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Does Laser Improve the Clinical Success in Direct Pulp Capping? A Systematic Review and Meta-Analysis

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Abstract

Objective: The aim of this study was to conduct a systematic review of the literature to evaluate the efficacy of laser as adjuvant therapy in direct pulp capping.

Materials & Methods: Two reviewers independently conducted the literature search in eight databases (Pubmed, Lilacs, Ibecs, Web of Science, BBO, Scopus, SciELO and The Cochrane Library) and in grey literature (Current Controlled Trials, International Clinical trials registry platform, ClinicalTrials.gov). Two authors extracted data, independently, using a standardized form. The characteristics of the studies included, such as the pulp capping agent, laser characteristics, restoration performed, methods used to assess pulp vitality, adverse effects and clinical success rate were analyzed. Clinical success was based on the percentage of teeth that remained vital after direct pulp capping. Statistical analyses were performed with the RevMan 5.2 program (The Cochrane Collaboration, Copenhagen, Denmark). A global comparison was performed with random-effects models at a significance level of $p < 0.05$.

Results: Initially, 896 studies recovered, 6 articles were selected and just 5 could be included in the meta-analysis. The types of lasers used in the studies were: Diode Laser, CO_2, Er:YAG, ErCr:YSGG and Nd:YAG. The overall risk ratio was 0.36 (95% CI 0.25 to 0.53). Although the laser therapy has improved the treatment success rate of teeth with exposed pulp ($p < 0.01$), the quality of the studies ranged between fair (4 studies) and poor (2 studies). Besides, the strength of evidence for the outcome was subsequently downgraded to very low.

Conclusion: There is insufficient evidence to support the efficacy of the laser as an adjuvant to improve the success rate of direct pulp capping. *PROSPERO registration number: CRD42015017356.*

Keywords: Clinical trial; Dental pulp capping; Lasers; Permanent teeth; Review

Introduction

Dental pulp can be exposed as the result of deep caries, accidental trauma or by preparation techniques used during the restoration of carious lesions [1]. In these cases, maintaining the pulp vitality greatly improves tooth prognosis, because the survival rate of endodontically treated teeth is not as high as it is for vital teeth [2]. One way of maintain the vital teeth is using direct pulp capping techniques, especially in cases of mechanical or trauma exposure [3,4]. In order to obtain the success of these treatments should be noted the absence of inflammation, hemorrhage control, seal antibacterial and placement of the suitable material over the exposed area [5,6].

Direct pulp capping (DPC) consists in placing a biocompatible material on the exposed pulp, preserving tooth vitality and function. The success rate of DPC in teeth with pulp exposure due to caries varied from 87.5% (> 6 months -1 year) to 72.9% (> 3 years) [7]. The materials for DPC should have resistance to bacterial leakage in the long-term, and stimulate the remaining pulp tissue to retain pulp function and vitality [8]. Materials such as calcium hydroxide and Mineral Trioxide Aggregate (MTA) have been tested as pulp capping agents [9,10] over the course of time. Calcium hydroxide has excellent antibacterial action, and the ability to induce dentin barrier formation [11], however, it provides a poor seal and the self-cure formulations are soluble and subject to dissolution over time [12]. Whereas, MTA has shown good biocompatibility; stability for the long-term, prevention of bacterial infiltration, and it is capable of inducing reparative dentin formation [13-15].

Nowadays, as result of new technologies, different types of lasers have been used in the treatment of oral and dental tissues. In endodontics, the laser has been used in various situations for pulp diagnosis, dentinal hypersensitivity, pulp capping and pulpotomy, modification of root canal walls, sterilization of root canals, root canal shaping and obturation, full root canal treatment and apicectomy [16-19]. The main types of lasers used in dentistry at present are the Neodymium:yttrium aluminum garnet (Nd:YAG), CO_2; Argon; Diode, and Erbium: yttrium aluminum garnet (Er:YAG) lasers [20]. When a tissue is laser irradiated, both an irreversible reaction from a photothermal effect and a reversible reaction from a photoactive effect occur [21,22]. The photothermal effect generally produces highly efficient antibacterial action [21]. The photoactive effect contributes to cell proliferation and migration, cytodifferentiation of odontoblast-like cells, synthesis of dentin extracellular matrix and reparative dentin formation; and a reduction in pain and inflammation [22].

Some clinical studies have suggested that laser used as adjuvant therapy could to increase the clinical success rates of pulp capping agents, such as calcium hydroxide [23,24] and resin-modified glass ionomer cement [25]. On the other hand, some animal experiments have shown that there are no statistically significant differences in the morphological responses between treated and non-laser treated groups after its application in direct pulp capping [22,26]. Thus, although some studies have shown the benefits of laser therapy in improving success rates of vital pulp therapy [23-26], the clinical efficiency of adjuvant laser is still controversial. Therefore, the aim of this study was to conduct a systematic review of the literature to evaluate the efficacy of laser as adjuvant therapy in direct pulp capping. The hypothesis tested was that adjuvant laser irradiation improves the efficacy of DPC and may increase the clinical success rate compared to the control: pulp capping material alone.

Materials & Methods

The protocol of this review was registered in the international database for systematic reviews PROSPERO (CRD42015017356), and it has been reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA Statement) [27]. To formulate the question in evidence-based practice, the authors used the following PICO: Population: patients that present pulp exposure; Intervention: laser-irradiation as adjuvant treatment; Comparison: direct pulp capping without laser-irradiation; Outcome: clinical success rate. The research question was: Does adjuvant laser irradiation improve the clinical treatment success rates of direct pulp capping?

Search strategies

The literature search was carried out by two independent reviewers until May 2016. The reviewers screened eight of the following databases: Pubmed (MedLine), Lilacs, Ibecs, Web of Science, BBO, Scopus, SciELO and The Cochrane Library - using the search strategy initially developed for PubMed (MedLine) (Table 1) and adapted for use in other databases. Additionally, a search in grey literature was also perfomed in the following databases: *Current Controlled Trials*, *International Clinical trials registry platform*, *ClinicalTrials.gov*. The references cited in the articles included were also checked to identify other potentially relevant articles. After the articles were identified in the databases, they were imported into Endnote X7 software (Thompson Reuters, Philadelphia, PA, USA) to remove duplicates.

Study selection

Two review authors independently assessed the titles and abstracts of all of the documents. The studies were analyzed according to the selection criteria (Table 2). Full copies of all of the potentially relevant studies were identified. Those that appeared to meet the inclusion criteria, or for which there were insufficient data in the title and abstract to make a clear decision, were selected for full analysis. The full-text papers were assessed independently and in duplicate by two review authors. Any disagreement regarding the eligibility of studies included was resolved by discussion and consensus or by a third reviewer. Only articles that fulfilled all of the eligibility criteria were admitted, being them studies evaluating laser used as adjuvant treatment in direct pulp capping in which the pulp was exposed due to deep caries; or the pulp was accidentally exposed during cavity preparation.

Data extraction

The data were extracted using a standardized form in Microsoft Office Excel 2013 software (Microsoft Corporation, Redmond, WA, USA). If there was any information missing, the authors of the papers included were contacted via e-mail to obtain the missing data.

The reviewers tabulated data of interest to compose a spreadsheet in Excel format, with all studies included, containing the following data: authors, study design, country, age of patients, number of patients and teeth, follow-up period (Table 3). The characteristics of the studies

Table 1: Search strategy used in PubMed (*MedLine*).

	Search Terms
#4	Search #1 AND #2 AND #3
#3	Search Controlled Clinical Trial OR Retrospective Studies OR Randomized Controlled Trial OR Studies, Retrospective OR Study, Retrospective OR Retrospective Study OR Prospective Studies OR Prospective Study OR Studies, Prospective OR Study, Prospective OR Clinical Trial OR ((clinical[Title/Abstract] AND trial[Title/Abstract]) OR clinical trials[MeSH Terms] OR clinical trial[Publication Type] OR random*[Title/Abstract] OR random allocation[MeSH Terms] OR therapeutic use[MeSH Subheading]) OR (randomized controlled trial[Publication Type] OR (randomized[Title/Abstract] AND controlled[Title/Abstract] AND trial[Title/Abstract]))
#2	Search Lasers OR Laser OR Q-Switched Lasers OR Laser, Q-Switched OR Lasers, Q-Switched OR Q Switched Lasers OR Q-Switched Laser OR Pulsed Lasers OR Laser, Pulsed OR Lasers, Pulsed OR Pulsed Laser OR Continuous Wave Lasers OR Continuous Wave Laser OR Laser, Continuous Wave OR Lasers, Continuous Wave OR Laser Therapy OR Laser Therapies OR Therapies, Laser OR Therapy, Laser OR Vaporization, Laser OR Laser Surgery OR Laser Surgeries OR Surgeries, Laser OR Surgery, Laser OR Laser Therapy, Low-Level OR Laser Therapies, Low-Level OR Laser Therapy, Low Level OR Low-Level Laser Therapies OR Laser Irradiation, Low-Power OR Irradiation, Low-Power Laser OR Laser Irradiation, Low Power OR Laser Phototherapy OR Phototherapy, Laser OR Low-Power Laser Therapy OR Low Power Laser Therapy OR LLLT OR Low-Level Laser Therapy OR Low Level Laser Therapy OR Low-Power Laser Irradiation OR Low Power Laser Irradiation OR Laser Biostimulation OR Biostimulation, Laser OR Laser Therapy, Low-Power OR Laser Therapies, Low-Power OR Laser Therapy, Low Power OR Low-Power Laser Therapies OR Laser Phototherapy
#1	Search Dental Pulp Exposure OR Exposure, Dental Pulp OR Pulp Exposure, Dental OR dental pulp OR Pulp, Dental OR Pulps, Dental OR Dental Pulps OR Pulpitis OR Pulpitides OR Pulpite OR Inflammation, Endodontic OR Pulp Capping and Pulpectomy Agents OR Pulp Capping Agents OR Agent, Pulp Capping OR Agents, Pulp Capping OR Capping Agent, Pulp OR Capping Agents, Pulp OR Pulp Capping Agent OR Dental Pulp Capping OR Recubrimiento de la Pulpa Dental OR Capeamento da Polpa Dentária OR Calcium Hydroxide OR Hydroxide, Calcium OR Mineral Trioxide Aggregate OR MTA

Table 2: Inclusion and Exclusion Criteria.

	Inclusion Criteria	**Exclusion Criteria**
Population	Studies of participants with:	Studies of participants with:
	§ Human vital permanent teeth	§ Human vital deciduous teeth
	§ Pulp exposure by deep caries, trauma or during caries removal	§ Non vital teeth
Intervention	Studies of participants who have undergone the following procedures:	Studies of participants who have undergone the following procedures:
	§ Laser irradiation used as adjuvant treatment in Direct Pulp Capping	§ Use of lasers as treatment
	§ Materials used in pulp capping with and without previous laser irradiation	§ Bases or liners were used before laser application
		§ Lack of an adequate control group without laser therapy
Outcomes	Studies investigating:	-
	§ Clinical success based on pulp vitality	
Study Design	§ Prospective or retrospective clinical trials	§ Non-controlled clinical trials
		§ Animal experiments
		§ Reviews, editorial letters, case reports, case series
		§ Studies published in a language other than English, Portuguese or Spanish

Table 3: Description of demographic data, study design and main objectives of studies included.

Study	Country	Study Design	Objectives	Age	Number of patients	Number of teeth (at beginning)	Follow-up (months)	Number of teeth (at the end)
Moritz et al. 1998 [23]	Austria	RCT, Parallel Groups	To analyze the efficacy of using CO_2 laser working in superpulsed mode with $Ca(OH)_2$ in direct pulp capping	9–68	260	260	24	200
Moritz et al. 1998 [24]	Austria	RCT, Parallel Groups	To evaluate the CO_2 laser as an aid in direct pulp capping	8–74	200	200	12	200
Santucci 1999 [25]	United States	Retrospective Study	To analyze the efficacy of treating permanent teeth with Nd:YAG laser and resin-modified glass ionomer cement and compare with $Ca(OH)_2$.	-	83	93	54	22
Olivi et al. 2007 [36]	Italy	CCT, Parallel Groups	To verify the effectiveness of two types of laser combined with calcium hydroxide base in pulp capping of carious teeth.	11-40	34	64	48	64
Yazdanfar et al. 2015 [35]	Iran	RCT, Parallel Groups (Pilot study)	To compare the effectiveness of conventional and diode laser-assisted methods in direct pulp capping of carious teeth.	12–40	10	10	12	10
Cengiz & Yilmaz 2016 [37]	Turkey	RCT, Parallel Groups	To evaluate the efficiency of Er,Cr:YSGG laser irradiation combined with a resin modified tricalcium silicate–based material and CH in direct pulp capping performed on the exposed pulps of permanent teeth	18-41	60	60	6	60

RCT: Randomized Clinical Trial; CCT: Controlled Clinical Trial

included, such as the selection criteria, treatment agent, laser irradiation application, restoration, methods used to assess pulp vitality, adverse effects and clinical success rate were also analyzed (Table 4).

Statistical analysis

The analyses were performed with Review Manager Software version 5.2 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark), considering the teeth with pulp vitality of both the laser and control group of each study. In addition, for studies that evaluated more than one type of laser, both data sets were analyzed, and studies that evaluated more than one laser were included twice. Multiple groups from the same study were analyzed according to Cochrane guidelines formula for combining groups [28]. Pooled-effect estimates were obtained by comparing the risk ratio of each study with a 95% confidence interval (CI). Random-effects models were used; and heterogeneity was assessed by using Cochran's Q test and inconsistency I^2 statistics, with values higher than 50% being considered indicative of substantial heterogeneity [28].

Quality assessment and level of evidence

The methodological quality of each study included was independently assessed by the two reviewers based on the checklist created by Downs and Black [29], in order to provide a framework for judging the methodological quality of the clinical trials and the power of the scientific evidence. This checklist assessed the quality of both randomized and non-randomized studies of health care interventions, and it consisted of 27 questions divided into 5 sections: reporting, external validity, internal validity–bias, internal validity–confounding, and power. According to previous systematic reviews [30-32], the scoring for question 27 (that addresses statistical power) was simplified to a choice of awarding either 1 point or 0 points, depending on whether there was sufficient power. The scores of the Downs and Black checklist could be grouped into four quality levels: ≤14; poor; 15–19, fair; 20 –25, good; and 26 –28, excellent. Moreover, the evidence for the outcome was graded according to the GRADE working group of evidence using Grade Profiler 3.6 [33]. In this method, the overall body evidence is classified as high, moderate, low or very low. Thereafter, a weighting system with some factors is used to reduce (in the presence of study limitation (risk of bias), inconsistency of results (heterogeneity), indirect evidence, inaccuracy, and publication bias) or increase the quality of evidence (in the presence of large magnitude of effect, dose-response gradient, confounders or biases would reduce the effect found). After that, the results from the outcomes are presented together with the quality of the evidence.

Results

Search strategy

A total of 896 potentially relevant studies were identified in all of the databases, with no additional studies being identified as relevant after a search of the reference lists. Figure 1 is a flowchart that summarizes the article selection process according to the PRISMA Statement [27]. After examining the title and abstract, 618 studies were excluded because they did not meet the eligibility criteria. Of the 7 studies retained for detailed review, 1 study could not be included because the treatment performed was not DPC in permanent teeth [34]. A total of 6 studies fulfilled all of the selection criteria and were included in the qualitative analysis, and 5 studies were included in the meta-analysis. One study [25] was not included in the meta-analysis due to not having adequate control for comparison of laser efficacy (study did not compare the same pulp capping material with and without laser irradiation).

Descriptive analysis

Six studies investigating the vitality of teeth after direct pulp capping were published between 1998 and 2016, of which one was a retrospective study [25], the others were controlled and/or randomized clinical trials. The sample size ranged from 10 teeth [35] to 200 teeth [23,24] among the studies. A total of 556 teeth were evaluated in this review, considering all clinical trials included, and the age of patients ranged from 8 to 74 years. All clinical studies had a minimum of 6 months of follow-up.

The lasers used in the studies included were Diode Laser, CO_2, Er:YAG, ErCr:YSGG and Nd:YAG. The protocol and type of laser

Table 4: Clinical success rate and characteristics of included studies.

Study	Selection criteria	Treatment Agent	Laser application	Restoration	Evaluation method	Clinical Success (%)	Adverse effects
Moritz et al. 1998 [23]	Healthy patients; Clinically asymptomatic pulps; Pulps accidentally exposed during (mechanical) cavity preparation by the inadvertent removal of a layer of healthy dentin.	Superpulsed CO_2 laser + $Ca(OH)_2$ (Life, Kerr, USA)	Superpulsed mode, wavelength 10.6 µm, Output power of 1W - 0.1 s pulses with 1 s pulse intervals	Glass Ionomer Cement (Ketac-Fil, 3M ESPE, USA)	Thermal test and Laser Doppler Flowmetry (LDF)	93 (E)	None
		$Ca(OH)_2$ (Life, Kerr, USA)	-			68 (E)	
Moritz et al. 1998 [24]	Healthy patients; Clinically asymptomatic pulps; Pulps accidentally exposed during (mechanical) cavity preparation by the inadvertent removal of a layer of healthy dentin.	CO_2 laser + $Ca(OH)_2$ (Life, Kerr, USA)	Wavelength of 10.6 µm, output power of 1W, 0.1 s pulses with 1 s pulse intervals. An additional helium-neon aiming beam was incorporated into the delivery system.	Glass Ionomer Cement (Ketac-Fil, 3M ESPE, USA)	Thermal test and Laser Doppler Flowmetry (LDF)	89 (E)	None
		$Ca(OH)_2$ (Life, Kerr, USA)	-			68 (E)	
Santucci 1999 [25]	Patients with sensitivity to cold or sweet, of short duration, and no other history of pain; Absence of periapical pathosis in the radiograph.	Nd:YAG laser + Resin-modified glass ionomer cement (Vitrebond, 3M ESPE, USA)	Average power of 1.75 W and 20 pulses per second	Composite resin or cast gold restoration	Thermal test	90.3 (E)	None
		$Ca(OH)_2$	-			43.6 (E)	
Olivi et al. 2007 [36]	Patients aged between 11 and 18 years who underwent conservative treatment for deep caries of permanent teeth	$Ca(OH)_2$*(Life, Kerr, USA)	-	-	Anamnesis, vitality testing and intraoral x-ray	63	None
		Er,Cr:YSGG laser + $Ca(OH)_2$ (Life, Kerr, USA)*	Power of 1-1,5 W for 60 sec			80	
		Er:YAG laser + $Ca(OH)_2$* (Life, Kerr, USA)	Power of 1-1,5 W for 60 sec			75	
		$Ca(OH)_2$**(Life, Kerr, USA)	-			50	
		Er,Cr:YSGG laser + $Ca(OH)_2$*(Life, Kerr, USA)*	Power of 1-1,5 W for 60 sec			80	
		Er:YAG laser + $Ca(OH)_2$**	Power of 1-1,5 W for 60 sec			70	
Yazdanfar et al. 2015 [35]	Permanent teeth with deep caries; Vitality of teeth; No periapical radiographic changes.	Diode laser + Resin-modified glass ionomer cement (Vitrebond, 3M ESPE, USA)	Two steps: 1. Hemostatic agent 1.5 W, continuous wave, fiber diameter of 400 µm, in contact, 2 s per 1 mm, vertical and horizontal scanning movement on the exposure site. 2. Decontamination of the cavity: 1 W, continuous wave, fiber diameter of 400 µm, in contact, 2 mm per s, circular movement.	A layer of flowable Z350 XT; and composite resin (P60, 3M ESPE, USA)	Anamnesis, vitality testing (thermal test, percussion test and palpation test) and intraoral x-ray	100 (E)	None
		Resin-modified glass ionomer cement (Vitrebond, 3M ESPE, USA)				60 (E)	

Cengiz & Yilmaz 2016 [37]	Permanent teeth with deep caries; No clinical symptoms; Vitality of teeth; No periapical radiographic changes; Diameter of the exposed area between 0.5 and 1.5 mm.	$Ca(OH)_2$ (Dycal, Dentsply, USA)	-	Resin-modified glass ionomer (GC Fuji II LC; GC Corp, Japan) + Composite resin (Clearfil Majesty Posterior; Kuraray Medical Inc, Japan)	Anamnesis, vitality testing (thermal test, percussion test) and intraoral x-ray	73.3	None
		Er,Cr:YSGG laser + $Ca(OH)_2$ (Dycal, Dentsply, USA)	Energy level of 0.5 W, a repetition rate of 20 Hz, and a 140-µs pulse duration with 0% water and 45% air for 10 s			100	
		Resin-based tricalcium silicate (TheraCal LC, Bisco, USA)	-			66.6	
		Er,Cr:YSGG laser + Resin-based tricalcium silicate (TheraCal LC, Bisco, USA)	Energy level of 0.5 W, a repetition rate of 20 Hz, and a 140-µs pulse duration with 0% water and 45% air for 10 s			100	

E, Estimated cumulative survival function; O, Observed proportion of teeth surviving;
*Patients between 11 and 18 years old; **Patients between 19 to 40 years old.

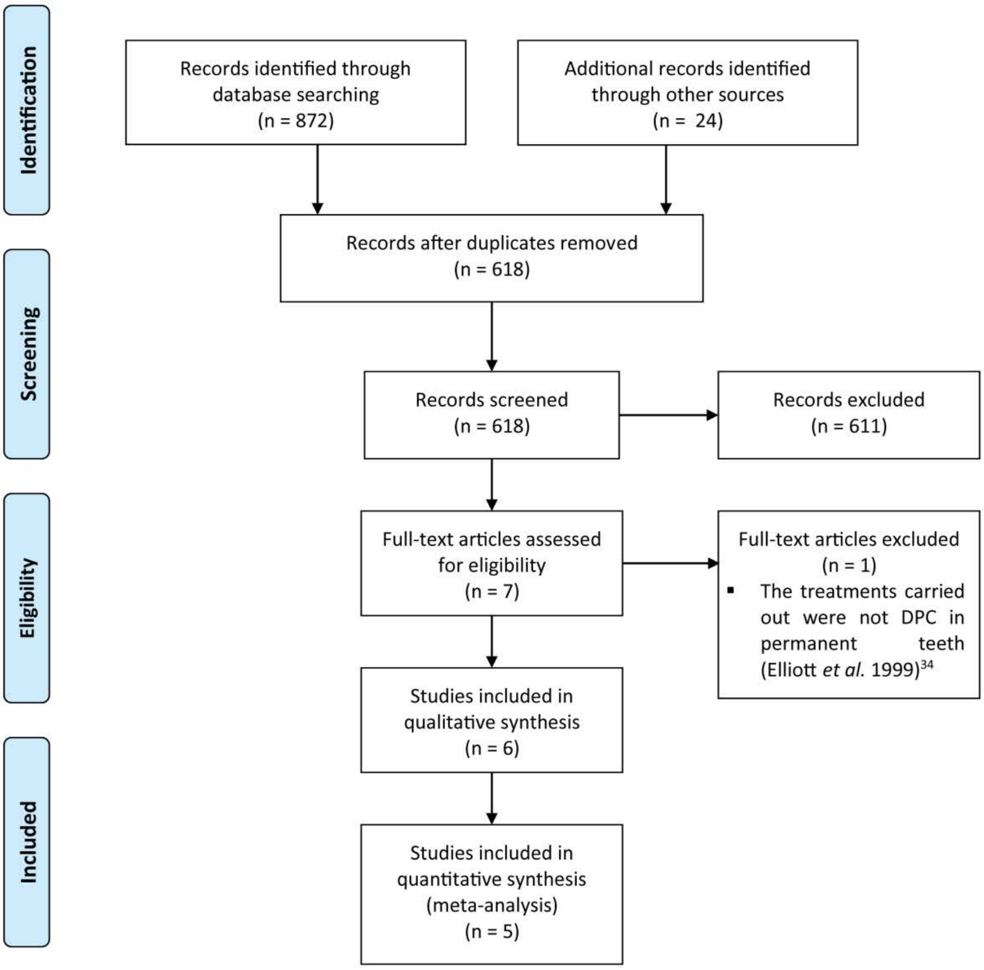

Figure 1: Search flow (as described in the PRISMA statement).

used varied in each study, as described in Table 3. Thermal tests, radiographic examination, clinical tests and Laser Doppler Flowmetry (LDF) were the evaluation methods used to assess pulp vitality in clinical trials. None of the studies included reported any adverse events associated with laser-irradiation used as adjuvant to treatments for pulp exposures.

Meta-analysis

A meta-analysis was performed with 5 prospective clinical trials. The overall risk ratio was 0.36 (95% CI 0.25 to 0.53) (Figure 2), meaning that laser therapy influenced the success rate of teeth with exposed pulp ($p < 0.01$). Moreover, the heterogeneity of the studies included in the analysis of pulp vitality was not significant (x^2 test; $p = 0.42$), and the variability of the studies is probably attributable to chance alone ($I^2 = 0\%$) and not heterogeneity.

Risk of bias and level of evidence

The articles included in this review scored between 10 and 17 on the Downs and Black [29] scale**,** with a mean of 12.8 ± 2.78. Agreement between the 2 authors was substantial (Kappa = 0.9076). The results indicated that the quality of the studies ranged between fair (4 studies) and poor (2 studies) (Table 5). The studies scored particularly poorly

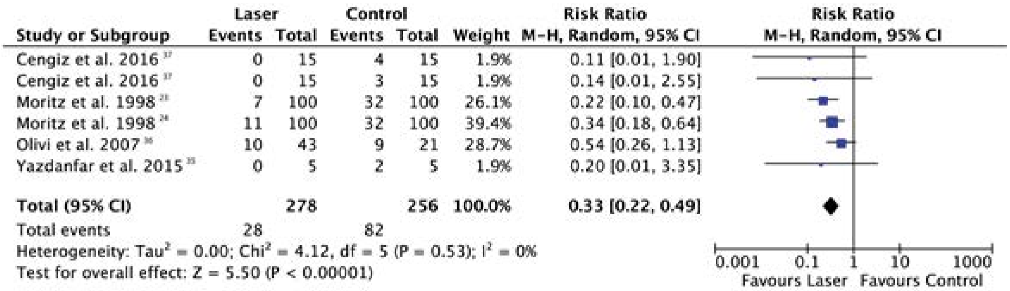

Figure 2: Forest plot for the analysis of the success rate of teeth with exposed pulp after laser therapy when compared with control group. Laser therapy influenced the success rate and it differed statistically from the control ($p < 0.01$).

Table 5: Quality assessment using the Downs and Black Scale.

Author	**Reporting**										**External Validity**			**Internal Validity**															**Quality level**
														Bias							Confounding						Power		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	**Total**	
Moritz et al.1998 [23]	1	1	1	1	0	1	0	0	1	0	0	1	1	0	0	1	1	1	1	1	1	0	1	0	0	1	0	16	fair
Moritz et al. 1998 [24]	1	1	1	1	0	1	0	0	1	0	0	1	1	0	0	1	1	1	1	1	1	0	1	0	0	1	0	16	fair
Santucci 1999 [25]	1	1	1	1	0	1	1	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	1	0	15	fair
Olivi et al. 2007 [36]	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	9	poor
Yazdanfar et al. 2015 [35]	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	0	0	1	0	13	poor
Cengiz & Yilmaz 2016 [37]	1	1	1	1	0	1	1	0	1	1	0	0	1	0	0	1	1	1	1	1	1	0	1	0	0	1	0	17	fair

*The scores of the Downs and Black checklist are grouped into four quality levels: ≤14: poor; 15-19: fair; 20-25: good; and 26-28: excellent

in the following items: descriptions of adverse events, sample representativeness, patient and assessor blinding, adjustment for confounding factors in the analysis, and power.

The strength of evidence (GRADE) for the outcome was subsequently downgraded to very low. It was arising from risk of bias being very serious in study limitations, imprecision and inconsistency (Table 6).

Discussion

The results of this review must be interpreted with caution due to very low level of evidence of studies and further studies must be conducted once there was insufficient evidence to support the efficacy of the laser as an adjuvant to improve the success rate of direct pulp capping. At first sight, it seems that the hypothesis is accepted, however, if we take into account other variables evaluated (the quality of evidence was very low) it is possible to note that the evidence found is not enough to be supported. As regards post-treatment outcome, success rates with adjuvant laser therapy ranged between 70% [36] and 100% [35,37], being higher than the control in all trials included, which varied from 43% [25] to 73.3% [37]. The depth and extent of tissue changes can be more superficial or deeper according of wavelengths utilized. The CO_2 laser (wavelength of 10.600 nm) for example, penetrates pulpal / oral tissue to a depth of 0.1-0.2 mm whereas Nd: YAG laser (wavelength of 1.064 nm) and Diode laser (wavelength of 670 -980 nm) penetrate more deeply (3-5 mm). This can represent different biological effects for each type of laser. Thus, the clinical trials that evaluated different types of laser supported different approaches, and their effective comparison was difficult. Some experiments in animals have shown that the use of different lasers can contribute to reparative dentin formation, hemostasis and sterilization due the thermal effects of laser treatment [26,38-41]. In addition, laser was shown to be effective in controlling bleeding after pulp exposure [26,42], contributed to a smaller inflammatory response and induced tissue organization [22]. A recent study [43] summarized the main biological advantages and disadvantages of lasers used in pulp capping. Among the advantages it can be highlighted hemostasis, decontamination and photobiostimulation the pulp tissue. However, the CO_2, Nd: YAG and Diode lasers showed a higher thermal change (carbonization and strong coagulation), which can be a great inconvenience, as well presents a high cost.

Some factors that could influence success rate of vital pulp therapies must be carefully considered. The outcome of deep caries lesion treatment, with or without pulp exposure, depends on how extensively the pulp is infected at the time of treatment, in addition to the patient's age; treatment approach; choice of material applied to the exposed pulp tissue, and the restorative material capacity to prevent bacterial leakage [44,45]. Although some studies presented a wide variation in patients' age, one study compared the treatments with and without two different types of laser (Er,Cr:YSGG and Er:YAG) in adults and children, and showed that the age and the type of laser tested did not interfere in the outcome of this study [36]. Furthermore, as an adjuvant therapy in pulp

Table 6: The overall quality of clinical recommendations for each of the main outcomes using the Grades of Recommendation, Assessment, Development, and Evaluation (GRADE).

Does laser improve the clinical success in direct pulp capping? A systematic review and meta-analysis			
Patient or population: Patients that present pulp exposure **Settings:** Clinical trials **Intervention:** Laser-irradiation as adjuvant treatment			
Outcomes	**Number of Teeth (Studies)**	**Quality of the evidence (GRADE)**	**Comments**
Clinical success rate	556 teeth (6 studies)	⊖⊖⊖⊖ **very low [1-4]**	Study limitations, imprecision, inconsistency
GRADE Working Group grades of evidence **High quality:** Further research is very unlikely to change our confidence in the estimate of effect. **Moderate quality:** Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate. **Low quality:** Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate. **Very low quality:** We are very uncertain about the estimate.			
[1]No random sequence generation [2]No allocation concealment [3]No blinding of participants or outcome assessment [4]Small sample size			

capping, laser can be used with different purposes. For example, one pilot study with promising results evaluated the use of diode laser in two different application protocols: initially to act as a hemostatic agent, followed by another protocol for decontamination of the cavity [35]. Other applications, depending on the situation and type of laser, are ablation of carious dentin without direct contact (minimizing mechanical damage to the exposed pulp) and diagnosis (pulp vitality test) [43].

With regard to the evaluation methods used to assess clinical success rate in pulp exposures, pulp vitality can be analyzed based on anamnesis, vitality tests and intraoral radiographs. In some cases, pulp blood flow can be measured with Laser Doppler Flowmetry (LDF) - a noninvasive, objective and painless method to evaluate pulp vitality [46]. The true state of the pulp that interferes with the choice of treatment and its outcome, is difficult to diagnose. Pulp vitality testing is hampered by its subjectivity and the fact that it is a measure of neuronal status, and not true pulp viability. The thermal test, for example, reveals only a dichotomous response. The clinical signs and symptoms such as degree or characteristic of pain do not precisely reflect the pulp condition [47]. To assess tooth vitality, thermal tests and measurements of pulpal blood flow with Laser Doppler Flowmetry (LDF) were carried out by two studies [23,24]. With this method, typical perfusion curves synchronous with heart beat and vasomotion can be obtained, allowing tooth vitality to be assessed [23]. Although assessments by LDF may be highly susceptible to environmental and technique-related factors, it has been shown to be a reliable method for measuring pulp blood flow, and consequently, pulp vitality [46,48].

Systematic reviews are important tools for clinical practice, since they provide a critical approach of the scientific knowledge with the aims of answering clinically relevant questions based on the best scientific evidence available [49,50]. One limitation of this review was the degree of scientific evidence obtained and the quality level of the studies found, capable of incurring a risk of bias, thus their results must be considered with caution. Although this is the best currently available evidence that demonstrates a clinical benefit of using laser as adjuvant therapy in direct pulp capping, the strength of clinical inference is not strong. Even the randomized clinical trials included showed design discrepancies. The majority of studies included analyzed the clinical success rate with a wide variation in the evaluation period. Moreover, the studies included also showed heterogeneity regarding the type of laser used and the treatment protocol, thus precluding a direct comparison. It was not possible to establish the type of laser that would be the most suitable for use as an adjuvant to direct pulp capping treatment. Another limitation of this study was that only studies in English, Spanish and Portuguese were included, which may have limited the number of studies recovered. Finally, the quality of the studies included emphasized the need for further well-designed, randomized and controlled clinical trials to highlight the benefits of using laser therapy used as adjuvant to pulp exposures treatments. Factors such as sample randomization, sample size calculation, use of blinding (patients and/or evaluators), analysis of restoration quality, and use of different evaluation methods could improve the quality of further clinical trials in this field of research. This way, it is important to point out the quality of evidence obtained from included studies was very low and although this is the best scientific evidence available, further studies examining different laser types and irradiation protocol are required in order to obtain stronger conclusions.

Conclusion

Our review demonstrated that there is insufficient evidence to support the efficacy of the laser as adjuvant to improve the success rate of direct pulp capping. Therefore, the risk of bias 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.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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