("low level laser"):ti,ab,kw (Word variations have been searched) | 4,341 |
| | #6 MeSH descriptor: [Low-Level Light Therapy] explode all trees | 1,182 |
| | #7 #5 OR #6 | 4,847 |
| | #8 #3 AND #4 AND #7 | 9 |
| Google Scholar | Low-level laser therapy, diode laser, formocresol, pulpotomy | 238 |
| EBSCO Host | Low-level laser therapy pulpotomy and formocresol pulpotomy | 132 |

**Table 2:** Eligibility criteria

| *PICOS* | *Inclusion* | *Exclusion* |
|---|---|---|
| Population: Primary molars | Age-group of 3–10 years | Above 11 years of age |
| Intervention: LLLT used for pulpotomy procedure | Wavelength of 600–1000 nm | >1000 nm<br>High level laser therapy |
| Comparison: Buckley's formocresol pulpotomy | Pulpotomy—Buckley's formocresol solution (diluted at 1:5) | Pulpotomy—MTA, ferric sulphate, electrosurgery |
| Outcome: Clinical and radiographical outcome | Clinical and radiographical outcome >6 months follow-up | Histological or any other outcome assessment test |
| Study design | Randomized controlled trials (RCTs) | • Case reports, case series<br>• Laboratory studies<br>• Cross-sectional studies<br>• Discussions, interviews, opinions<br>• Editorials, unpublished studies.<br>• Review articles<br>• Conference abstracts |

- Intervention (I): LLLT used for pulpotomy procedure. Pulpotomy procedure performed using LLLT with a wavelength of 600–1000 nm.
- Comparison (C): Pulpotomy performed in primary molars using Buckley's formocresol solution (diluted at 1:5).
- Outcome (O): Clinical and radiographic success rates of using LLLT vs formocresol as pulpotomy agents.
- Study design (S): Randomized clinical trials (RCTs).

The following types of studies were excluded: nonrandomized clinical trials, case reports, review articles, case series, interviews, conference abstracts, commentaries, editorials, letters, opinion pieces, studies involving animals, and research involving artificial teeth.

### Selection of Studies

Two authors independently reviewed the retrieved studies by evaluating their titles and abstracts. Full texts were retrieved for studies when the title and abstract did not provide enough information for evaluation. In the next stage, the full texts were examined to determine eligibility based on the PICOS criteria. Any disagreements about study inclusion were resolved through consensus with the involvement of a third author. Duplicate studies identified during the database search were included only once.

### Data Extraction

Data from the included studies were independently collected by three authors. Any disagreements were resolved through consensus among the three authors. The extracted information included publication details (authors, year), study type, participant age, tooth type, sample size, pulpotomy agents used, characteristics of low-level lasers, and outcomes based on clinical and radiographic success rates.

### Quality Assessment

To assess the validity of the included RCTs, we used a risk of bias evaluation tool developed by the Cochrane Collaboration. This tool assessed the following parameters: (1) random sequence generation, (2) allocation concealment, (3) blinding of participants and personnel, (4) intention-to-treat analysis (blinding of outcome assessment), (5) incomplete outcome data, (6) selective reporting (reporting bias), and (7) other potential biases (e.g., design or contamination bias). Each study's methodological quality was categorized as low, high, or unclear risk. Studies were marked with "high" risk of bias (red) for negative domains, "low" risk of bias (green) for positive domains, and "uncertain" risk (yellow) when the response was ambiguous.

### Data Analysis

A meta-analysis was conducted for studies with similar methodologies using RevMan 5.4 (RevMan 5.4, The Nordic Cochrane Centre, Copenhagen). Heterogeneity was evaluated using the Q test and quantified with $I^2$ statistics. Data on event frequency and total sample size were extracted from the included studies. The primary outcome measures were radiological and clinical success rates for teeth treated with either formocresol or LLLT.

Four distinct comparisons were conducted to evaluate success rates:

- Comparison of radiological failure between LLLT and formocresol pulpotomy after 6–9 months.
- Comparison of radiological failure between LLLT and formocresol pulpotomy after 12 months.
- Comparison of clinical failure between LLLT and formocresol pulpotomy after 6–9 months.
- Comparison of clinical failure between LLLT and formocresol pulpotomy after 12 months.

Failure rates were determined based on the number of failed cases relative to the total sample size. In the analyses, if substantial heterogeneity was detected ($I^2 > 50\%$), a random effects model was used; otherwise, a fixed-effects model was applied ($I^2 \leq 50\%$).

## Results

### Search Results

Initially, 390 studies were identified from electronic databases (Fig. 1). Of these, 62 were duplicates and were excluded. Subsequently, after reviewing the titles and abstracts of the remaining 328 articles, 21 studies were included in the analysis. These 21 articles were sought for retrieval. All 21 articles were retrieved and then further assessed for eligibility. Following a thorough review, seven articles[8,25–30] were omitted based on the inclusion criteria. The reasons for their exclusion are detailed in Table 3.

Ultimately, 14 studies[11–24] were preferred for the systematic review. Following the electronic search, the references of these studies were manually checked, but no additional articles were identified. Nine studies with homogeneous data were selected for meta-analysis for the success rate of LLLT and formocresol pulpotomy at 12 months follow-up period. A total of 11 studies with homogeneous data were selected for meta-analysis for the success rate of LLLT and formocresol pulpotomy at 6–9 months follow-up period.

### Study Characteristics

Data from the 14 studies included in the systematic review[11–24] are summarized in Table 4.

### Risk of Bias

All included studies were categorized as having a "high" risk of bias regarding methodological factors (Figs 1 to 3).[22–28] The findings revealed a high risk of bias in random sequence generation, allocation concealment, and blinding of participants and personnel (Table 5).

### Meta-analysis

A meta-analysis was performed on 11 studies with 6–9 months of follow-up and nine studies with 12 months of follow-up, focusing on the clinical and radiographic success rates of LLLT and formocresol pulpotomy that could be inspected quantitatively. The results of the overall comparison are illustrated in a forest plot. Given that heterogeneity was <50% ($I^2 = 49\%$) in the meta-analysis, a fixed-effects model was applied.

- Comparison of clinical success between LLLT and formocresol pulpotomy after 6–9 months (Fig. 4): There was no difference in clinical failure ($p = 0.70$) among the teeth treated with LLLT and formocresol pulpotomy after 6–9 months, with an odds ratio of 1.34 (95% CI = 0.16–3.39; $Z$-value = 0.38).
- Comparison of clinical success between LLLT and formocresol pulpotomy after 12 months (Fig. 5): There was no difference in clinical failure ($p = 0.56$) among the teeth treated with LLLT and

formocresol pulpotomy after 12 months, with an odds ratio of 1.29 (95% CI = 0.56–2.97; *Z*-value = 0.59).

- Comparison of radiological success between LLLT and formocresol pulpotomy after 6–9 months (Fig. 6): Teeth treated with LLLT showed lower radiological failure compared to formocresol pulpotomy after 6–9 months, with an odds ratio of 1.38 (95% CI = 0.79–2.43; *Z*-value = 1.12); however, the difference between the two groups was statistically nonsignificant ($p = 0.26$).
- Comparison of radiological success between LLLT and formocresol pulpotomy after 12 months (Fig. 7): Teeth treated with formocresol showed lower radiological failure compared to LLLT after 12 months, with an odds ratio of 0.87 (95% CI = 0.49–1.55; *Z*-value = 0.47); however, the difference between the two groups was statistically nonsignificant ($p = 0.64$).

## Discussion

The ultimate goal of a pediatric dentist is to save the deciduous teeth until their normal exfoliation time to maintain occlusion and oral health. The success of the pulpotomy procedure depends on appropriate case selection, adherence to aseptic techniques, the medicament used to preserve the vitality of the radicular pulp, base material, and restorative materials. The ideal properties of a medicament for use in pulpotomy procedures should include bactericidal effects, safety for the pulp and surrounding tissues, promotion of healing in the remaining radicular pulp tissue, nontoxicity, and prevention of physiological root resorption.[31]

A systematic review and meta-analysis by Jamali et al.[32] concluded that LLLT is more effective than other types of lasers, such as $CO_2$, InGaAlP, Nd;YAG, and Er;YAG lasers. The key distinction between low-level and high-power lasers is that LLLT induces photochemical reactions without generating heat. Unlike high-power lasers that can cause tissue ablation, LLLT avoids this effect. The crucial factor for achieving the desired light characteristics in these lasers is not their total power but their power density per unit area (i.e., $cm^2$). A power density of <670 mW/$cm^2$, without generating heat, is sufficient to produce the therapeutic effects of low-level lasers. The wavelength of LLLT ranges mainly from 600 to 1000 nm. The output power for LLLT should be <500 mW. As LLLT does not create a heating sensation, it is often referred to as cold lasers.[25]

In the present systematic review, 14 RCT studies were assessed. Studies differed in their laser characteristics, the base materials used after hemostasis, follow-up durations, and outcomes. The results were heterogeneous: eight studies demonstrated that LLLT pulpotomy had a success rate equal to or higher than that of conventional formocresol (FC) methods. Conversely, six studies reported lower clinical or radiographic success rates for LLLT

**Table 3:** Characteristics of excluded articles

| *Sr. no.* | *Author and year* | *Reason for exclusion* |
|---|---|---|
| 1 | Marques et al.[25] 2014 | Outcome measured using histopathological assessment |
| 2 | Golpayegani et al.[27] 2010 | Duplicate |
| 3 | Uloopi et al.[26] 2016 | Formocresol not used as comparator group |
| 4 | Šimunović et al.[28] 2022 | Formocresol not used as comparator group |
| 5 | Saltzman et al.[29] 2004 | Thesis article |
| 6 | Seby et al.[30] 2016 | Thesis article |
| 7 | Huth et al.[8] 2012 | High level laser therapy used as intervention group |

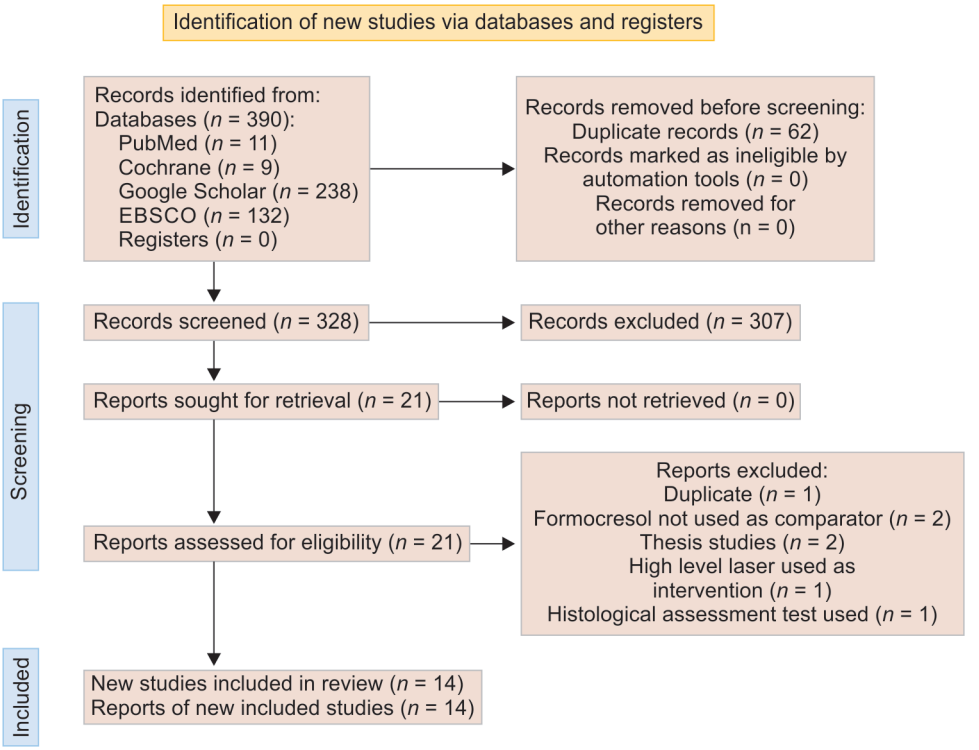


**Fig. 1:** Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart of the literature search and selection process

**Table 4:** Characteristics of included articles

| Sr. no. | Author and year | Study design | Age (year) | Tooth | Sample size (teeth each group) | Agents used for pulpotomy | Laser characteristics | | | | | Outcomes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | W (nm) | E ($J/cm^2$) | P (W) | F (Hz) | T (s) | Clinically | Radiographically |
| 1 | Saltzman et al.[15] 2005 | Randomized, single-blinded, split-mouth study | 3–8 | Maxillary and mandibular molars | 26 | LLLT + MTA<br>FC + ZOE | 980 | – | 3 | – | – | All teeth were sound at 2.3, 5.2, 9.5, 15.7 months follow-up | 2.3 months follow-up, 4.2% failure in laser group compared to 0.00% of the FC group<br>5.2 months follow-up, 5.3% failure in laser group compared to 0.00% of the FC group<br>9.5 months follow-up, 22.2% failure in laser group compared to 5.3% of the FC group<br>15.7 months follow-up, 28.6% failure in laser group compared to 15.4% of the FC group<br>The results were not found to be significant in any follow-up |
| 2 | Golpayegani et al.[11] 2009 | RCT | 4–7 | Primary molars | 23 | LLLT<br>FC | 632 | 4 | – | – | 31 | Both LLLT and FC group showed 100% success at 6-month follow-up<br>12-month follow-up, 7% failure in FC group compared to 0.00% of the LLLT group | 6 months follow-up, 11% failure in LLLT group compared to 0.00% of the FC group<br>12 months follow-up, 33% failure in LLLT group compared to 20% of the FC group<br>No statistically significant difference was seen |
| 3 | Fernandes et al.[16] 2015 | RCT | 5–9 | Mandibular first and second deciduous molar | 15 | FC<br>CH<br>LLLT<br>LLLT + CH | 660 | 2.5 | 0.01 | 50–60 | 10 | All the groups studied were successful in the clinical evaluation over the follow-up period of 6,12, and 18 months | At 6 months, FC group was 100%, 80% for the LLLT group<br>After 12 months, FC group was 100%, 80% for the LLLT group<br>At the 18 months follow-up, FC group was 100%, 73.3% of the LLLT group |
| 4 | Durmus et al.[17] 2014 | RCT | 5–9 | Primary molars | 40 | LLLT<br>FC<br>FS | 810 | 50 mJ | 1.5 | 30 | 10 | LLLT group showed 100% success rate throughout the 12-month follow-up period<br>The FC group had a success rate of 100% at 6 months, 97% at 9 and 12 months.<br>No significant differences were detected among in all groups | LLLT group showed 95, 87, and 75% and FC group, 97, 92, and 87%, the success rates at 3, 6, and 12 months, respectively<br>The differences among the groups were not statistically significant |
| 5 | Joshi et al.[12] 2017 | RCT, double-blinded | 4–9 | Primary molars | 20 | LLLT<br>FC | 980 | – | 1.5 | – | 2 | 100% success in both the groups at the end of 3, 6, and 12 months was observed | 94.4, 78.8, and 57.8% success rate in FC group compared to 100, 94.4, and 78.8% success rate in LLLT group at 3, 6, and 12 months follow-up was observed respectively |
| 6 | Ansari et al.[18] 2018 | RCT | 3–9 | Primary molars | 40 | Calcium-enriched mixture (CEM) cement<br>LLLT + CEM cement<br>FC<br>FS | 632 | 4 | – | – | 135 s | The 6-month success rate for:<br>FC = 100%<br>FS=97.5%<br>CEM = 100%<br>LLLT/CEM = 100%<br>The 12-month success rate for:<br>FC = 100%<br>FS = 95%<br>CEM = 97.5%<br>LLLT/CEM = 100% with no significant differences | 6-month success rate for:<br>FC = 100%<br>FS = 97.5%<br>CEM = 100%<br>LLLT/CEM = 100%<br>12-month success rate for:<br>FC = 100%<br>FS = 92.5%<br>CEM = 95%,<br>LLLT/CEM = 100% with no significant differences |

*Contd…*

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| Sr. no. | Author and year | Study design | Age (year) | Tooth | Sample size (teeth each group) | Agents used for pulpotomy | Laser characteristics | | | | | Outcomes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | W (nm) | E ($J/cm^2$) | P (W) | F (Hz) | T (s) | Clinically | Radiographically |
| 7 | Ansari et al.[14] 2018 | Double-blind, split-mouth RCT | 3–9 | Primary molars | 20 | Diode laser<br>FC | 810 | – | 10 | 20 | 0.02 | Success rate of diode laser, at 6 and 12 months was 100% same as FC treated | Success rate of diode laser at 6- and 12-month follow-up were 95 and 90%, respectively, and that of FC was 100%, with no statistical significance |
| 8 | Shaikh et al.[19] 2019 | Randomized, split-mouth study | 4–8 | Primary teeth | 20 | Diode laser<br>FC | 810 | – | 1.5 | – | 10 | Clinical scores of both the groups at 1, 3, 6, and 9 months<br>Chi-square value was 0.54, 1.74, 1.11, and 2.32 and *p*-value (<0.05) was found to be 0.76, 0.42, 0.57, and 0.67, respectively, which was not significant | Radiographic scores of all two groups at 1, 3, 6, and 9 months, Chi-square value was 0.54, 4.75, 6.04, and 6.46 and *p*-value (<0.05) was found to be 0.76, 0.57, 0.64, and 0.59, respectively, which was not significant |
| 9 | Alamoudi et al.[20] 2019 | RCT | 5–8 | Primary molars | 53 | LLLT<br>FC | 810 | 6.7 | 2 | 0.1–50 | 40 | Success rates for both the LLLT and FC groups was 98% at 6 months and 96.1% at 12 months follow-up | Success rates for the LLLT and FC groups were 100 and 98%, respectively at 6 and 12 months follow-up |
| 10 | Pei et al.[21] 2020 | RCT | 2–8 | Primary molars | 45 | Diode laser<br>FC | 915 | – | 2 | 100 | 3 | Success rates for laser group 100, 96.8, and 92.9% at 3, 6, and 12 months, respectively<br>Similarly, for FC group were 100, 97.1, and 90.9% at 3, 6 and 12 months, respectively | Success rates for laser group 100, 90.3, and 78.6% at 3, 6, and 12 months, respectively<br>Similarly, for FC group were 100, 91.4, and 72.7% at 3, 6, and 12 months, respectively |
| 11 | Kharbotly et al.[22] 2020 | RCT | 4–6 | Mandibular primary molars | 30 | FC/ZOE<br>Diode laser/MTA<br>Diode laser/BD | 810 | – | 1.5 | – | 1–2 | The entire three groups showed 100% success rate at 1, 3, 6, and 9 months check-up period. At 12 months follow-up period, the success rate of FC/ZOE group was 90.3%, diode laser/MTA group showed 96.3% and diode laser/BD group showed 100% | The entire three groups showed 100% success rate at 1, 3, and 6 months follow-up<br>At 9 months follow-up, the success rate in FC/ZOE group was 93.3 and 100% for diode laser /MTA and diode laser/BD groups<br>At 12 months follow-up period, the FC/ZOE group had 90.3%, success rate, diode laser/MTA group, the success rate was 96.3% and in diode laser/BD group, the success rate was 100% |
| 12 | Nadhreen et al.[23] 2021 | Randomized split-mouth clinical trial | 5–8 | Primary molars | 53 | LLLT<br>FC | 810 | 6.7 | 3 | 0.1–50 | 40 s | Both the groups at 3 and 9 months follow-up period showed 98% success rate | 9 months success rate was 100% for laser group and 98% for FC group |
| 13 | Yavagal et al.[13] 2022 | Randomized split-mouth clinical trial | 4–7 | Primary molars | 34 | LLLT<br>FC | 660 | – | 0.036 | – | 240 | There was no statistically significant difference in the success rates between the FC group (97.05%) and LLLT group (94.1%) | Success rate was significantly high in the LLT group (94.1%) compared to the FC group (58.82%) |
| 14 | Kaya et al.[24] 2021 | RCT | 5–8 | Primary first or second mandibular molars | 43 | LLLT + CH<br>CH<br>FC<br>MTA | 820 | 2.5 | 0.01 | – | 12 | The success rate of FC at 6 and 12 months was 97% and for LLLT group 89 and 87%, respectively | The success rate of FC at 6 and 12 months was 92% and for LLLT group 76 and 73%, respectively |

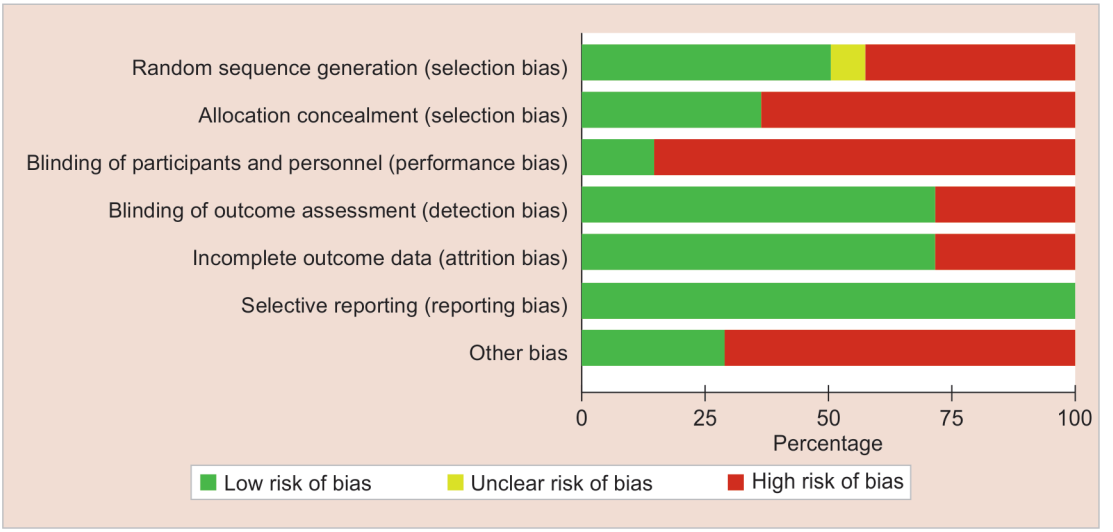


**Fig. 2:** Risk of bias graph

**Table 5:** Quality of assessment of the included studies

| *Sr. no.* | *Study* | *Random sequence generation* | *Allocation concealment* | *Blinding of participants and personnel* | *Blinding of outcome assessment* | *Incomplete outcome data assessment* | *Selective reporting of outcome* | *Other sources of bias* |
|---|---|---|---|---|---|---|---|---|
| 1 | Alamoudi et al. 2020 | Low risk | Low risk | Low risk | Low risk | Low risk | Low risk | Low risk |
| 2 | Ansari et al. 2018 | Unclear risk | High risk | High risk | Low risk | High risk | Low risk | High risk |
| 3 | Ansari et al. 2018 | Low risk | High risk | High risk | Low risk | Low risk | Low risk | High risk |
| 4 | Durmus et al. 2014 | High risk | High risk | High risk | Low risk | Low risk | Low risk | High risk |
| 5 | Fernandes et al. 2014 | Low risk | High risk | High risk | Low risk | High risk | Low risk | Low risk |
| 6 | Golpayegani et al. 2009 | High risk | High risk | High risk | Low risk | High risk | Low risk | High risk |
| 7 | Joshi et al. 2017 | High risk | High risk | High risk | High risk | Low risk | Low risk | High risk |
| 8 | Kaya et al. 2022 | Low risk | Low risk | Low risk | Low risk | Low risk | Low risk | Low risk |
| 9 | Kharbotly et al. 2020 | Low risk | Low risk | High risk | Low risk | Low risk | Low risk | High risk |
| 10 | Nadhreen et al. 2021 | Low risk | Low risk | High risk | Low risk | Low risk | Low risk | Low risk |
| 11 | Pei et al. 2020 | High risk | High risk | High risk | High risk | Low risk | Low risk | High risk |
| 12 | Saltzman et al. 2005 | High risk | High risk | High risk | Low risk | High risk | Low risk | High risk |
| 13 | Shaikh et al. 2019 | High risk | High risk | High risk | High risk | Low risk | Low risk | High risk |
| 14 | Yavagal et al. 2022 | Low risk | Low risk | High risk | High risk | Low risk | Low risk | High risk |


**Fig. 3:** Risk of bias summary

compared to FC methods. Hence, further meta-analysis was also planned to uncover the argument between the success rates of LLLT and FC in the pulpotomy procedure.

Quality assessment was performed for all 14 included studies. Seven of these studies provided adequate reporting on random sequence generation[13,14,16,20,22–24] but failed to provide satisfactory data in the other seven studies.[11,12,15,17–19,21] Only five studies adequately reported allocation concealment[13,20,22–24] and were categorized overall as high risk. The nature of the interventions did not allow for examiner and participant blinding; however, examiner blinding was reported in two studies.[20,24] Four studies did not describe the blinding of outcome assessment.[12,13,19,21] Additionally, four studies[11,15,16,18] inadequately addressed incomplete outcomes, as they did not specify appropriate measures to handle missing data. All studies were adequate in terms of selective reporting. Other potential biases were associated with insufficient information on sample size estimation, inclusion and exclusion criteria, and examiner calibration.

The laser characteristics such as wavelength, power, and time of application for the pulpotomy procedure play a major role in achieving the benefits of LLLT. Different wavelengths and powers are used in the literature, ranging from 632 to 980 nm and 0.01 to 3 W, respectively. No standard parameters have yet been set for the laser characteristics to be used during the pulpotomy procedure. Saltzman et al.[15] used a 980 nm wavelength and a 3 W power laser until hemostasis was achieved and reported a low radiographic success rate with the LLLT group compared to the FC group. The major cause of failure among the LLLT group radiographically was due to furcal radiolucency and pathologic root resorption.

Similarly, Joshi et al.[12] used a 980 nm wavelength laser with a lower power of 1.5 W and a 2-second application time, considering that a longer application might result in pulp stumps free of hemorrhage but could cause hyperemia of the remaining pulp tissue, which might influence the treatment outcome. Twelve months follow-up showed a clinical success rate of 100% in both groups. However, the radiographic success rate was higher in the LLLT group (78.6%) compared to the FC group (57.8%). Another study conducted by Fernandes et al.[16] reported a success rate of 73.3% for the LLLT group using 660 nm wavelengths and a 0.01 W power output, which is the lowest among all the studies reported. Internal resorption was the main cause of failure among the LLLT group. Based on the observations, it can be attributed that lower laser power generates less heat and produces more beneficial photobiomodulation effects.

The meta-analysis results of the present study did not show any statistically significant differences clinically and radiographically when comparing LLLT and FC pulpotomy over the 6–9 and 12 months follow-up periods. Among all 14 included studies, only the study conducted by Yavagal et al.[13] showed statistically significant results with respect to the radiographic success rate, with 94.1% for the LLLT group and 58.82% for the FC group, using a 660 nm wavelength and 0.036 W power.

Healing of the pulp tissue after pulpotomy is influenced by the type of subbase material used. Various materials or medicaments have been used to cap the amputated pulp, including ZOE, MTA, CH, and Biodentine (BD). ZOE, when placed directly on pulp tissue, often results in persistent chronic inflammation and a lack of calcific repair.[33] In contrast, MTA is known for inducing pulp healing and dentin bridge formation.[34] In a study by Saltzman et al.,[15] MTA was used as a base material for LLLT-treated teeth, while ZOE was used for FC-treated teeth. The study found that 29.16% (7 out of 24) of teeth treated with LLLT-MTA were classified as failures, compared to 12.50% (3 out of 24) of teeth treated with FC-ZOE. Conversely, a study by Kharbotly et al.[22] used MTA and BD as base materials with LLLT pulpotomy. At the 12-month follow-up, the clinical and radiographic success rate was 100% for the LLLT group with BD as the base material, while the MTA base observed a success rate of 96.3%.

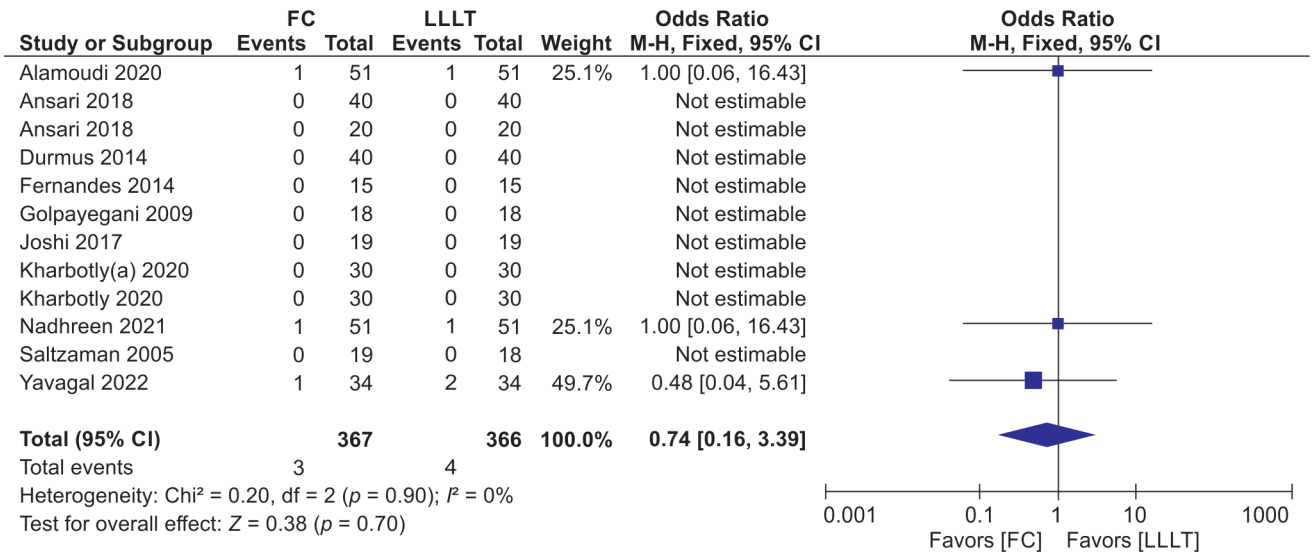


**Fig. 4:** Forest plot comparing clinical failure between LLLT and FC pulpotomy after 6–9 months

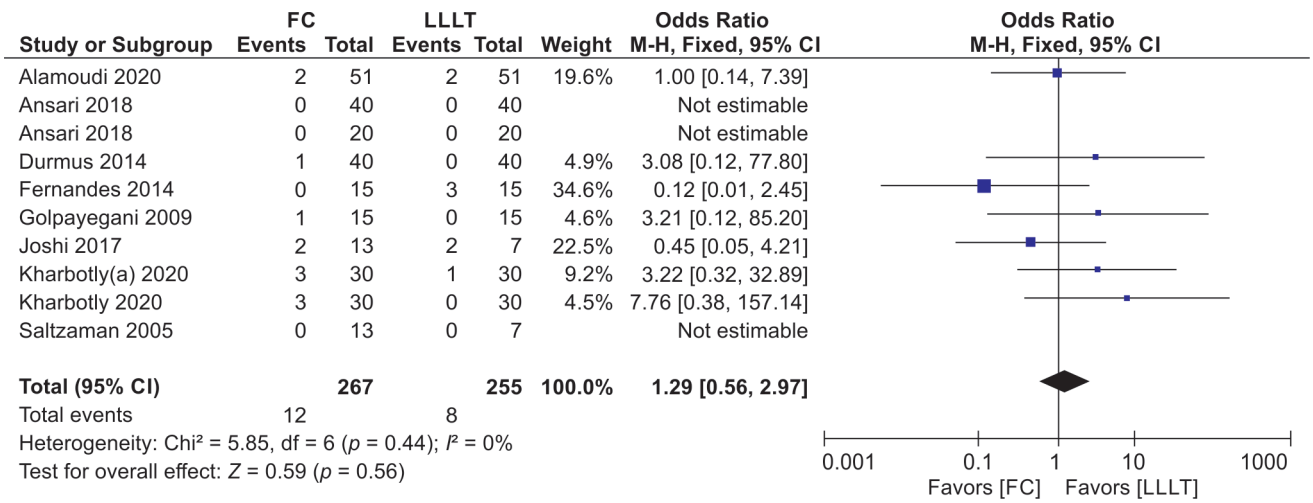


**Fig. 5:** Forest plot comparing clinical failure between LLLT and FC pulpotomy after 12 months

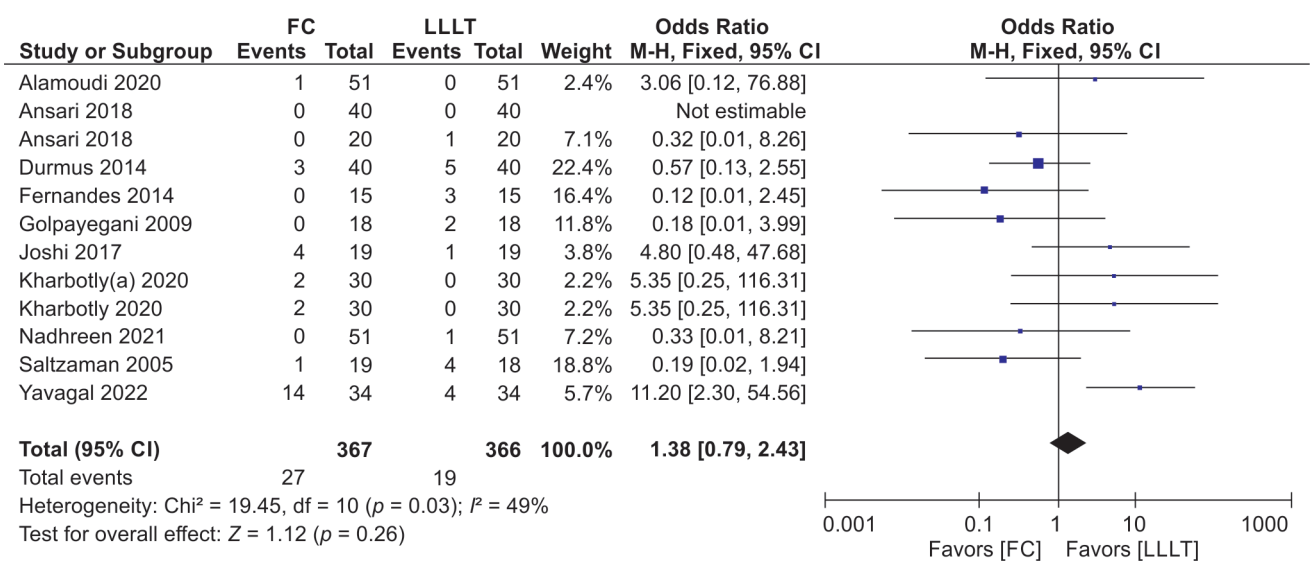


**Fig. 6:** Forest plot comparing radiological failure between LLLT and FC pulpotomy after 6–9 months

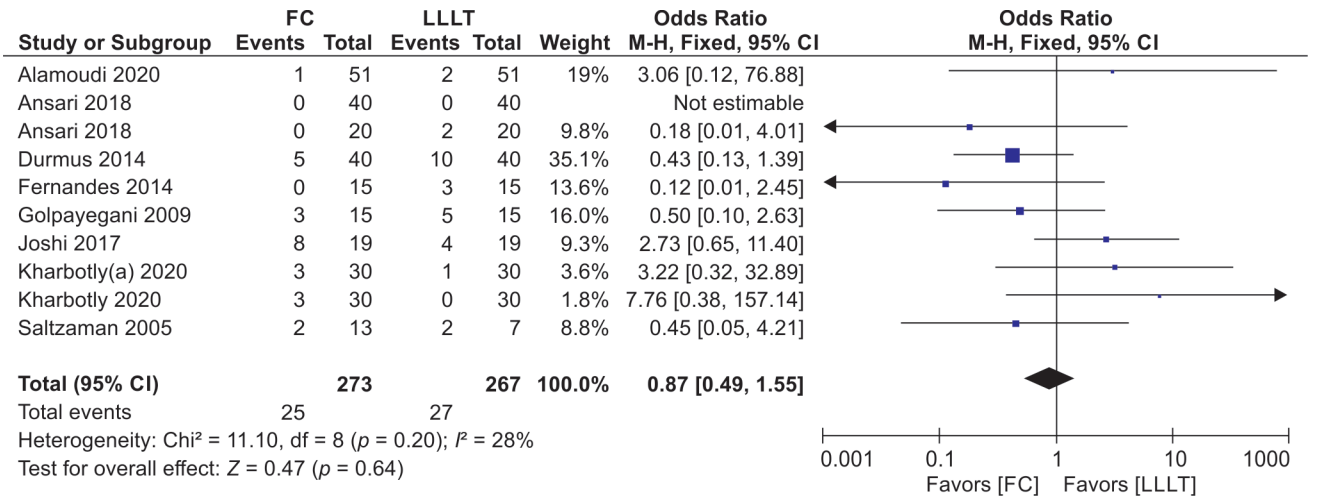


**Fig. 7:** Forest plot comparing radiological failure between LLLT and FC pulpotomy after 12 months

Zinc oxide eugenol and CH have been used as base materials over the amputated pulp after LLLT and FC in pulpotomy procedures. Fernandes et al.[16] reported that CH with LLLT resulted in a higher number of cases with hard tissue barrier formation compared to ZOE-LLLT and CH-FC pulpotomy. Calcium enriched mixture (CEM) was used as a base material by Ansari et al.[18] following LLLT application. They found that LLLT with CEM was a safe and successful pulpotomy agent, achieving a 100% clinical and radiographic success rate compared to conventional methods. A 12-month follow-up study by Kaya et al.[24] found that FC achieved clinical and radiographic success rates of 97% when CH was used as a subbase material. In contrast, LLLT with CH showed success rates of 87% clinically and 73% radiographically.

The success rate of LLLT in pulpotomy procedures can be influenced by the choice of base material used. Future research should focus on evaluating the effectiveness of LLLT pulpotomy with various base materials to determine the optimal combination for best results. Additionally, to reduce the risk of bias, future studies should adopt standardized protocols and parameters for laser pulpotomy. This approach will help ensure consistency and reliability in the evaluation of LLLT's effectiveness in pulpotomy.

## Conclusion

Low-level laser therapy is a viable alternative to conventional FC medicaments in pulpotomy procedures. The comparison between LLLT and FC showed no statistically significant differences based on clinical and radiographic follow-ups at 6–9 and 12 months. Therefore, LLLT can be considered a suitable alternative to FC in pulpotomy. However, the studies included in this systematic review were associated with a high risk of selection and performance bias. Future research should focus on conducting more randomized controlled trials (RCTs) with larger sample sizes, consistent methodologies, and standardized laser characteristics to address these issues.

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