Review Article

Effectiveness of lasers in direct pulp capping among permanent teeth – A systematic review and meta-analysis

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Abstract

Background: Laser-assisted direct pulp capping (DPC) has considerable advantages compared to traditional methods such as: decontaminant effect; hemostatic and coagulant effect; reduced rise in pulp temperature; reduction of intracavitary pressure; dentinal melting; and biostimulation effect.

Objective: The aim of this study was to conduct a systematic review of the literature and meta-analysis to evaluate the effectiveness of laser as adjuvant therapy in DPC among permanent teeth.

Methods: Research question was formulated based on the population, intervention, comparison, and outcomes strategy. A comprehensive electronic literature search was conducted through Cochrane, PubMed, and Google scholar using MeSH words, text words, and Boolean operators, independently by two reviewers. Based on the specified inclusion and exclusion criteria, the selected articles were subjected to quality assessment and the risk of bias (ROB) was evaluated. Cochrane ROB 2.0 and Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I) tools were used to assess the ROB.

Results: Initially, 45 studies recovered, 9 articles were selected for systematic review and 7 articles could be included in the meta-analysis. Teeth treated with low level laser therapy pulp capping therapy showed lower clinical/radiological failure as compared to nonlaser pulp capping therapy with an odds ratio of 0.24 (95% confidence interval = 0.15–0.38; $Z = 6.15$); and the difference between two groups was statistically significant ($P < 0.00001$).

Discussion: This systematic review and meta-analysis included both the randomized and nonrandomized controlled trial (RCT). The non-RCTs had low ROB when compared to the RCTs included in the study. All included RCT studies met the inclusion and exclusion criteria, but some did not adequately describe their methods in detail.

Conclusion: Based on the limited evidence, the results of the meta-analysis demonstrated DPC treatment could achieve better clinical outcomes with the aid of lasers.

Keywords: Direct pulp capping; lasers; meta-analysis; permanent teeth

INTRODUCTION

Direct pulp capping (DPC) is defined as the treatment of a mechanical or traumatic vital pulp exposure by sealing the pulpal wound with a biomaterial placed directly on exposed pulp to facilitate formation of reparative dentin and maintenance of the vital pulp (American Association

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of Endodontists guideline, 2003). The success rate of DPC in cariously exposed pulp ranged from 87.5% to 95.4%, which is comparable to values reported in the literature on treatment results following iatrogenic pulp exposure, which ranged from 70% to 98%.[1] *In vivo* studies have already proved the effectiveness of laser use in DPC treatment among permanent teeth by overcoming the hurdles such as possible bacterial contamination and to achieve proper hemostasis of pulp, but there is always a need of evidence based studies in the form of systematic review and meta-analysis for its successful clinical translation.

METHODS

Protocol and registration

This review was conducted and reported in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and was registered in PROSPERO database with registration number CRD42022350567.

Structured question

Does use of adjuvant laser irradiation improve the success rates of DPC procedure among permanent teeth?

Detailed search strategies were used for the databases for the identification of studies considered.

The controlled vocabulary (MeSH terms) and free terms were used to define search strategy based on the elements of PICOS question as follow as:

1. Population (P): Patient with permanent teeth having exposed pulps treated with DPC procedures
2. Intervention (I): The use of lasers as adjunct for the DPC
3. Comparison (C): Conventional therapy for DPC without laser
4. Outcome (O): Clinical success rate based on the pulp vitality at the end of the follow-up period
5. Study design (S): Randomized controlled trials (RCTs) and non-RCT.

A systematic search following the principle of systematic review search was carried out in the Cochrane (CENTRAL), PubMed, and Google scholar using MeSH words, text words, and Boolean operators. We used the following keyword in the initial search: "direct pulp capping," "Dental pulp exposure," "LASERS." The manual search was conducted to identify additional studies by using the references of the obtained articles. The articles in the English language were considered. The period of publication considered was between January 1, 1990 and May 31, 2022. The complete search methodology is described in Table 1.

Reference lists of the reviews and the identified studies were also checked for possible additional studies.

Eligibility criteria

The studies were selected according to the inclusion and exclusion criteria as mentioned in Table 2.

Study selection

An overview of the selection process is shown in Figure 1. From the 45 articles removing the duplicates, 23 full texts articles were screened on the basis of title and abstract and 8 articles excluded due to reason such as different treatment options such as pulpotomy instead of DPC. A total of 13 articles were assessed for eligibility, among them, 4 articles were excluded due to following reasons:

1. Pulpotomy, instead of direct pulpal capping, was performed on patients (2 articles)
2. Retrospective study (1 article)

Table 1: Search strategy in PubMed database

Category	Keywords
Population	Dental Pulp Exposure [MeSH] OR Exposure [MeSH] OR Dental Pulp [MeSH] OR Pulp Exposure [MeSH] AND Permanent teeth [MeSH]
Intervention	Lasers [MeSH] OR Laser [MeSH] OR Q-Switched Lasers [MeSH] OR Continuous Wave [MeSH] OR Laser Irradiation [MeSH] OR Laser Biostimulation [MeSH] OR Laser therapy [MeSH]
Comparison	Pulp Capping [MeSH] OR Capping Agent [MeSH] OR Calcium Hydroxide [MeSH] OR Mineral Trioxide Aggregate [MeSH] OR MTA [MeSH] OR BIODENTINE [MeSH] OR TheraCal [MeSH] OR Glass Ionomer Cement [MeSH] OR GIC [MeSH] OR Resin Modified Glass Ionomer Cement [MeSH] OR RMGIC [MeSH]
Outcome	Pulp Vitality [MeSH] OR Clinical Success [MeSH] OR Survival rate [MeSH]
	1 AND 2 AND 3 AND 4

Table 2: Selection criteria for the systematic review

Inclusion criteria	Exclusion criteria
Randomized and nonrandomized controlled trial	Animal experiments and reviews, editorial letters, case reports, case series and studies published in a language other than English
Studies of participants with permanent teeth undergoing DPC procedure due to caries, trauma or intentional therapy	Studies of participant with deciduous teeth undergoing DPC procedure and with nonvital teeth
The use of lasers was the only treatment difference between the 2 groups, regardless of whether there was combined therapy or not	Lack of an adequate control group without laser therapy
DPC procedure done using laser as an adjunct	An indirect pulp capping (the deepest carious dentin layer approximating the pulp remained and was covered with biocompatible materials), or pulpotomy (the affected or infected coronal pulp is surgical amputated) was completed rather than a DPC
Clinical success rate evaluated through pulp vitality, histological deposition of dentin or through radiographic examination	Studies with incomplete data on the outcome measures

DPC: Direct pulp capping

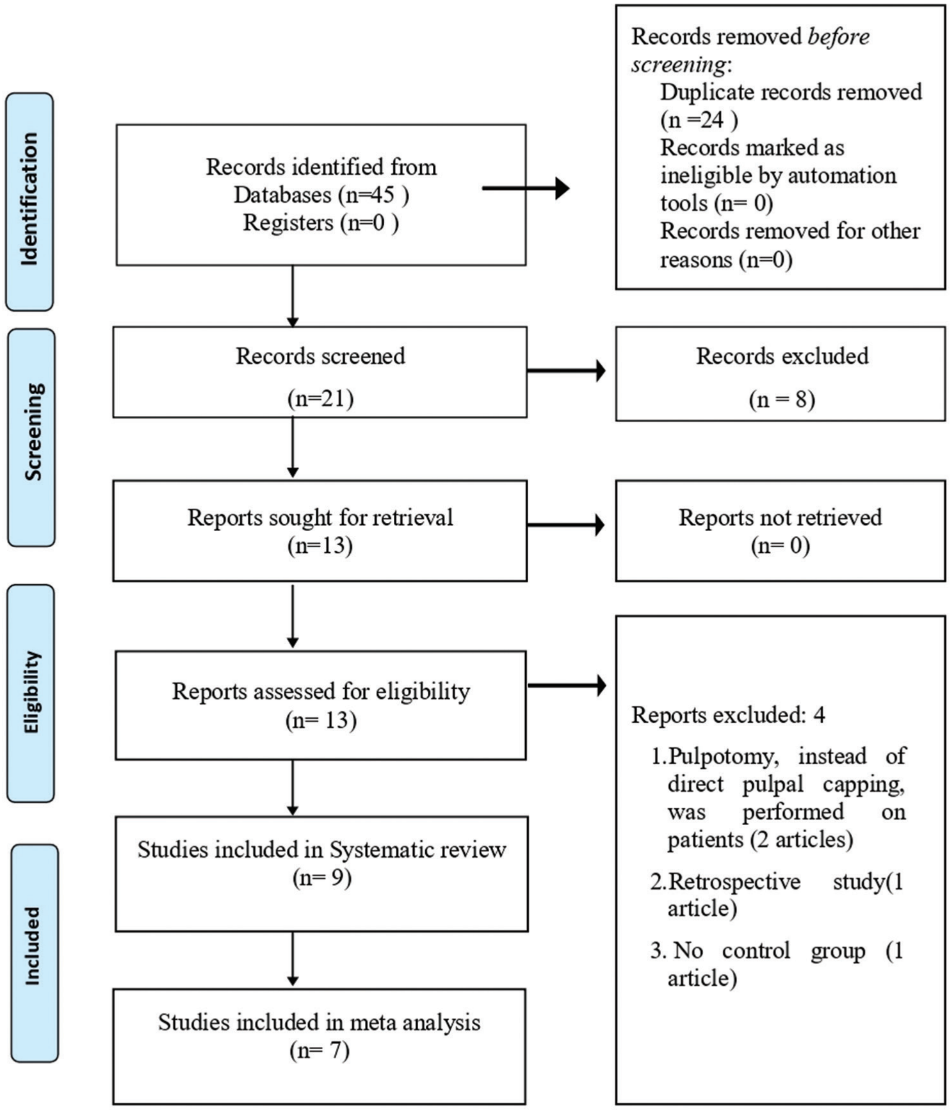

Figure 1: Flow chart of methodology according to preferred reporting items for systematic review and meta-analysis 2020 guidelines

3. No control group (1 article).

Data collection process

The data were extracted using a standardized form in Microsoft Corporation Microsoft Office Excel 2013 software (One Microsoft Way Redmond, Washington, U.S.). The reviewers tabulated data of interest to compose a spreadsheet in Excel format. The characteristics of the studies included, such as the author, year of the study, treatment agent, laser irradiation application, restoration, methods used to assess pulp vitality, follow-up and clinical success rate were also analyzed [Table 3]. Two reviewers independently extracted the necessary information after reading the full text of the included articles using a standardized form. We evaluated all of the included studies based on the Cochrane Risk of Bias (ROB) Tool recommended by the Cochrane Handbook for Systematic Reviews of Interventions, Two reviewers independently assessed the study quality using the following 7 criteria: random sequence generation, allocation concealment, masking of participants, masking of outcome assessment, incomplete outcome data, selective reporting, and other bias. If there was disagreement, consensus was reached through discussion or consultation with a third reviewer.

RESULTS

Quality of included studies

To determine the validity of the included RCTs, a tool developed by the Cochrane Collaboration was used to assess the ROB in clinical trials. Using this tool, the reviewer evaluated the ROB of the selected studies using the following parameters: random sequence generation, allocation concealment, blinding of participants and

Table 3: Characteristics of included studies

Author of the study	Year of study	Study design	Age of patient	Study sample	Laser type	Treatment agent	Restoration	Evaluation method	Follow up	Outcome
Moritz *et al.*[11]	1998	RCT	9–68 years	260	CO_2 laser superpulsed mode, wavelength 10.6 µm, Output power of 1 W - 0.1 s pulses with 1 s pulse intervals	$Ca(OH)_2$	Glass ionomer cement	Thermal test and laser doppler flowmetry	24 months	93% success rate with laser group 66.6% success rate with control group
Moritz *et al.*[4]	1998	RCT	8–74 years	200	CO_2 laser wavelength of 10.6 µm, output power of 1 W, 0.1 s pulses with 1 s pulse intervals. An additional helium neon aiming beam was incorporated into the delivery system	$Ca(OH)_2$	Glass Ionomer Cement	Thermal test and laser doppler flowmetry	12 months	89% success rate with laser group 68% success rate with control group
Olivi *et al.*[23]	2007	CCT	11–40 years	Total: 64 Control: 21 Er, Cr: YSGG: 25 Er: YAG laser: 18	Er, Cr: YSGG laser+Ca $(OH)_2$ Er: YAG laser+Ca $(OH)_2$ irradiated at 75–100 mJ (1–1.5 W) for 60 s	$Ca(OH)_2$	Composite restoration	Vitality testing and Intraoral X-ray	4 years	80% success rate with laser with Er, Cr: YSGG laser + Ca $(OH)_2$ 75% success rate with Er: YAG laser + Ca $(OH)_2$ 63% success rate with control group
Yazdanfar *et al.*[16]	2015	RCT (pilot study)	12–40 years	10	Diode lasere 808-nm Hemostatic agent: 1.5 W, CW, fiber diameter of 400 µm, in contact, 2 s per 1 mm, vertical and horizontal scanning movement on the exposure site Decontamination of the cavity: 1 W, CW, fiber diameter of 400 µm, in contact, 2 mm per s, circular movement	Resin-modified glass ionomer cement	Resin composite	Clinical assessment and periapical radiograpsh	12 months	100% success rate with laser group 60% success rate with control group
Cengiz *et al.*[13]	2016	RCT	18–41 years	60	Er, Cr: YSGG laser using the noncontact mode at an energy level of 0.5 W, a repetition rate of 20 Hz, and a 140 ms pulse duration with 0% water and 45% air for 10 s	Calcium hydroxide and theracal	Resin modified glass ionomer and composite resin	Clinical assessment and periapical radiographs	6 months	100% success rate with laser group 73.3% with CH control group 66.6% theracal control group
Suzuki *et al.*[10]	2019	RCT	18–33 years	28	CO_2 laser wavelength of 10.6 µm , power output of 0.5–5 W (changeable at 0.1-W increments), focus beam diameter of 0.15 mm at super-pulsed mode (pulse duration, 0.2 ms; interval, 5.8 ms; 0.003 J/pulse)	$Ca(OH)_2$	Resin composite	Clinical and histological examination	12 months	All of the teeth from the CO_2 laser group showed RDF the Dycal group showed one tooth with partial RDF, three with complete RDF, and three with no RDF
Yazdanfar *et al.*[15]	2020	RCT	15–35 years	20	Diode laser 808-nm Hemostatic agent: 1.5 W, CW, fiber diameter of 400 µm, in contact, 2 s per 1 mm, vertical and horizontal scanning movement on the exposure site Decontamination of the cavity: 1 W, CW, fiber diameter of 400 µm, in contact, 2 mm per s, circular movement	TheraCal LC Paste	Resin composite	vitality testing (thermal test, percussion test and palpation test) and dentin deposition in periapical radiograph	6 months	In the TheraCal group tertiary dentin deposition was 0.60±0.23 mm of dentin In the laser-TheraCal group, tertiary dentin deposition was 0.69±0.25 mm

Contd...

Table 3: Contd...

Author of the study	Year of study	Study design	Age of patient	Study sample	Laser type	Treatment agent	Restoration	Evaluation method	Follow up	Outcome
Wang *et al.*[12]	2020	RCT (pilot study)	21–66 years	47	Er: YAG laser 2940 nm was irradiated at settings of 15 Hz and 30 mJ with no water using a 0.6 mm tip Each time for 15 s and repeated three to five times until adequate haemostasis was achieved	$Ca(OH)_2$	Glass ionomer and composite resin	Clinical and radiographic examination	12 months	91.7% success rate with laser group 68.2% success rate with control group
Keranshah *et al.*[14]	2020	CCT	17–46 years	26	Er: YAG laser 2940 nm wavelength, 10 Hz repetition rate, 1mm tip diameter with minimal distance from the exposure site was used for 10 seconds in a scanning mode on the site with 0.5 mm of the surrounding tissues	ProRoot MTA	Resin composite or high copper amalgam	clinical and radiographic examinations	3 months	75% success rate in the laser group and 93% success rate in the control group

RCT: Randomized controlled trial, CCT: Controlled clinical trial, MTA: Mineral trioxide aggregate, CW: Continuous wave, ER: YAG: Erbium-doped yttrium-aluminum-garnet, erbium, Er, Cr: YSGG: Erbium, chromium: yttrium-scandium-gallium-garnet, CH: Calcium hydoxide, RDF: Remaining dentin thickness

personnel, analysis intention (blinding of outcome assessment), incomplete outcome data, selective reporting (selection of the reported results), and other types of bias not considered previously (e.g., design bias, contamination bias). The methodological quality of each study was classified as low, high, or unclear risk. Random sequence generation was reported adequately in three studies and inadequately in four studies. Allocation concealment was not reported adequately in any of the studies and was categorized as high risk. The nature of the interventions did not allow for examiner and participant blinding; however, examiner blinding was reported in one study. Blinding of outcome assessment was reported only in one study. Six studies were adequate in reporting the outcome data and one study did not report appropriate measures to compensate for missing data. All the studies were adequate in reporting. Other unspecified types of bias were also considered as associated with the lack of information on sample size estimation, inclusion and exclusion criteria, and examiner calibration. Table 4 depicts the ROB of included non-RCT studies. Figure 2 depicts the ROB of included RCT studies.

The meta-analyses, using the random effects model, were applied with RevMan 5.4 (RevMan 5.4, the Nordic Cochrane Centre, Copenhagen). Heterogeneity was assessed by *Q*-test and quantified with I^2 statistics. Data on event frequency of the event and total sample size were obtained from selected studies. Clinical/radiological success/failure among the teeth treated with either low-level laser therapy or nonlaser therapy was considered the main outcome. Comparisons for failure were performed using number of failed cases among the total sample size. For analyses, if the test showed substantial heterogeneity ($I^2 > 50\%$), a

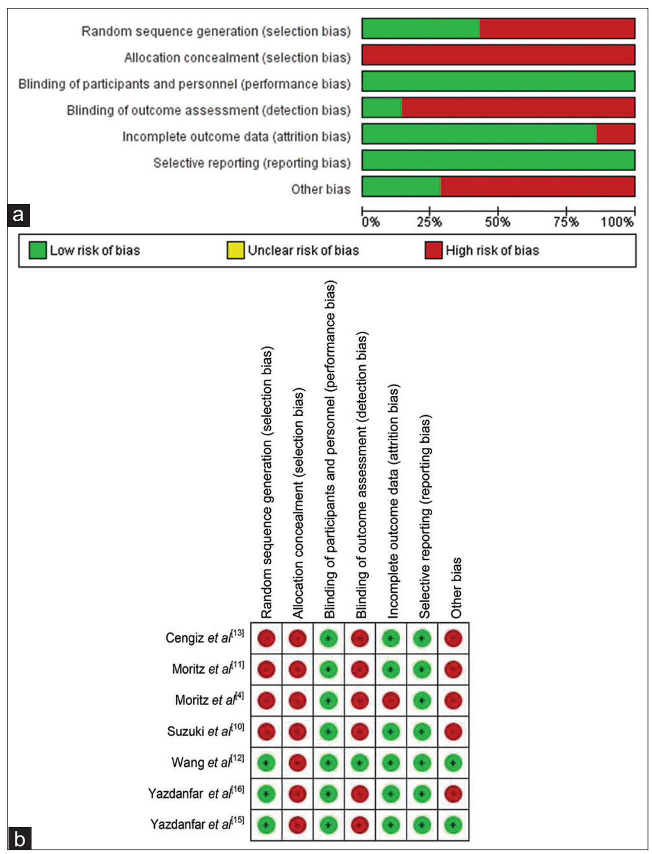

Figure 2: (a) Risk of bias graph: review authors' judgments about each risk of bias item presented as percentages across all included randomized studies (b) Risk of bias summary: review authors' judgements about each risk of bias item for each included randomized study

random effects model was applied, or else ($I^2 \leq 50\%$), a fixed effects model would be used. The meta-analysis

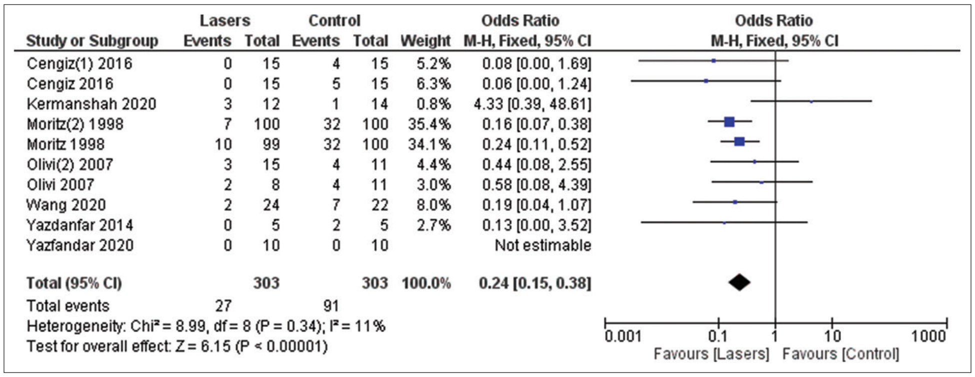

Figure 3: Forest plot of the meta-analysis results. CI: Confidence interval. Events: The number of failure

Table 4: Risk of bias assessment of included nonrandomized studies

Study ID	Olivi *et al*. 2007[23]	Karmenshah *et al*. 2020[14]
Bias due to confounding	Low	Low
Bias in selection of participants into the study	Low	Low
Bias in classification of interventions	Low	Low
Bias due to deviations from intended interventions	Low	Low
Bias due to missing data	Moderate	Low
Bias in measurement of outcome	Low	Low
Bias in selection of the reported result	Low	Low
Risk of bias	Low	Low

was performed on ten comparisons from seven studies that have qualified with the required data outcome that could be analyzed quantitatively. The results of the overall comparison have been depicted as a forest plot [Figure 3]. With the meta-analysis conducted for selected studies, heterogeneity was <50% (I^2 = 11%); hence, fixed effect model was applied. Teeth treated with low-level laser therapy pulp capping therapy showed lower clinical/radiological failure as compared to nonlaser pulp capping therapy with an odds ratio of 0.24 (95% confidence interval = 0.15–0.38; Z = 6.15); and the difference between two groups was statistically significant ($P < 0.00001$).

DISCUSSION

The specialty discipline of "Endodontics" not only revolves around the root canal therapy anymore, shift in the paradigm wherein maintaining the vitality and integrity of the pulp organ have become prime focus. Among the treatment options available, DPC is the most conservative and simplest approach to maintain the vitality of pulp as it does not involve the removal of pulp tissue compared with pulpotomy procedures.[2] The primary steps in treating DPC are hemostasis and cleaning of the exposed pulp tissue and the surrounding dentin, followed by sealing the exposed pulp with one of the aforementioned dental materials. The most popular method for hemostasis of exposed pulp tissue is using mild pressure with cotton pellets wet with 3%–6% sodium hypochlorite, which is time-consuming and technique sensitive whereas laser used as an adjunct yielded better treatment outcome.[3]

Patients of different ages have been taken in different studies. The age of the participant included in the study varied from the youngest patient being 8[4] and the oldest patient being 74.[4] It has been reported that the prognosis of DPC is better in young patients because the pulps of younger patients are richer in cells and have a greater ability to regenerate. Dammaschke *et al*.'s study[5] and Cho *et al*.'s study[6] reported that the age of the patient has an influence on the success of the DPC procedure. Recent retrospective studies[7,8] stated that neither the different age groups nor gender affected the treatment planning and outcome for pulp capping. Finally, the influence of age on the outcome of DPC could not be found in this meta-analysis due to the limited data.

The DPC techniques in each of the included trials utilized rubber dam, creating ideal circumstances for infection prevention.[9] DPC treatment is designed to treat reversible pulpitis from injury by stimulating the formation of the dentin bridge which is often considered to be the sign of successful pulp healing. Depending on their wavelengths, each laser system has its own characteristics, advantages, and disadvantages. Seven studies included in meta-analysis used CO2 laser at wave-length 10,600 nm,[4,10,11] Erbium-doped: Yttrium-aluminum-garnet (Er: YAG) laser at 2936 nm,[12-14] Er, chromium: Yttrium-scandium-gallium-garnet (Cr: YSGG) laser 2780 nm,[13] Diode laser at 808 nm.[15,16] Only a study that compared two different lasers (Er: YAG and Er, Cr: YSGG) with control was done by Cengiz and Yilmaz[13] and concluded with the result 80% success rate with laser with Er, Cr: YSGG laser and success rate of 75% with Er: YAG laser.

Calcium hydroxide, gold standard material still has blatant drawbacks such as the potential for cytotoxicity, high solubility, and poor seal formation. Mineral trioxide aggregate (MTA) has gained popularity due to its many advantageous characteristics, such as biocompatibility, antibacterial activity, excellent sealing effects, and stable for the long run. In the present systematic review, 4 of the 6 included studies used $Ca(OH)_2$ as the pulp capping material, one study used Resin modified Glass Ionomer Cement, one study used Theracal LC (calcium disilicate cement), and one clinical study have evaluated the effects of lasers when ProRoot MTA was used as the pulp capping material. The success rate of MTA in DPC is superior with a higher proportion of calcified dentin bridge development, according to a systematic review and meta-analysis.[17-19] However, only one study in our analysis used MTA as a pulp capping agent. MTA requires humid circumstances for setting, which is one explanation. MTA cannot absorb moisture from the pulp tissue after it has been exposed to lasers because of the hemostasis and thermal coagulation action of the lasers.[3]

Pulp vitality can be examined using anamnesis, vitality tests, and intraoral radiography as part of the evaluation techniques used to gauge the clinical success rate in pulp exposures. Laser Doppler Flowmetry (LDF), a noninvasive, impartial, and painless technique to assess pulp vitality, can in some circumstances be used to monitor pulp blood flow. The test that came closest to serving as the sole gold standard was LDF, which showed remarkable promise.[20] There is a poor correlation between vitality test results and histology results. Numerous investigations have demonstrated that there is no relationship between the results of different pulp testing techniques and the pulp's true histological condition.[21] Comparing the pulse oximeter to the electric pulp test, cold test, and heat test, it can be said that the pulse oximeter is the most accurate diagnostic tool.[22] In the present study, two clinical studies used LDF for the final assessment of vitality of teeth and one clinical study[10] used histological analysis where the thickness and quality of the reparative dentin formed was evaluated.

Among all studies included in the present study, one clinical study[14] reported less success rate with laser (75%) when compared with the control group (93%). All other included clinical trials reported significantly more success rates with the laser group when compared to that of the control group in DPC procedure among permanent teeth.

This systematic review and meta-analysis included both the randomized and non-RCT. The Non-RCTs[14,23] had low ROB when compared to the RCTs included in the study. All included RCT studies met the inclusion and exclusion criteria, but some did not adequately describe their methods in detail (e.g., random sequence generation and allocation concealment). Only the performance bias of all the included was low. Hence, the results of this review must be interpreted with caution due to the very low level of evidence of studies and further studies must be conducted since there was insufficient evidence to support the effectiveness of the laser as an adjuvant to improve the success rate of DPC.

CONCLUSION

The present systematic review demonstrated that there is insufficient evidence to support the effectiveness of the laser as an adjuvant to improve the success rate of DPC. Therefore, the ROB of the included studies emphasized that further studies with a stronger methodological quality must be performed to elucidate which type of laser and irradiation protocol would be the most effective in this treatment. Based on the available information, the results of this meta-analysis demonstrated DPC treatment could achieve better clinical outcomes with the aid of lasers.

Limitations

In the present study, both randomized and non-RCTs were included. But to arrive at the best conclusion more RCTs are required. Many of the included studies exhibited small sample sizes, such that their overall veracity is questionable, and their results should be interpreted with caution. Comparison of different lasers has been done in only one study, more studies comparing different laser for DPC procedure among permanent teeth are needed so that stronger conclusions could be obtained.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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