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REVIEW ARTICLE

Efficacy of low-level laser therapy in pain management after root canal treatment or retreatment: a systematic review

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Abstract

The aim of this study was to assess the effectiveness of low-level laser therapy (LLLT) for pain management after root canal treatment or retreatment. An electronic search for randomized controlled trials was conducted prior to November 2018, through PubMed, EMBASE, the Cochrane library (CENTRAL), and Web of Science. After filtering, seven articles were included, five related to root canal therapy (RCT) and two related to root canal retreatment (RCR). Six of the included studies presented a moderate risk of bias and a one low risk of bias, based on the Cochrane tool of risk of bias evaluation. The laser treatment included diode laser and indium–gallium–aluminum laser. LLLT was compared with placebo, blank, and ibuprofen treatment. Clinical outcome variables included the prevalence of pain, pain intensity, and need for analgesics after treatment. Three studies showed LLLT could reduce the prevalence of pain significantly after RCT or RCR. Although the effect of LLLT on pain intensity varied at different observation time points and among different studies, most of them found patients had lower pain intensity in the LLLT group. Of the three studies that assessed the need for analgesics after treatment, two studies showed significant benefits. Based on the current evidence, the use of LLLT for pain control in postendodontic therapy may be promising. However, solid conclusions should not be drawn definitely, given that more high-quality randomized controlled trials are required to further evaluate the efficacy of LLLT for pain management after RCT and RCR.

Keywords Low-level laser therapy · Pain · Root canal treatment · Root canal retreatment · Systematic review

Introduction

Postoperative pain is one of the most common complications of endodontic treatment. It not only brings discomfort to patients, but can lead to emergency room visits. The prevalence of pain after endodontic treatment is reported to range from 3 to 58% according to a systematic review [1]. The pain after endodontic treatment can be categorized into two different types: flare-up and general postoperative pain. Flare-up manifests as pain and/or swelling within a few hours or days after treatment, which is characteristic of a pain with more severe intensity than the general postoperative pain [1]. Root canal retreatment (RCR) is reported to have a higher prevalence of flare-up pain than root canal treatment (RCT), yet no significant differences in postoperative pain levels have been found between the two groups [2–4].

The postoperative pain caused by RCT and RCR is related to an inflammatory response in the periapical tissue [1]. This response triggers nociceptors through inflammatory mediators, such as prostaglandins, leukotrienes, bradykinin, and serotonin, which results in pain after treatment. Mechanical, chemical, and microbial factors are key links associated with periapical inflammation after RCR and RCT, even when the root canal preparation did not exceed the apical foramen during the treatment. Extrusion of tooth debris, intracanal medicaments, root canal irrigation solutions, and microorganisms might still occur, followed by unexpected inflammation and pain [5, 6].

For better postoperative pain assessment, researches sought to assess factors mediating postoperative pains after RCR and RCT. It is widely suggested that preoperative pain is significantly associated with postoperative pain intensity [7–9]. Law

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et al. pointed out that pain that interfered with daily activities and was enhanced with the stress and diagnosis of symptomatic apical peridodontitis can be regarded as an independent predictor for postoperative pain intensity [7–9]. Different instrumentation techniques for root canal preparation, such as working length determination methods, reducing the occlusion, irrigation system, cold lateral compaction, and obturation techniques, were also considered to influence the occurrence and intensity of postoperative pain [10–13].

Several treatment strategies have been suggested for the management of postendodontic therapy pain; most of them are pharmaceutical treatments, prescribed as prophylactic medications and postoperative analgesics (pain-reliever drugs) [10].

Recently, low-level laser therapy (LLLT) has attracted increasing attention due to its effectiveness in pain relief. LLLT, discovered by Mester in 1967, is defined as a non-thermal, red, or near-infrared laser with a wavelength range of 600 to 1000 nm and an energy output range of 5 to 500 mW [14, 15]. Currently, LLLT has a wide range of applications in dental treatments, including the management of orthodontic pain, the management of symptomatic oral lichen planus, the healing of human bone maxillofacial defects, and prophylaxis of stomatitis among others [16–19]. LLLT was introduced to endodontic treatment due to its capability in promoting wound healing, role in root canal disinfection, pain relief, and the lack of adverse events [20, 21]. However, the underlying mechanisms of pain reduction via LLLT have not been fully understood yet. Attractive hypotheses postulate that LLLT can reduce pain through biochemical mechanisms based on increased adenosine triphosphates (ATPs) and reduced oxidative stress [15]. Chow et al. conducted a systematic review and suggested that the laser light (energy intensity above 300 mW/cm^2) absorbed by nociceptors can exert an inhibitory effect on A^{δ} and C pain fibers, thereby slowing down conduction velocity, reducing amplitude of compound action potential, and suppressing neurogenic inflammation [22].

The reduction of postendodontic treatment pain has always been a hot research area, with the past 2 years witnessing a bloom of studies focused on the analgesic properties of LLLT for RCR and RCT [23–27]. However, none has systematically reviewed the effectiveness of LLLT for postoperative pain management in RCR and RCT. Thus, the aim of this systematic review was to synthesize the available evidence from randomized controlled trials to evaluate the effectiveness of postoperative pain reduction of LLLT for RCT and RCR.

Materials and methods

This systematic review was carried out following the Cochrane Handbook for the Systematic Reviews of Interventions and the preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [28].

Focused PICO question

Some patients experience pain after root canal treatment or retreatment; our focused question of interest was “does LLLT have an effect on postoperative pain control after RCT or RCR?”

Literature search and study selection

An electronic literature search was conducted for randomized controlled trials without language limitations prior to November 2018 via PubMed, EMBASE, the Cochrane library (CENTRAL), and Web of Science. Appropriate search strategies were developed for each database using the following search terms: (root canal therapy OR root canal treatment OR endodontic treatment OR endodontic therapy OR root canal obturation OR endodontic obturation OR root canal filling OR root filling OR endodontic retreatment OR root canal retreatment) AND (pain OR discomfort OR analgesia) AND (laser OR laser therapy OR laser irradiation OR phototherapy OR low-level laser OR low-intensity laser OR low-output laser OR soft laser).

Two independent authors (Y.C and X.L.C) screened the titles and abstracts derived from the electronic search to identify potentially eligible studies. The full texts of all candidate studies were further evaluated to identify studies that met all inclusion criteria. To avoid missing any eligible studies, the references of all included articles or relevant reviews were also searched. Any discrepancies were resolved by discussion.

Eligible criteria

The inclusion criteria were as follows:

1. Studies were randomized controlled trials reporting the efficacy of LLLT on pain control after RCT or RCR.
2. Participants received conventional RCT or RCR. There were no limitations on age, gender, ethnicity, or socioeconomic status of the participants.
3. Participants were allocated to the LLLT group or to a control group. The LLLT group was treated with a low-level laser. In contrast, the control group received an alternative treatment, a pseudo-laser application, or did not receive any treatment.
4. Outcome variables included the prevalence of pain, pain intensity, or the need for analgesics.
5. The follow-up time was at least 24 h after therapy.

The exclusion criteria were as follows:

1. Studies characterized as case reports, case series, review papers, letters to the editor, monographs, conference papers, or in vitro studies

2. Participants with any systematic disease, dental disease, or on any medication at the time of treatment that could interfere with the presence of pain after endodontic treatment
3. Studies that were not published in English
4. Studies had participants less than 20.

Data collection and analysis

Two independent authors (Y.C and X.L.C) extracted the data with a specially designed sheet as shown in Table 1, which included the following: authors, study location, study year, number of patients by gender, mean age (range), study design, tooth type, tooth number associated with each group, number of drop-out participants, type of endodontic treatment, evaluation method, and evaluation interval. Furthermore, the laser parameters were recorded as follows: authors, year of study, type of laser, wavelength, power output, total dose per point (tooth), exposure time, and application method (Table 2). When data were missing or unclear, we tried to contact the authors of the study to obtain the necessary information. Any differences between the independent authors were resolved by discussion and the accuracy of the data was confirmed by a third author (X.L.Z).

Quality assessment

After verifying that the data were summarized correctly, the two independent authors (Y.C and X.L.C) assessed the quality of the included studies using the Cochrane risk of bias assessment tool for seven domains. For this, each domain was divided into three categories: low risk of bias, unclear risk of bias, and high risk of bias. The studies were classified as low risk of bias if all domains were evaluated to be of low risk, as moderate risk bias if one or more domains were evaluated to be of unknown risk, or as high risk if any domain was evaluated as high risk. Any disagreements on the data were resolved by discussion.

Results

Search results

In this study, 192 articles were retrieved from the databases during the search process (Fig. 1). After removing duplicated researches, 100 studies remained. When we screened titles and abstracts, a full-text assessment of 14 articles was retrieved and assessed by the two independent investigators (Y.C and X.L.C). Finally, only seven studies were included in the systematic review for qualitative analysis. The entire selection process is presented in Fig. 1.

General characteristics of included studies

The characteristics of all included studies are summarized in Table 1. The seven included studies were published between 2011 and 2018 [23–27, 29, 30], and among them, three were published in 2018, two were in 2017, and the other two were in 2014 and 2011, respectively. Two of them were conducted by the same author in Iran during different time periods [27, 29], two were in India [26, 30], and the remaining three were carried out in Turkey [24], Malaysia [23], and Brazil [25], respectively. All the seven studies were parallel trials, and five of them focused on the effect of LLLT in pain control after RCT [24–26, 29, 30], while the other two studied the effect of LLLT in pain management after RCR [23, 27]. The sample size ranged from 33 to 120 participants. The mean age or age range of patients was described in five studies, ranging from 25.76 to 35.8 years. One study did not report the gender distribution of the subjects [27], while in the remaining six studies, the majority of the subjects were males [23–26, 29, 30]. Out of these, five studies used a visual analogue scale (VAS) for measuring pain status (one study also used the McGill Pain Questionnaires [MPQ]) [23, 24, 27, 29, 30]; one used the Heft and Parker pain rating scale [26], one used the verbal rating scale (VRS) and numerical rating scale (NRS) simutaneously [25]. Follow-up periods also varied among these studies, the most frequently applied follow-up period was 12 and 24 h after treatment applications.

Moreover, five studies compared the efficacy of laser treatment with a placebo laser in pain management [23, 24, 27, 29, 30]. One study compared a laser treatment with a blank group and a placebo laser [24]; and one study compared a laser with preoperative ibuprofen, diode laser with preoperative ibuprofen, and a blank group [26].

Laser-related characteristics of included studies

Six studies introduced a type of laser [23–25, 27, 29, 30], and all of the studies used diode lasers, with wavelengths between 800 and 970 nm. Two studies used continuous wave; two used pulse wave, and the other three did not reported the emission mode. Furthermore, six studies reported the use of an output power ranging from 12 to 500 mW. Exposure time for each tooth also ranged from 60 to 180 s [23–27, 29]. The total dose per point was reported by six studies, ranging between 1.08 to 15 J/point. The laser application methods presented smaller differences, and most studies irradiated the mucosae overlying the apices of the target tooth (Table 2).

Table 1 Characteristics of included studies

Study ID	Country	Study design	No.(M/F)	Age mean ± SD (range)	Diagnoses	Tooth type	Groups	No. of drop-out	Endodontic treatment	Evaluation method	Evaluation interval
Lopes 2018	Brazil	Parallel	60 (23/37)	I, 30.4 ± 8.15 P, 28.1 ± 8.51 (18–60)	Irreversible pulpitis	Mandibular first or second molar	I, $N = 30$ P, $N = 30$	None	RCT, single visit	VRS, NRS	6, 12, and 24 h of posttherapy
Yildiz 2018	Turkey	Parallel	42 (23/19)	I, 28.14 ± 9.56 P, 27.43 ± 8.89 B, 26.00 ± 5.84 (18–46)	Symptomatic apical periodontitis	Mandibular molar	I, $N = 14$ P, $N = 14$ B, $N = 14$	None	RCT, single visit	VAS	1, 3, 5, 7, and 30 days of posttherapy
Asnaashari 2011	Iran	Parallel	80 (29/51)	I: 31.78 ± 9.18 P: 27.92 ± 8.11	NR	First permanent molars	I, $N = 40$ P, $N = 40$	None	RCT, single visit	MPQ, VAS	4, 8, 12, 24, and 48 h of posttherapy
Nabi 2018	India	Parallel	120 (68/52)	Ibuprofen, 34 ± 11.54 LLLT: 35.4 ± 11.5 Ibuprofen + LLLT, 35 ± 8.9 B: 35.8 ± 14.47 (18–64)	Symptomatic irreversible pulpitis	NR	Ibuprofen, $N = 30$ LLLT, $N = 30$ Ibuprofen + LLLT, $N = 30$ B, $N = 30$	None	RCT, single visit	Heft and Parker pain rating scale	4, 8, 12, 24, and 48 h of posttherapy
Arslan 2017	Malaysia	Parallel	33 (21/12)	I, 32.62 ± 9.27 P, 25.76 ± 8.14	Teeth with periapical lesions having a pain VAS < 50 and a percussion pain VAS < 50	Mandibular molars	I, $N = 16$ P, $N = 17$	I, $N = 2$ P, $N = 1$	RCR, two-visit	VAS	1, 2, 3, 4, 5, 6, and 7 days of posttherapy
Asnaashari 2017	Iran	Parallel	61	NR	NR	Posterior teeth	I, $N = 41$ P, $N = 20$	None	RCR, single visit	VAS	0, 4, 8, 12, 24, and 48 h of posttherapy
Pawar 2014	India	Parallel	50 (28/22)	NR	NR	Premolars	I, $N = 25$ P, $N = 25$	None	RCT, single visit	VAS	4, 8, 24, and 72 h of posttherapy

No. number of participants, *M* male, *F* female, *I* intervention group, *P* placebo group, *B* blank control group, *VAS* visual analogue scale, *VRS* verbal rating scale, *NRS* numerical rating scale, *MPQ* McGill Pain Questionnaires, *RCT* root canal treatment, *RCR* root canal retreatment, *NR* not reported

Table 2 Laser parameters of the included studies

Study ID	Type of laser	Mode	Wavelength	Output/energy (density)	Total dose per point (tooth)	Time of exposure	Method of application
Lopes 2018	Indium–gallium–aluminum laser	NR	808 nm	100 mW, 90 J/cm^2	2.5 J/point, 10 J/tooth	100 s/tooth	Perpendicular in contact with the gingiva on two points of the buccal and lingual side (4 points/tooth)
Yildiz 2018	Diode laser	NR	970 ± 15 nm	500 mW, 85.8 J/cm^2	15 J/point, 30 J/tooth	60 s/tooth	At a distance of approximately 10 mm from the tissue around the apex of the mesial and distal root (two points/tooth)
Asnaashari 2011	Diode laser	Continuous wave	808 nm	100 mW, 70 J/cm^2	4 J/point, 8 J/tooth	80 s/tooth	Applied to both the buccal and lingual mucosae overlying the apices of the target tooth (two points/tooth)
Nabi 2018	NR	Pulse wave	905 nm	12–16 mW	1.08–1.44 J/point, 2.16–2.88 J/tooth	180 s/tooth	In contact mode perpendicular to the periapical region of the teeth both bucally as well as lingually (two points/tooth)
Arslan 2017	Diode laser	NR	970 ± 15 nm	500 mW, 85.8 J/cm^2	15 J/point, 30 J/tooth	60 s/tooth	At a distance of approximately 10 mm from the tissue around the mesial and distal root apexes (two points/tooth)
Asnaashari 2017	Diode laser	Continuous wave	808 nm	100 mW, 70 J/cm^2	4 J/point, 8 J/tooth	80 s/tooth	Applied to the buccal and lingual mucosa overlying the apices of the target tooth (two points/tooth)
Pawar 2014	Diode laser	Pulse wave	800 nm	NR	NR	80 s/tooth	Applied to the buccal and lingual mucosae overlying the apices of the target tooth (two points/tooth)

NR not reported

Risk assessment

The quality of the included studies was assessed using the Cochrane risk of bias assessment tool (Fig. 2). Out of the seven included studies, one was evaluated to have a low risk of bias [23], and the remaining six were assessed to have a moderate risk of bias [24–27, 29, 30]. Only four studies explicitly mentioned blinding of patients [23, 25, 29, 30]. Furthermore, only one study used a double-blind method, and another one used a triple-blind method, in which the participants and key personnel were all blinded during both the experiment and assessment processes [23]. All seven included studies were randomized; two used the randomizer web program, available at www.randomizer.org [23, 24]. Another study used the Sealed Envelope® software [25], while the remaining four studies did not provide a detailed description of the randomization methods used. Out of all the included studies, only two studies stated the methods used for allocation concealment [23, 24]. Notably, none of these included studies had a bias of "incomplete outcome data," "selective reporting," or "other bias."

Outcome of the studies

Because of the wide heterogeneity of irradiation mode, application methods, energy density, and pain assessment tool, we were not able to conduct a meta-analysis and the data were only analyzed qualitatively.

Prevalence of pain

Three studies reported the prevalence of postsurgical pain [23, 25, 29], and two of these studies reported the occurrence after RCT [25, 29], and the other study reported the occurrence after RCR [23, 29] (Table 3). Asnnashari et al. (2011) and Asnnashari et al. (2017) found that LLLT was not effective in reducing the prevalence of postsurgical pain after RCT ($P > 0.05$) and RCR ($P > 0.05$), respectively. However, Lopes et al. (2018) reported LLLT could control pain incidence at 6 ($P = 0.04$) and 24 h ($P = 0.02$) after RCT, but the significant difference was not found at 12 h ($P > 0.05$).

Pain intensity

Five studies reported pain level measured with VAS, and most of them revealed that LLLT significantly reduced the pain intensity after RCT and RCR [23, 24, 29, 30] (Table 4). According to Yildiz's study, published in 2018, LLLT controlled pain levels on days 1 and 3 after RCT ($P < 0.05$). Asnnashari et al. (2011) also found that the pain intensity was significantly lower in LLLT group at 4 ($P = 0.0001$), 8 ($P = 0.0001$), 12 ($P = 0.032$), 24 ($P = 0.006$) h after RCT. Pawar et al. used the VAS measuring intensity

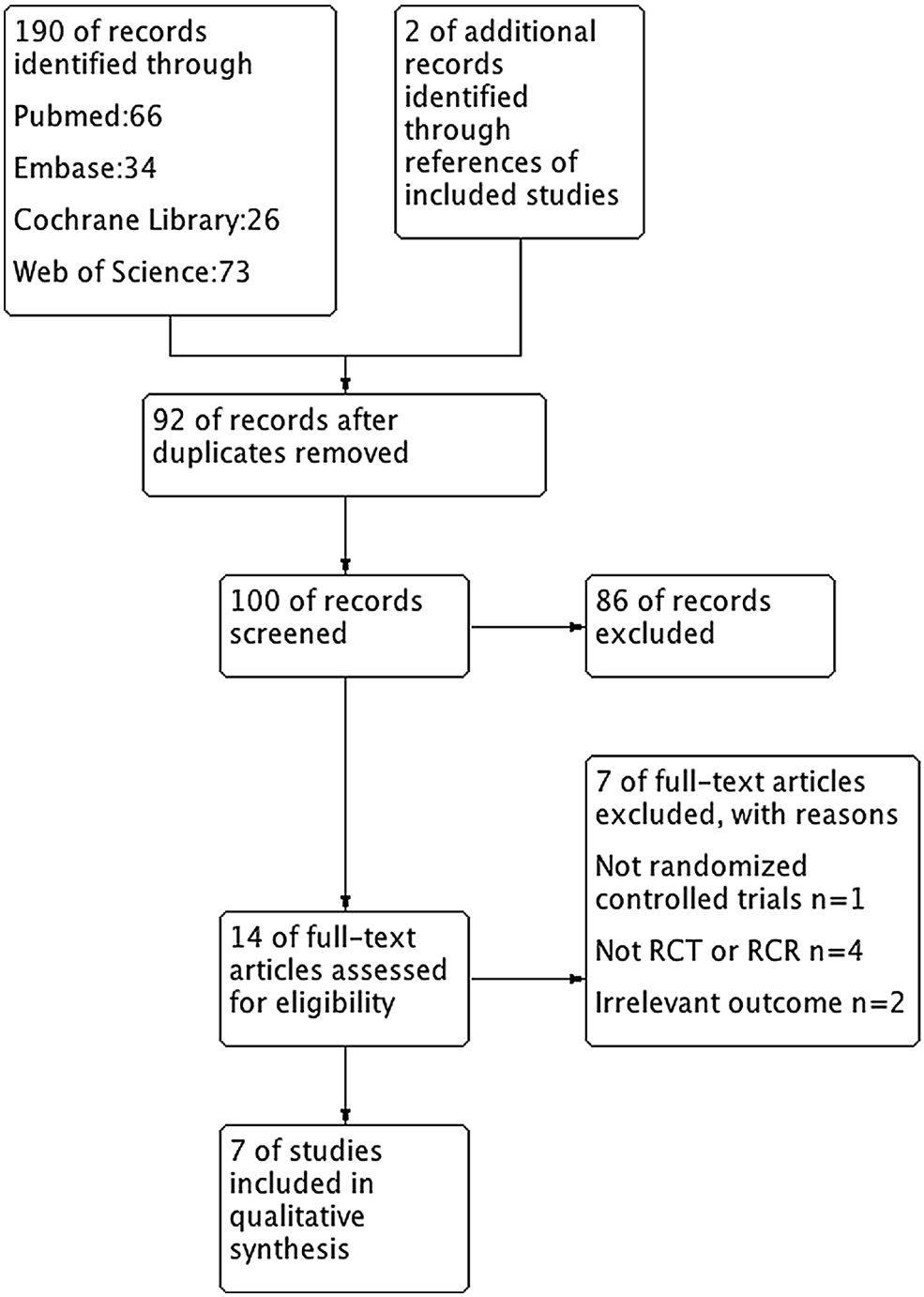

Fig. 1 Flowchart depicting the study selection process

of posttreatment pain at intervals of 4, 8, 24, and 72 h and observed significant pain reduction in the LLLT group at 4 and 8 h after RCT. As for RCR, Asnnashari et al. (2017) revealed there was no significant improvement in terms of pain intensity at 4 ($P < 0.84$), 8 ($P < 0.44$), 12 ($P < 0.62$), 24 ($P < 0.69$), and 48 ($P < 0.67$) h after treatment in LLLT group. However, Arslan et al. (2017) demonstrated the patients in LLLT group had lower pain intensity in the first 4 days ($P < 0.05$), while no significant difference was found after 5, 6, and 7 days ($P > 0.05$).

There were two other studies [25, 26] that reported pain intensity using a different pain scale (Table 4). Nabi et al. examined a patient's pain intensity with the Heft and Parker pain rating scale at 4, 8, 12, 24, and 48 h after treatment [26]. Preoperative ibuprofen, postoperative low-level laser, and preoperative ibuprofen followed with a postoperative low-level laser; all showed significant results in terms of pain control at 4 and 8 h [26]. Importantly, preoperative ibuprofen followed with postoperative LLLT presented the best effect on pain control at 12, 24, and 48 h,

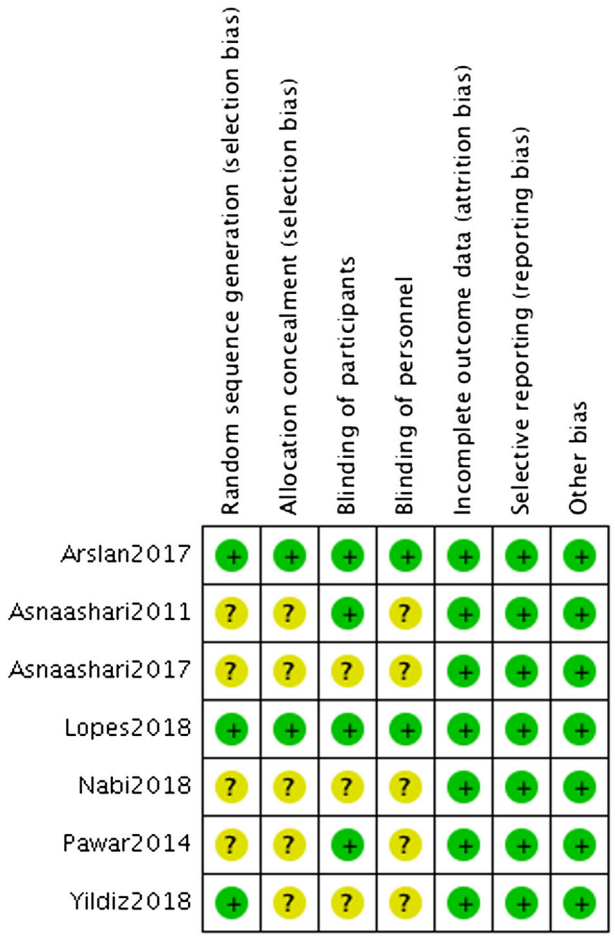

Fig. 2 Risk of bias summary: judgments of the two independent authors on the risk of bias items for each included study

followed by postoperative LLLT and preoperative ibuprofen. In addition, Lopes et al. examined patients' pain intensity with the VRS and the NRS at 6, 12, and 24 h [25]. Using the VRS, no significant statistical differences on postoperative pain were detected between the groups at 6 h ($P = 0.123$) and 12 h ($P = 0.127$), while a significant difference was found at 24 h after treatment between the groups ($P = 0.013$). When using the NRS, statistically significant differences were also detected at 24 h posttreatment ($P = 0.015$).

Table 3 Prevalence of pain reported in included studies

Study ID	Follow-up time	Prevalence of pain	*P* value
Asnaashari 2011	48 h	I, 29/40 P, 31/40	> 0.05
Asnaashari 2017	48 h	I, 21/41 P, 8/20	> 0.05
Lopes 2018	6 h	I, 10/30 P, 18/30	0.04
	12 h	I, 6/30 P, 12/30	> 0.05
	24 h	I, 2/30 P, 10/30	0.02

I intervention group, *P* placebo group

Number of patients in need of analgesics

Three studies reported the number of patients who were in need of analgesics after treatments. Two of these studies occurred after RCT and one after RCR [23, 24]. As for RCT, the study of Asnnashari et al. (2011) showed no patient needed analgesics in all groups and Yildiz et al. (2018) reported one patient needed analgesics in LLLT group, compared with three in control group without significant differences between groups ($P > 0.05$). Arslan et al. (2017) reported the number of patients who needed analgesics that was significantly lower in LLLT group ($P < 0.05$), including one patient in LLLT group and nine patients in control group.

Adverse events

No adverse events were reported in any of the included studies.

Discussion

This study is envisioned to assess the efficacy of LLLT on pain control after RCT and RCR. A total of seven RCT studies were included in our systematic review. The quality assessment performed revealed five studies with moderate risk of bias and one study with low risk of bias, indicating an under-grading of the quality of the existing evidence. Based on current evidence, conclusions should be drawn cautiously due to the following reasons: (1) given the different types, parameters, as well as laser applications used in the different studies and (2) the different methodologies used between the included studies.

Laser parameters can affect pain outcome

One of the reasons that hindered us to perform a quantitative analysis is the wide heterogeneity of the laser parameters among included studies, which might play an important role in pain outcome. The type of laser, emission mode, energy output, energy density, wavelength, and laser exposure time used are thought to influence the outcome of LLLT [15]. Except for one study that failed to describe the exact type of laser used [26], all of lasers used in our included studies were a diode laser, with one specifically study describing it to be an indium–gallium–aluminum diode laser [25]. Diode lasers have been long used in the control of orofacial pain, showing its superiority, when compared to traditional procedures in the pain

Table 4 Pain intensity reported in included studies

Study ID	Evaluation method	Follow-up periods	Pain intensity (Mean/S.D.)	*P* value
Yildiz 2018	VAS	Day 1	I, 6.29/6.28 P, 31.21/31.68 D:30.50/32.77	> 0.05
		Day 3	I, 0.79/1.31 P, 15.79/22.68 D, 19.50/20.05	> 0.05
		Day 5	I, 0.14/0.53 P, 7.50/10.14 D, 9.88/15.14	> 0.05
		Day 7	I, 0.00/0.00 P, 2.36/4.24 D, 1.50/2.93	> 0.05
		Day 30	I, 0.00/0.00 P, 0.00/0.00 D, 0.00/0.00	> 0.05
Asnaashari 2011	VAS	4 h	I, 1.80 P, 2.55	0.0001
		8 h	I, 1.27 P, 1.80	0.0001
		12 h	I, 1.00 P, 1.15	0.032
		24 h	I, 1.00 P, 1.02	0.323
		48 h	I, 1.00 P, 1.18	0.006
Arslan 2017	VAS	Day 1	I, 17.94/15.91 P, 32.59/20.85	< 0.05
		Day 2	I, 14.44/28.41 P, 32.71/27.73	< 0.05
		Day 3	I, 12.25/27.48 P, 25.65/24.94	< 0.05
		Day 4	I, 9.50/18.01 P, 15.41/20.62	< 0.05
		Day 5	I, 5.25/8.81 P, 11.47/16.90	> 0.05
		Day 6	I, 1.69/5.55 P, 7.65/13.21	> 0.05
		Day 7	I, 0.56/1.54 P, 5.29/12.43	> 0.05
Asnaashari 2017	VAS	4 h	NR	< 0.84
		8 h	NR	< 0.44
		12 h	NR	< 0.62
		24 h	NR	< 0.69
		48 h	NR	< 0.67
Pawar 2014	VAS	4 h	NR	< 0.05
		8 h	NR	< 0.05
		24 h	NR	> 0.05
		72 h	NR	> 0.05
Lopes 2018	VRS	6 h	I, 0.53/0.86 P, 0.77/0.82	0.123
		12 h	I, 0.30/0.70 P, 0.47/0.63	0.127
		24 h	I, 0.10/0.40 P, 0.40/0.62	0.013
	NRS	6 h	I, 1.43/2.60 P, 1.87/2.64	> 0.05
		12 h	I, 0.77/1.98 P, 1.27/2.18	> 0.05
		24 h	I, 0.27/1.05	0.015

Table 4 (continued)

Study ID	Evaluation method	Follow-up periods	Pain intensity (Mean/S.D.)	*P* value
			P, 1.00/2.08	
Nabi 2018	Heft and Parker pain rating scale	4 h	A, 7.5	A vs B, 0.241
			B, 14.2	A vs C, 0.490
			C, 3.6	A vs D, 0.002
			D, 25.7	B vs C, 0.041
				B vs D, 0.035
				C vs D, 0.001
		8 h	A, 6.8	A vs B, 0.195
			B, 13.4	A vs C, 0.508
			C, 3.5	A vs D, 0.001
			D, 24	B vs C, 0.039
				B vs D, 0.036
				C vs D, 0.001
		12 h	A, 17.6	A vs B, 0.036
			B, 7.4	A vs C, 0.003
			C, 3.1	A vs D, 0.285
			D, 22.7	B vs C, 0.363
				B vs D, 0.002
				C vs D, 0.001
		24 h	A, 14.3	A vs B, 0.040
			B, 5.4	A vs C, 0.009
			C, 2.3	A vs D, 0.340
			D, 18.6	B vs C, 0.495
				B vs D, 0.004
				C vs D, 0.001
		48 h	A, 7.1	A vs B, 0.046
			B, 1.5	A vs C, 0.044
			C, 0.8	A vs D, 0.184
			D, 11.3	B vs C, 0.808
				B vs D, 0.002
				C vs D, 0.001

VAS visual analogue scale, *VRS* verbal rating scale, *NRS* numerical rating scale, *I* intervention group, *P* placebo group, *D* blank group, *A* preoperative ibuprofen group, *B* postoperative low-level laser group, *C* preoperative ibuprofen followed with a postoperative low-level laser group, *NR* not reported

management of soft tissue and hard tissue conditions including premalignant lesions, gingival conditions, and dental extractions [31]. This laser is also known for its small size and application ease [32]. LLLT is a dose-dependent treatment, which is reported to have tissue repair ability with an optimal energy density of 2 J/cm^2 [33]. Using an incorrect selection of irradiation parameter and exposure time is likely to influence treatment success [34]. However, the optimal dosage range for pain relief is still not fully elucidated based on the current evidence and available literature. Bjordal et al. suggests a total dose beyond 5 J for a 904-nm laser and a total dose beyond 6 J for an 810 to 830 nm laser [35]. Furthermore, Kert and Rose recommend the use of energy between 0.5 and 10 J per treatment point and in contact with the tissue surface for deeper effect [36]. Some of our included studies utilize a dosage parameter beyond what has been recommended in previous studies, using a range of energy between 1.08 J to 15 J per point. Further research on the optimal range of energy needed to be applied should be formulated in order to provide better treatment outcomes. In addition, the laser wavelength influences its ability to penetrate soft tissue. Six of the included studies provide a detailed of the wavelength used, ranging from 800 to 970 nm. Some researchers reported a laser wavelength in the range of 670 to 900 nm, which penetrates soft tissue particularly well, having two peaks around 725 nm and 810 nm [15, 37]. Of note, the majority of our included studies were within the optimal range. Of the included studies, only four studies reported the emission mode of laser therapy [26, 27, 29, 30] and two of them used pulse wave [26, 30]. Benefit of pulsing regimens comes from better dissipation of heat; however, the interval between each wave can affect the dosage and the efficacy of LLLT [38]. Hadis et al. suggest that the peak irradiance, pulse frequency, and on/off interval should be defined when using a pulsing regimen, but none of the included studies have reported such data [39]. Also, it is notable that none of the researchers used a power meter to measure the power of laser; only the data provided by manufacturers can be achieved. The values provided by

manufacturers may not be useful in clinical studies since the beams are highly divergent, and the ways of application are different [39]. Beam profile and energy density with movement are also important parameters not reported by the researchers of the included studies; future research could improve its reliability by applying devices for light measurement including peak/average power, beam profile, and energy density with movement.

Study methodology on outcome

Pain is a rather subjective perception; thus, rating scales have been formulated by researchers, who are trying to quantify the intensity of pain. However, the golden standard for pain measurement has not been established yet and there are several types of pain rating scales that a researcher can use. Within the range of included studies, five rating scales were used, including the VAS, the VRS, the NRS, the Heft and Parker pain rating scale, and the MPQ. The VAS is a numeric scale, which presents a 10-cm continuous line, measured by a ruler counting from 0 to 100 (each 1 mm equals 1 score). The NRS is similar to the VAS, but an NRS score is recorded as integers. Both the VAS and the NRS are easy to understand by patients, and both show high reliability in literate patients [40]. The MPQ is a multidimensional rating scale, which contains four subscales that evaluate sensory, affective, evaluative, and miscellaneous aspects of pain. The MPQ is comprehensive but can be hard to comprehend sometimes. The reliability of this scale is high for a 1-day recall but falls during longer intervals [41]. The VRS, on the contrary, is the easiest rating scale to understand and is the preferred one by patients; however, it is the least sensitive of all the rating scales [42]. The Heft and Parker pain rating scale is a self-design scale, which uses a non-isometric rating method [43]. Studies using this scale are scanty; thus, its reliability and validity have not been well assessed.

Due to the subjective nature of pain perception, heterogeneity is always high among studies when evaluating pain intensity. Also, different evaluation intervals and different pain assessment tools hinders the synthesis of the data. The time intervals most often used in these studies range from 2 h to 24 h. In addition, among the five studies using the VAS to record pain intensity, three of them present their results as the mean value and standard error [23, 24, 29]. The study reported by Asnaashari et al. conducted in 2017 divided pain perception into five categories [27]. The study by Pawar et al. did not report any data about the mean value and standard error [30]; thus, no detailed data can be achieved from these studies. Future research should be improved by presenting data in a more detailed and comprehensive way.

Asnaashari et al., Yildiz et al., and Arslan et al. recorded the prevalence of analgesic intake after treatment [23, 24, 29], which reflected the occurrence of postoperative pain. Results of Arslan et al. revealed a protective effect of LLLT for pain management after RCR. However, the other two studies show contradictory results that no differences were observed between control and LLLT group in analgesics intake after RCT. The number of included studies is limited; thus, the conclusions drawn here cannot be definitive. Therefore, there is a need for high quality randomized controlled trials to further support the conclusion.

Differences between the treatment procedures used in the included studies are also a problem why a quantitative analysis can not be conducted. Whether treatments required a single visit or multiple visits can influence the pain experience after treatment remains debatable [44]. In the study of Arslan et al. [23], a multi-visit RCT was conducted, while the other studies conducted only single-visit treatments [24–27, 29, 30].

Quality assessments were conducted, and only one study presented a low risk of bias [25], while six of the included studies reported a moderate risk of bias [23, 24, 26, 27, 29, 30]. The main reason for this was the lack of complete randomization and blinding procedures. Four of the studies mentioned randomization but did not illustrate the details of the methods used [26, 27, 29, 30]. Additionally, three of the studies did not mention blinding of the patients [24, 26, 27]. Only two studies provided information on allocation concealment and blinding of personnel [23, 25]. Undoubtedly, the study design will have a bias on the accuracy of the outcomes. Future studies can greatly benefit from a study design that has detailed methods of randomization and blinding.

LLLT compared with NSAIDs

In addition to the use of placebo as a control, one of our included studies also evaluated the differences between the efficacy of LLLT with ibuprofen, which is a kind of non-steroid anti-inflammatory drugs (NSAIDs) [26]. In this study, LLLT showed comparable efficacy in pain control at 4 and 8 h intervals and presented a significant decrease of pain intensity after RCT at 12-, 24-, and 48-h intervals when compared to the ibuprofen group. Markedly, LLLT combined with preoperative NSAIDs resulted in a more profound pain reduction than LLLT or NSAIDs alone. NSAIDs are widely used in pain control after endodontic treatment, relieving pain via the reduction of chemical inflammatory mediators that activate peripheral nociceptors and thereby induce related subsequent events [45]. NSAIDs were recommended in the study by Aminoshariae et al., as a treatment option to alleviate or minimize postendodontic pain, as long as there were no contraindications [13]. However, NSAIDs are also known for their side effects, such as the delay of wound healing, which is unfavorable for postendodontic tissue repair [46]. LLLT shows a comparable effect, together with its capability to mediate tissue repair; thus, it may be an alternative option over the conventional treatment choice relying on NSAIDs in pain

management after RCT and RCR. Moreover, the combination of LLLT and preoperative NSAIDs may be an excellent option to reduce pain after RCT and RCR. However, with the small sample size of included studies, better-designed RCTs are warranted in order to further evaluate the efficacy of LLLT for pain control during root canal procedures.

Conclusion

In view of the present literature, the use of LLLT for pain control in postendodontic therapy looks promising. However, more high-quality randomized controlled trials are needed to further investigate the efficacy of LLLT for pain management after RCT and RCR. Future studies should focus on utilizing better methodologies with detailed randomization and blinding practices as well as reporting data more comprehensively and precisely. In addition, there is a high need for the establishment of a more accurate pain rating system and the determination of an optimal wavelength and energy intensity for LLLT, to aid researchers in their quest for better pain control and management.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

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