Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

EFFECTS OF LASER THERAPY IN ENDODONTIC TREATMENT

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ABSTRACT

Introduction: laser therapy has become an increasingly common technique in endodontics, used to improve disinfection, control postoperative pain, and accelerate healing. However, the efficacy of different laser types and settings remains uncertain. **Objective:** this work aimed to assess whether the use of laser therapy as an adjunct to conventional root canal treatments improves bacterial reduction, pain control, and healing outcomes. **Material and methods:** a systematized review was conducted, based on predefined inclusion and exclusion criteria. A total of 175 articles were identified through various scientific databases. After screening and eligibility assessment, 19 studies were included. These studies evaluated the effects of different laser systems, such as erbium lasers, diode lasers, and photosensitizer-based light therapies, on the outcomes of endodontic treatment. **Results:** most of the studies demonstrated that laser therapy significantly reduced bacterial load often exceeding 99% and provided better control of postoperative pain compared to conventional chemical irrigation. Laser-based treatments also promoted more rapid periapical healing and tissue regeneration. **Conclusions:** Laser therapy showed significant potential as a supportive tool in endodontic treatment. Nevertheless, the reviewed literature revealed substantial variability in protocols and outcomes. Standardized clinical guidelines and further studies are necessary to confirm the long-term benefits of laser-assisted techniques in root canal therapy.

KEYWORDS

Odontology, endodontics, laser therapy, bacterial reduction, postoperative pain

RESUMEN

Introducción: la terapia con láser se ha convertido en una técnica cada vez más común en endodoncia, utilizada para mejorar la desinfección, controlar el dolor postoperatorio y acelerar la cicatrización. Sin embargo, la eficacia de los diferentes tipos de láser y sus configuraciones sigue siendo incierta. **Objetivo:** este trabajo tuvo como objetivo evaluar si el uso de la terapia con láser como complemento a los tratamientos convencionales de conductos radiculares mejora la reducción bacteriana, el control del dolor y los resultados de cicatrización. **Material y métodos:** Se llevó a cabo una revisión sistematizada basada en criterios de inclusión y exclusión previamente definidos. Se identificaron 175 artículos a través de diversas bases de datos científicas. Tras la selección y evaluación de elegibilidad, se incluyeron 19 estudios. Estos estudios evaluaron los efectos de diferentes sistemas láser, como los láseres de erbio, los láseres de diodo y las terapias basadas en luz con fotosensibilizadores, sobre los resultados del tratamiento endodóntico. **Resultados:** la mayoría de los estudios demostraron que la terapia con láser redujo significativamente la carga bacteriana a menudo por encima del 99 % y proporcionó un mejor control del dolor postoperatorio en comparación con la irrigación química convencional. Los tratamientos con láser también promovieron una cicatrización periapical más rápida y la regeneración de tejidos. **Conclusiones:** la terapia con láser mostró un gran potencial como herramienta complementaria en el tratamiento endodóntico. No obstante, la literatura revisada reveló una notable variabilidad en los protocolos y resultados. Se necesitan directrices clínicas estandarizadas y más estudios para confirmar los beneficios a largo plazo de estas técnicas.

PALABRAS CLAVE

Odontología, endodoncia, terapia con láser, reducción bacteriana, dolor postoperatorio

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1. INTRODUCTION

1.1. Definition

Endodontic treatment:

Endodontic treatment commonly known as root canal treatment (RCT), is a procedure to eliminate the infection or inflammation in a tooth's root canal. It consists in removing diseased pulp tissue, thoroughly disinfecting the canal, and sealing it (with gutta-percha) to treat the actual pathology and prevent further infection. This procedure is essential to preserving tooth function and preventing periapical disease (1). Despite the precision of RCT, persistent bacteria particularly Enterococcus faecalis (2), can hide in complex canal structures and compromise all the treatment success (3). Studies indicate a success rate of up to 85-90% for primary RCTs, this results depend on infection severity and treatment approach (4).

Laser therapy:

Laser therapy involves using concentrated light energy to assist in dental treatments. This approach aims to reach and sterilize areas within the root canal system that are often inaccessible to traditional methods (5). Laser energy interacts with dental tissues, providing photothermal, photomechanical, and photobiomodulatory (PBM) effects, which can enhance disinfection, alleviate pain, and promote tissue healing (6).

1.2. Background

Traditional endodontic approaches rely heavily on both mechanical and chemical methods for canal disinfection. Mechanical instrumentation includes the use of endodontic files, and chemical irrigation includes the use of solutions such as sodium hypochlorite (NaOCl). The combination of this two techniques is considered as standard practice and "gold standard" (1). However, these techniques often fail to penetrate in intricate complicated and unique anatomical features like accessory canals, isthmuses, recesses, and canal ramifications (7). Given these challenges, laser therapy offers an alternative with potential for more thorough debridement, enhanced antimicrobial capacity, and reduced risk of postoperative complications like infection and pain (5).

Laser history in dentistry:

Laser technology was first introduced in medicine then adapted in dentistry during the 1980s. Initially it was used for periodontal treatments. Since then, it has evolved to cover various applications, including endodontics, where it is increasingly used to optimize cleaning and disinfecting efficacy, and tissue regeneration processes in the root canal system. The

Erbium:Yttrium-Aluminum-Garnet (Er:YAG) laser was among the first to be used in endodontic procedures (5).

1.3. Theoretical framework

Lasers are employed in endodontics due to their unique photothermal, photomechanical, and photobiomodulation effects which facilitate canal debridement, enhance tissue healing, and reduce microbial load within dentinal tubules (5). Specific laser types, such as Er:YAG, Neodymium:YAG (Nd:YAG), diode, and carbon dioxide (CO_2) lasers, are specialized to different therapeutic needs (8).

For instance, Er:YAG lasers are highly effective in canal decontamination and debris removal. Diode lasers on the other hand, are primarily used for pain relief and enhancing tissue repair (3,9).

Photodynamic therapy (PDT), which uses photosensitizers such as indocyanine green (ICG), has proven effective in eliminating resistant bacteria within root canal systems by generating reactive oxygen species (ROS) when activated by laser light (5).

Techniques such as PIPS (photon-induced photoacoustic streaming) and SWEEPS (shock wave-enhanced emission photoacoustic streaming) offer additional methods to agitate irrigants and create shockwaves (10), which enhance biofilm disruption within the canal system (4). These innovative approaches further improve the efficacy of laser treatment in endodontics (5).

1.4. Current status of the topic

Recent studies highlight several advantages of laser-assisted endodontics including improved bacterial reduction (11), faster healing, and reduced postoperative pain (6). The Er:YAG laser, in particular, has shown some capacities in cleaning and shaping canals (4,8), while diode lasers contribute to pain management (5) and tissue healing (11). Despite these benefits, some studies show inconsistencies in laser therapy outcomes, and concerns remain regarding cost, the learning curve and availability of lasers in certain clinical environments (5). These factors highlight the need for further evaluation of long-term efficacy, standardization in the studies and practicality in common endodontic practice.

1.5. Justification

Given the growing interest in integrating laser technology into conventional endodontic treatment, there is a clear need to consolidate findings on its efficacy. This systematized review aims to determine whether laser-assisted methods indeed improve clinical outcomes, such as disinfection efficiency, pain management, and healing rates, in addition to what it is achievable through traditional RCT protocols. Evaluating these aspects could further inform clinical practice, reduce procedural risks, and enhance patient outcomes (5,6). While some studies examine laser as a potential alternative to conventional methods, such as replacing NaOCl or mechanical instrumentation, this review will focus on its role as an adjuvant, offering a more accessible and practical approach for optimizing current endodontic treatment (8).

2. OBJECTIVE

To evaluate the effectiveness of laser therapy in improving bacterial reduction, pain relief, and healing outcomes in endodontic treatment compared to conventional disinfection methods.

3. MATERIAL AND METHODS

The purpose of this systematized review was to assess how well laser therapy works to reduce bacteria, reduce discomfort, and promote healing after endodontic treatment. By adhering to specific inclusion and exclusion criteria and focusing on primary evidence, the procedure was structured to ensure a comprehensive and systematic method.

3.1. Research question and PICO framework:

The research question was formulated using the PICO framework to ensure a focused and structured investigation.

PICO framework:

Table 1. PICO framework used to formulate the research question for this review, specifying the population, intervention, comparison, and outcome criteria.

P (Population)	Permanent tooth undergoing endodontic treatment because of infected or inflamed root canals.
I (Intervention)	Use of laser therapy as an adjuvant to conventional endodontic disinfection.
C (Comparison)	Conventional root canal treatment considered as mechanical instrumentation combined with sodium hypochlorite irrigation (3).
O (Outcome)	Improvements in bacterial reduction, reduction in post treatment pain and better healing rates.

The research question is:

In patients undergoing endodontic treatment, how does laser therapy as an adjunct compare to conventional methods in improving bacterial reduction, pain relief, and healing outcomes?

3.2. Eligibility criteria

Table 2. Eligibility criteria used for study selection, outlining both inclusion and exclusion conditions for articles considered in this review.

Inclusion criteria:	Exclusion criteria:
1. Studies involving permanent teeth undergoing endodontic treatment. 2. Primary studies evaluating laser therapy as an adjunct in bacterial reduction, pain management, or healing enhancement. 3. Studies comparing laser-assisted techniques with conventional methods of root canal disinfection. 4. Studies less than 10 years old	1. Studies in non-permanent teeth 2. Studies with incomplete or unclear data on laser parameters or outcomes. 3. In vitro studies. 4. Studies older than 10 years old 5. Meta-analysis and systematic reviews

3.3. Information sources

The literature search was conducted across the following databases:

- PubMed
- Scopus
- Google scholar

To guarantee thorough coverage, further searches were conducted in grey literature, including conference proceedings and doctoral theses.

3.4. Search strategy

MeSH (Medical Subject Headings) terms and free terms associated with the PICO elements were combined to create the search terms. To combine words, boolean operators (AND, OR) were employed. "Laser therapy" OR "laser disinfection" AND "endodontics" OR "root canal treatment" AND "bacterial reduction" OR "pain relief" OR "healing rates" is the initial search formula.

3.5. Study selection process

1) Identification of duplicate records:

Bibliographic software (such Zotero) was used to eliminate duplicate items from the database search.

2) Screening titles and abstracts:

Articles that met the inclusion criteria were selected based on their titles and abstracts, which were evaluated for relevance to the study issue.

3) Full-text evaluation:

The predetermined criteria were used to assess the eligibility of full-text publications. For the purpose of transparency, the reasons for exclusion were recorded.

3.6. Data extraction

The following data were extracted from the selected studies:

- Year of publication
- Study design (e.g., randomized controlled trial, cohort study)
- Sample size
- Laser type and parameters used (e.g., wavelength, power)
- Comparison method (e.g., conventional irrigation with NaOCl)
- Outcomes measured (bacterial reduction, pain scores, healing rates)
- Key findings

3.7. Data synthesis

The efficiency of conventional and laser-assisted treatments was compared through a qualitative synthesis. Key findings were summarized by descriptive analysis of quantitative data, when available.

4. RESULTS

4.1. Study selection

An initial search across multiple databases identified a total of 175 articles. After removing duplicates, 72 full-text articles were screened for eligibility. Following the application of the predefined inclusion and exclusion criteria, a total of 19 studies were included in this review. These studies comprised randomized controlled trials (RCTs) and clinical case reports focused on laser therapy as an adjunct to endodontic treatment for bacterial reduction, pain relief, and healing improvement.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart:

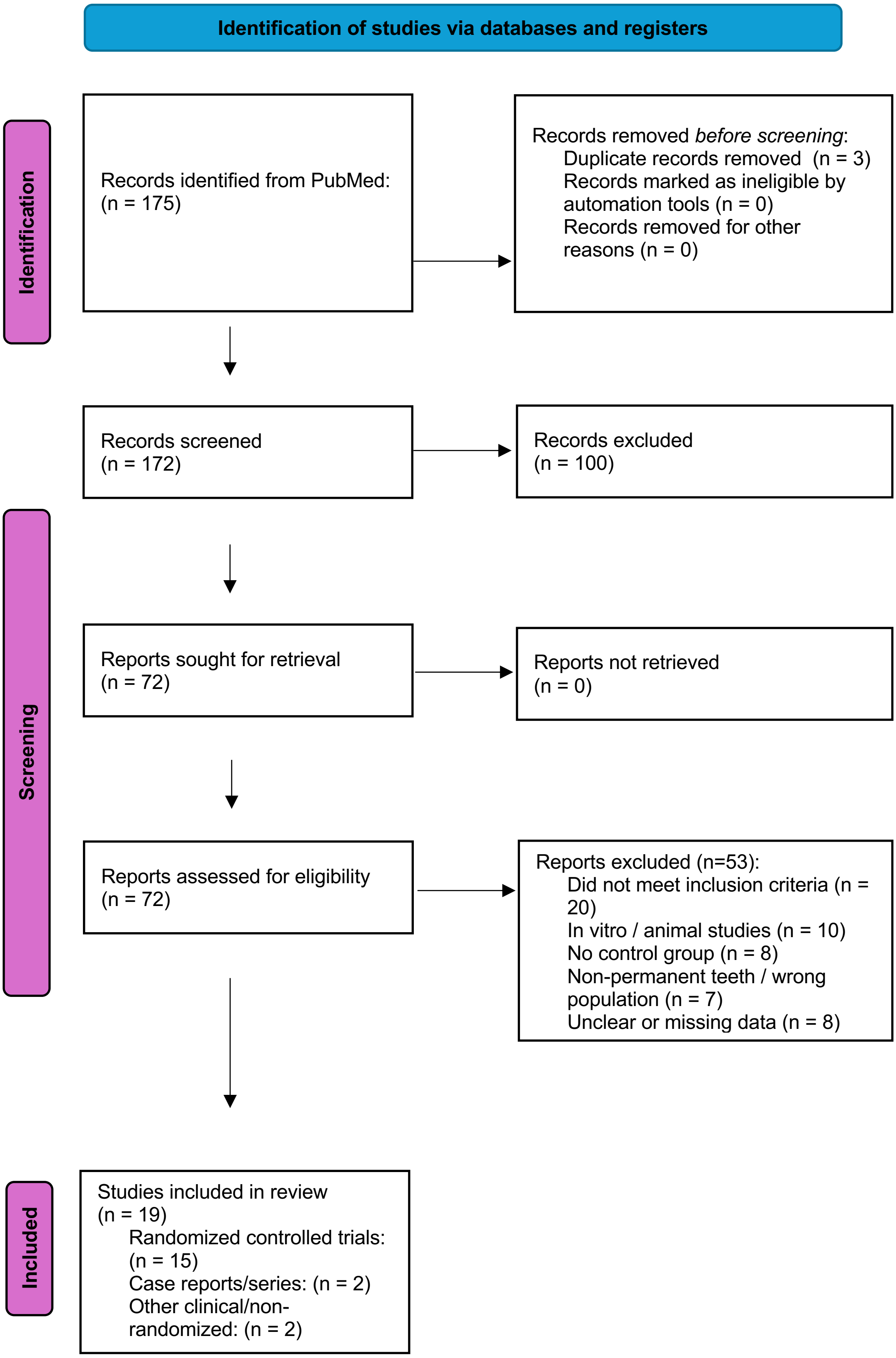

Diagram 1: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

4.2. Summary of results

4.2.1. Study type

The studies were categorized based on the clinical outcomes assessed in each study:

- Bacterial reduction (n = 5 studies)
- Pain reduction (n = 12 studies)
- Healing outcomes (n = 5 studies)

Below is the summary table of findings, providing a breakdown of positive results across these categories.

Table 3. Summary of the clinical outcomes evaluated in the included studies, showing the distribution of results in terms of bacterial reduction, pain relief, and healing outcomes. Studies reporting significant improvement are marked as “Positive effect.” Adapted from the reviewed studies (see annex 9.1.).

Studies	Positive effect (n)	No difference (n)	Total	% Positive results
Bacterial reduction	4	1	5	80%
Pain relief	9	3	12	75%
Healing outcomes	4	1	5	80%

These studies analyze laser therapy as an adjunct in endodontic treatment, focusing on bacterial reduction, pain relief, and healing enhancement.

4.2.2. Intervention and control groups

Intervention groups:

The intervention groups across the studies included a variety of laser types, each used for different purposes, such as bacterial reduction, pain management, and healing enhancement. The most commonly used lasers were Er:YAG lasers, diode lasers, and Er,Cr:YSGG lasers, with some studies also incorporating photodynamic therapy (PDT).

Er:YAG laser (2940 nm) was often used for bacterial disinfection and canal cleaning. This laser is effective in removing biofilm and achieving thorough decontamination, especially in the deep regions of the canal system where traditional methods might struggle (5).
Example: In Nagahashi et al. (2022) (4), Er:YAG laser was used to decontaminate the root canal, significantly reducing E. faecalis and C. albicans compared to the conventional NaOCl irrigation group.

Diode laser (660–980 nm) was primarily used in studies investigating pain reduction and tissue healing. These lasers are highly versatile and are known for their photobiomodulatory effects, enhancing tissue repair and reducing pain post-treatment (5).
Example: In Kaplan et al. (2021) (12), patients received diode laser therapy for postoperative pain management, and the results showed a significant decrease in visual analogue scale (VAS) pain scores compared to the control group.

Er,Cr:YSGG laser (2780 nm) was utilized in studies focusing on thermal ablation and biofilm disruption. This laser type has shown promise in enhancing disinfection and improving clinical outcomes, particularly when combined with photobiomodulation techniques (6).
Example: In Fahim et al. (2024) (13), both Er,Cr:YSGG and diode lasers were used in combination with ethylenediaminetetraacetic acid (EDTA) for bacterial reduction, achieving greater than 99% bacterial reduction, significantly outperforming conventional methods.

Photodynamic therapy (PDT): This therapy, typically combining diode lasers with indocyanine green (ICG) or methylene blue (MB), was used in studies examining the bacterial reduction potential of laser therapy. PDT is highly effective in eliminating bacterial biofilms through the generation of reactive oxygen species (ROS) (6).
Example: Leonardo et al. (2023) (7) demonstrated that ICG-PDT with diode lasers led to a greater reduction in bacterial load, especially in E. faecalis biofilms. In Bago Jurič et al. (2014) (14), the study evaluated the effectiveness of photodynamic therapy (aPDT) as an adjunct to conventional endodontic re-treatment.

Control groups:
The control groups typically received conventional endodontic treatment methods, which involved mechanical instrumentation with sodium hypochlorite (NaOCl) irrigation for bacterial disinfection, and sometimes calcium hydroxide as an intracanal medicament (6). The main objective of the control groups was to compare the efficacy of traditional methods with laser-assisted therapies.
Mechanical instrumentation + NaOCl irrigation:
This is the gold standard (5) in endodontic treatment, where endodontic files are used for canal cleaning followed by NaOCl irrigation to disinfect the canal. NaOCl is widely used due to its antimicrobial properties, but it has limitations, especially in complex root canal systems (1).

Example: In Ahangari et al. (2017) (15), the control group underwent mechanical preparation with NaOCl irrigation, but the results showed no significant difference in bacterial reduction compared to the laser-treated groups.

No treatment:

In some cases, studies included a no-treatment group as a baseline to assess the effects of laser therapy against no intervention.

Example: in Nabi et al. (2018) (16), the study included a no-treatment group (Group D) as the control. This group did not receive any preoperative analgesics or laser therapy, which served as the baseline to assess the effectiveness of the interventions (ibuprofen and low-level laser therapy) in managing postendodontic pain. Guimarães et al. (2021) (17) used too, a no-treatment control to evaluate the healing potential in periapical tissues, noting a significant improvement in the laser group in terms of bone regeneration and tissue repair.

Intracanal medicament control:

In Shah et al. (2021) (18), the control group involved the use of an intracanal medicament consisting of a mixture of 2% chlorhexidine and calcium hydroxide placed between appointments. The study aimed to compare the effects of low-level laser therapy (LLLT) combined with root canal treatment to conventional root canal therapy with an intracanal medicament on periapical healing. The results indicated that the laser-treated group (Group I) showed superior healing outcomes, with significant reductions in periapical lesion size after 3 and 9 months, compared to the control group (Group II) which only received conventional treatment with the intracanal medicament. Although the pain relief was better in the laser group, the difference was statistically non-significant.

Results comparison between intervention and control groups:

Across the studies reviewed, laser therapy consistently outperformed conventional methods in terms of bacterial reduction and pain relief. However, there was heterogeneity in results due to differences in laser types, treatment protocols, and outcome measures.

Bacterial reduction:

Studies using Er:YAG and PDT reported significantly higher bacterial reductions compared to NaOCl or calcium hydroxide in the control groups, particularly in the deeper regions of the canal that are difficult to reach with conventional irrigation methods (4,7,13,14).

Pain relief:

In terms of postoperative pain, diode lasers and LLLT were effective in reducing pain and analgesic consumption, with significant pain relief noted in the first 72 hours post-treatment (12,16,19,20).

Healing outcomes:

Studies measuring healing outcomes (periapical healing and bone regeneration) showed superior results in laser-treated groups, with diode lasers and PDT contributing to faster bone regeneration and periapical healing (9,20,22).

4.3. Data extraction table

Table 4. Summary of key characteristics and outcomes of the clinical studies included in this review. Details include laser type, wavelength, power, evaluation period, and main findings. References correspond to those cited in the reference list and are noted inline within the table.

Reference	Intervention	Study design / number of samples	Groups	Laser type / protocol	Evaluation period	Key findings	p-value
Leonardo et al. (7) (2023)	Laser ablation combined with ICG, (bacterial reduction)	Clinical trial / 60 patients with periapical lesion in single canal teeth	3 groups (n=20): apical sizes 25/04, 30/04, 35/04 Each group split into - NaOCl (n=10) - saline (n=10) subgroups	- Diode laser with ICG dye, 810 nm wavelength	Post-treatment evaluation : Samples collected: S1 (before), S2 (post-instrumentation), S3 (post-LA with ICG)	**Bacterial reduction:** - LA + ICG: significant bacterial reduction across sizes - No difference between NaOCl and saline groups	$p < 0.05$
Liapis et al. (23) (2021)	Laser-activated irrigation vs ultrasonic regarding post-operative pain (pain relief)	Randomnized clinical trial / 56 patients with asymptomatic tooth but need of RCT	- Ultrasonic active irrigation (UAI) group (n=28): 60s activation with	Er:YAG laser at 2940nm	6-, 24-, 48- and 72-hours post-treatment	**Pain relief:** - No significant difference in postoperative pain between ultrasonic and	Not specified

			Irrisafe tip (ultrasonic) - LAI group (n=28): Laser-activated irrigation			laser-activated irrigation.	
Shah et al. (18) (2021)	LLLT (low level laser therapy) with intracanal medicament + conventional root canal therapy postoperative pain and periapical healing (pain reduction, healing improvement)	Double-blind randomized clinical trial/ 40 patients	- Conventional RCT + intracanal medicament (no LLLT): n = 20 - Conventional root canal therapy along with LLLT	Diode laser (660 nm, 100 mW, 1 J/cm², 80 s per session), 3 sessions at 0, 7, and 14 days	Pain: 0, 7, 14 days; Healing: baseline, 3, 6, 9 months	**Pain relief:** - The LLLT group experienced lower pain intensity compared to the non-laser group during treatment. **Healing:** - Lesion size reduction was greater in the LLLT group than	p = 0.01

						in the non-laser group. - LLLT promoted faster healing, especially in cases with extensive periapical lesions.	
Fahim et al. (13) (2024)	Er,Cr:YSGG/Diode laser + EDTA vs NaOCl/EDTA (bacterial reduction)	Randomized clinical trial/ 30 patients	- Conventional irrigation (NaOCl + EDTA) : n= 10 - Dual laser group, Er,Cr:YSGG : n = 10 - Diode laser: n = 10	Er,Cr:YSGG (2780 nm, 1.25 W, 20 Hz) + Diode laser (940 nm, 1 W)	Immediate post-treatment bacterial analysis	**Bacterial reduction:** - Both dual laser (Er,Cr:YSGG/Diode) and combined (EDTA/Diode) groups showed significantly higher bacterial reduction (>99.9%) compared to	$p < 0.05$

						conventional (57.6%); - No significant difference between the two laser groups.	
Naseri et al. (24) (2020)	Low-level laser therapy (LLLT) with buccal only irradiation (BI) and buccal-lingual irradiation (BLI) (pain reduction)	Double-blind randomized clinical trial/ 75 patients	- Sham laser (placebo): n= 25 - BI: n = 25 - BLI: n= 25	Diode laser (808 nm, 100 mW, 80s BI; 160s BLI)	4, 8, 24, and 48 hours	**Pain relief:** - BLI significantly reduced postoperative endodontic pain (PEP) compared to placebo at all intervals BLI more effective than BI at 8h and 48h; BLI group used fewer	$p < 0.05$

						analgesics than placebo (p=0.001).	
Guimarães et al. (17) (2021)	Photobiomodulation (PBM) with aPDT + LLLT (post- operative pain, tenderness, oedema, and the use of analgesics)	Randomized clinical trial / 70 patients	- Conventional root canal treatment (no PBM): n= 35 - PBM: n=35	Diode laser: InGaAIP (Indium Gallium Aluminium Phosphide, a diode laser type) (660 nm, 100 mW, 9 J), GaAlAs (Gallium Aluminium Arsenide, an other diode laser type) (808 nm, 100 mW, 4 J); aPDT with methylene blue	Pain assessed over 1, 2, 3, 4, 5, 6, 7, 14, and 30 days	**Pain relief:** - No significant differences in postoperative pain, tenderness, edema, or analgesic use between PBM and control groups; pain decreased over time regardless of treatment.	$p < 0.05$
Mathevanan et al. (19) (2023)	Laser vs ultrasonic activation in	Randomnized clinical trial / 75 patients	- Conventional needle	Er:Cr: YSGG (Erbium, Chromium:	6, 24, 48 hours post-treatment	**Pain relief:** - PUI showed greater	$p < 0.05$

	postoperative pain reduction (pain reduction, analgesic intake)		irrigation (CNI): n=25 - Passive ultrasonic irrigation (PUI) : n =25 - LAI: n= 25	Yttrium Scandium Gallium Garnet) laser		postoperative pain reduction than LAI and CNI. - PUI provided better results with minimal patient discomfort. **Analgesic intake:** - Highest in CNI, followed by PUI and LAI.	
Genc Sen et al. (25) (2019)	Pain relief, analgesic use	Randomized clinical trial/ 84 patients	- Laser disinfection (LD) (n = 42) - Pseudo laser disinfection(PLD) (n = 42)	Diode laser 940 nm	24h, 48h, 72h, 4th day	**Pain relief:** - Pain was significantly lower in LD group at 24h and 48h **Analgesic intake:** - Analgesic use and percussion	$p < 0.05$

						pain were also reduced in LD group	
De Miranda et al. (21) (2018)	PDT (bacterial reduction, healing)	Randomized clinical trial/ 32 patients	- Conventional mechanical disinfection (CMD) only (n = 16) - CMD + PDT (n = 16)	Diode laser 660 nm, methylene blue 25 µg/mL, 100 mW, 5 min	3 and 6 months	**Bacterial reduction:** - Both groups showed microbial reduction - No significant difference in microbial levels **Healing:** - PDT group showed significantly better periapical healing at 6 months	$p < 0.05$

						Pain relief: - does not report a significant difference in postoperative pain between the aPDT and control groups	
Arslan et al. (26) (2017)	LLLT (pain relief)	Randomized clinical trial / 36 patients	- LLLT group (n=18) - Placebo group (n=18)	Diode laser (970 ±15 nm, 0.5W, 10Hz, 30s irradiation)	Day 1 to Day 7	**Pain reduction:** - Significant reduction in postoperative pain in LLLT group during first 4 days - No significant difference after day 5 **Analgesic Use:** - Fewer patients required	$p < 0.05$

						analgesics in LLLT group	
Ahangari et al. (15) (2017)	Photodynamic therapy (bacterial reduction)	In vivo RCT / 20 patients	- aPDT group (n=10) - Calcium hydroxide group (n=10)	Diode laser (810 nm) + methylene blue (50 mg/mL), 0.2 W	Before and after intervention (Colony-forming units analysis)	**Bacterial reduction:** - Both groups showed significant reduction in E. faecalis and C. albicans colony counts No significant difference between groups	$p < 0.05$
Kaplan et al. (12) (2021)	Diode laser disinfection (pain relief)	Randomized clinical trial/ 60 patients	- Control: conventional irrigation (n = 30) - Laser group: diode laser after irrigation (n = 30)	Diode laser 980 nm; 2.4 W pulsed, 4 cycles of 10s pulses per visit	8h, 24h, 48h, 7d (post-op after both visits)	**Pain relief:** - Laser group had significantly lower pain at 24h post-visit 1 and 2 ($p < 0.05$)	$p < 0.05$

						Analgesic use : - Lower analgesic use in laser group at 8h and 24h ($p < 0.05$) No pain reported at 7 days in either group	
Nabi et al. (16) (2018)	Pain relief	Randomized clinical trial / 120 patients	- Group A: Ibuprofen only (n=30) - Group B: LLLT only (n=30) - Group C: Ibuprofen + LLLT (n=30) - Group D: Control (n=30)	LLLT (905 nm), 50Hz, 3 min post-op on buccal and lingual periapical areas	4h, 8h, 12h, 24h, 48h	**Pain reduction**: - All groups showed pain reduction - Best results in combination group (Ibuprofen + LLLT) - LLLT alone more effective than ibuprofen alone after 12h	$p < 0.05$

						LLLT and combination group showed statistically significant lower pain at all time points vs. control	
Nagahashi et al. (4) (2022)	Er:YAG laser irrigation activation (bacterial reduction)	In vivo study (pig model)/ 16 roots	- Positive control (needle with saline solution) - CNI (needle with 5% NaOCl) - Intracanal laser-activated irrigation (LAI) - Coronal LAI (LAI with 5% NaOCl) - Each group n= 4 roots	Er:YAG laser, 2940 nm wavelength	Immediate post-treatment analysis	**Bacterial reduction:** - I-LAI (internal LAI) and C-LAI (coronal LAI) groups: Significant bacterial reduction compared to controls - No significant difference between I-LAI and C-LAI	$p < 0.05$

Barciela et al. (27) (2019)	Photodynamic therapy (pain relief)	Randomized clinical trial/ 40 patients	- PDT group (n = 20) - Control group (n = 20)	Diode laser 660 nm + methylene blue, 90s irradiation	24h, 72h, 7 days	**Pain relief**: - No significant difference in pain levels between groups at any time point	$p > 0.05$
Bago Jurič et al. (14) (2014)	Supplemental photodynamic therapy (aPDT) in endodontic re-treatment (bacterial reduction)	Clinical study / 21 patients	- Single group: Measures taken before, after re-treatment, and after aPDT	Diode laser (660 nm), 100 mW, 1 minute irradiation combined with NaOCl and EDTA irrigation	Before re-treatment, after re-treatment, and after PDT	**Bacterial reduction:** - aPDT significantly reduced bacterial species after PDT compared to after re-treatment alone. - No difference between chlorhexidine	$p < 0.001$

						(CHX), NaOCl and PDT	
Vieira et al. (22) (2018)	Photodynamic therapy during endodontic surgery (bacterial reduction, healing)	Clinical case series / 19 teeth	- Pre-PDT - Post-PDT	Diode laser 660 nm, 40 mW, 7.2 J, with methylene blue as photosensitizer, applied 3 minutes per region	Follow-up 12–21 months	**Bacterial reduction:** - Significant reduction in total bacteria and streptococci on root-end and cut surfaces **Healing:** - 93% success with loose criteria, - 73% with strict criteria	$p < 0.05$
Rubio et al. (9) (2022)	PBM + root canal disinfection (healing)	Case report / 2 cases	- None (self-controlled cases)	Diode laser (940 nm), 1.0 W for disinfection; PBM: 0.1 W, 40	6 months (cone beam computed tomography follow-up)	**Healing:** Significant bone healing and neoformation;	Not specified

				s per point, 6 J/cm²		reduced apical lesion size	
Cirisola et al. (20) (2023)	Diode laser therapy (940 nm) (pain relief)	Randomized controlled trial/ 84 patients	- Laser disinfection (LD) group (n = 42) - Pseudo-laser disinfection (PLD) group (n = 42)	Diode laser 940 nm. Used after filling removal and chemo-mechanical preparation. Mock application in control group (laser off)	- Pain scores at 24 h, 48 h, and 72 h - Analgesic intake tracked - Pain on percussion evaluated on day 4	**Pain relief:** - Significantly lower pain at 24 h and 48 h in laser group - No difference at 72 h - Lower analgesic intake in laser group - Reduced percussion sensitivity on day 4 **Healing:** - Notes accelerated	$p < 0.05$

				healing, including tissue regeneration indicators

5. DISCUSION

5.1. Comparison of laser types and protocols

A significant variability exists in the results reported in the studies reviewed, mainly due to differences in laser types, protocols, and study designs. The three primary laser modalities studied Er:YAG, diode lasers, and PDT; each showed different efficacy levels across the three main outcomes: bacterial reduction, pain relief, and healing enhancement.

Er:YAG lasers:

Er:YAG lasers were primarily used for bacterial reduction and canal decontamination. Studies by Fahim et al. (2024)(13) and Nagahashi et al. (2022) (4) demonstrated that Er:YAG lasers achieved significant bacterial load reduction, particularly for E. faecalis and C. albicans, with reductions exceeding 99%. These results align with the established notion that Er:YAG lasers are highly effective for biofilm removal and debris disinfection due to their thermal and cavitation effects.

Diode lasers:

Diode lasers were used in several studies, primarily for pain management and healing promotion through PBM. Kaplan et al. (2021) (12) and Nabi et al. (2018) (16) reported significant pain reduction and lower analgesic consumption in the laser-treated groups compared to controls. Diode lasers were also effective in enhancing tissue healing (9,18,21,22) and reducing inflammation, making them a preferred option for pain management post-treatment.

Photodynamic therapy (PDT) with ICG:

Studies utilizing PDT in conjunction with indocyanine green (ICG) photosensitizer demonstrated outstanding bacterial reduction results, particularly for resistant biofilms. Leonardo et al. (2023) (7) reported >99% reduction in bacterial load, especially for E. faecalis. PDT was found to be highly effective in disrupting bacterial biofilms, especially in difficult-to-reach areas of the root canal system. Bago Jurič et al. (2014) (14) further supports this, showing that PDT, when used as an adjunct to conventional endodontic re-treatment, significantly reduced the bacterial load in root canals, achieving superior disinfection compared to re-treatment alone, with $p < 0.001$ for bacterial reduction.

5.2. Agreement with existing literature

The findings of this review largely support the results reported in existing literature on laser-assisted endodontic treatments. The use of Er:YAG and PDT for bacterial reduction aligns with previous studies, and the efficacy of diode lasers for pain relief and tissue healing is consistent with the broader body of research.

Bacterial reduction:

Studies have long established that laser therapy provides superior bacterial disinfection compared to traditional methods. In line with this, our findings indicate that Er:YAG and PDT are highly effective in reducing bacterial load, especially E. faecalis. This aligns with the results of Fahim et al. (2024) (13) and Nagahashi et al. (2022) (4), who also demonstrated the superior bacterial reduction capabilities of Er:YAG lasers and PDT. This agreement confirms that laser therapy can achieve better disinfection than conventional NaOCl irrigation, particularly in difficult-to-reach areas. The addition of PDT to conventional re-treatment, as shown by Bago Jurič et al. (2014) (14), provides superior bacterial reduction, further supporting the effectiveness of laser-assisted disinfection

Pain relief:

The studies reviewed consistently reported significant reductions in pain after laser-assisted treatments. This is in agreement with findings from Kaplan et al. (2021) (12) and Nabi et al. (2018) (16), who noted that diode lasers and PBM were particularly effective for reducing postoperative pain. These studies are consistent with the wider body of literature that supports the analgesic effects of diode lasers and PBM, which work through cellular biostimulation and anti-inflammatory mechanisms (28).

Healing outcomes:

Healing improvements, including bone regeneration and periapical healing, observed in this review also align with existing studies. PDT with ICG and diode lasers have shown significant improvements in tissue healing, as reported by Shah et al. (2021) (18) and De Miranda et al. (2018) (21). This confirms that laser therapy can accelerate healing and promote better bone regeneration compared to conventional methods.

5.3. Discrepancies and limitations

While this review largely supports the existing literature, discrepancies exist between studies in certain outcomes. Ahangari et al. (2017) (15) and Guimarães et al. (2021) (17) did not observe significant differences in bacterial reduction or pain relief in the laser groups. Several factors could explain these discrepancies:

Sample size and statistical power:

Many studies, particularly Ahangari et al. (2017) (15), suffered from small sample sizes, which may have reduced the statistical power to detect significant effects. This issue is particularly relevant when comparing treatments that yield small to moderate differences in clinical outcomes. Small sample sizes increase the risk of type II errors (failure to detect a real effect), which might explain the non-significant findings in certain studies (29).

Protocol variability:

Variability in laser protocols was a key limitation in the studies included in this review. Differences in wavelengths, power settings, and treatment durations led to a wide range of outcomes. This makes direct comparison difficult. For example, the Er:YAG laser has been shown to be highly effective for bacterial reduction, but this depends on the exact settings used . Some studies used lower power settings or shorter exposure times, which could explain the lack of significant results in those studies (5).

Bias and confounding factors:

Study design issues such as lack of blinding or inconsistent randomization could introduce bias into the results. Operator skills and patient variability (e.g., age, degree of infection) could also have confounded the results, affecting the interpretation of laser efficacy (6) .

5.4. Clinical implications

The findings of this review suggest several important clinical implications for laser therapy in endodontic practice:

Laser therapy as an adjunct:

Laser therapy, particularly PDT with ICG and Er:YAG lasers, should be considered an effective adjunct to conventional root canal treatments, particularly for cases involving persistent infections or complex canal systems (3). The superior bacterial reduction and pain relief observed with lasers make them an attractive option for difficult-to-treat cases, especially when conventional methods are insufficient.

Standardization of protocols:

To optimize clinical outcomes, there is a clear need to standardize laser protocols, including wavelength, power, and application time. Future studies should focus on identifying the most effective settings for each type of laser, based on the clinical goal (bacterial reduction, pain relief, or healing enhancement). Clinicians should follow evidence-based protocols to maximize the benefits of laser therapy and ensure consistent outcomes (30).

Cost and accessibility:

While the initial cost of laser systems may be high, long-term savings can be achieved through reduced postoperative complications and lower analgesic use. Laser-assisted treatments could be cost-effective in the long run, especially if they reduce the need for follow-up treatments and extended patient care (31).

5.5. Future directions

Future research should focus on the following key areas to improve our understanding of laser therapy in endodontics:

Long-term outcomes:

Long-term studies are necessary to assess the sustainability of the benefits of laser therapy. Research should follow patients for extended periods to evaluate the long-term efficacy of laser therapy in reducing bacterial recurrence and improving tooth survival (32).

Optimizing laser parameters:

Future studies should aim to optimize laser settings for specific clinical scenarios. Research should focus on identifying the optimal power, wavelength, and treatment duration to maximize clinical efficacy across different laser types (5).

Comparative studies:

More head-to-head comparative studies between different laser modalities (e.g., Er:YAG vs. diode lasers) are needed to clarify the relative benefits of each type of laser. Future trials should also include a larger sample size and multicenter designs to enhance the generalizability of results.

5.6. Discussion's conclusion

This systematized review confirms the positive impact of laser therapy as an adjunct in endodontic treatments, particularly for bacterial disinfection, pain relief, and healing enhancement. However, variability in study protocols, laser types, and sample sizes indicates the need for further research to optimize laser parameters and ensure standardized application in clinical practice. Laser therapy holds significant promise for improving endodontic outcomes, and future research should focus on long-term efficacy, cost-effectiveness, and clinical standardization to enhance its role in routine endodontic care.

6. CONCLUSIONS

This systematized review aimed to evaluate the effectiveness of laser therapy in endodontic treatment, specifically focusing on bacterial reduction, pain relief, and healing outcomes in comparison to conventional disinfection methods. Based on the findings from the 19 studies reviewed, the following conclusions are drawn:

6.1. Bacterial reduction

Laser therapy, particularly Er:YAG lasers and PDT with ICG, significantly reduces bacterial load compared to traditional method such as NaOCl. This aligns with previous studies that highlight Er:YAG and PDT as highly effective in eliminating E. faecalis and other root canal pathogens. As noted by Fahim et al. (2024) (13) and Leonardo et al. (2023) (7), laser-assisted disinfection provides more thorough bacterial elimination, particularly in the deeper recesses of the root canal system, where traditional methods often fail to reach.

6.2. Pain relief

Laser therapy, especially diode lasers and PBM, significantly reduces postoperative pain, as evidenced by several studies, including Kaplan et al. (2021) (12) and Nabi et al. (2018) (16). The reduction in pain and analgesic consumption reported in these studies supports the use of diode lasers and PBM for pain management in endodontics. This confirms that laser therapy provides an effective adjunct to conventional methods in managing post-treatment discomfort.

6.3. Healing outcomes

Laser therapy enhances periapical healing and bone regeneration, particularly with PDT and diode lasers, which significantly improve healing compared to traditional treatments. Studies by Shah et al. (2021) (18) and De Miranda et al. (2018) (21) showed that PDT and diode lasers contribute to faster tissue regeneration and improved bone healing post-treatment. This reinforces the therapeutic potential of laser-assisted treatments for promoting faster recovery and better healing outcomes.

6.4. Clinical implications

Laser therapy should be considered an effective adjunct to conventional endodontic procedures, especially for bacterial disinfection, pain relief, and healing enhancement. Its integration into clinical practice could improve patient outcomes, particularly in difficult cases where traditional methods may not be sufficient (5). However, standardized protocols and further research are required to fully establish the optimal laser settings and treatment approaches for various clinical scenarios.

7. SUSTAINABILITY

The integration of laser therapy into endodontic practice offers several potential sustainability benefits in terms of environmental impact, economic feasibility, and social equity.

7.1. Environmental sustainability

Laser therapy, particularly PDT and diode lasers, can reduce the reliance on chemical irrigants such as NaOCl and chlorhexidine (CHX), which are commonly used in traditional root canal disinfection methods (33). This reduction in chemical use could lower chemical waste and minimize the environmental impact associated with the disposal of chemical irrigants. As Leonardo et al. (2023) (7) highlighted, laser therapy not only reduces the need for these chemicals but also enhances disinfection through non-thermal mechanisms, offering a greener alternative to conventional approaches .

7.2. Economic sustainability

The initial investment cost for laser equipment can be high, but the long-term cost-effectiveness of laser therapy is significant (34). The reduction in postoperative complications, analgesic use, and follow-up treatments can result in long-term savings (35). Fahim et al. (2024) (13) and Kaplan et al. (2021) (12) noted that laser-assisted treatments reduce the need for additional pain management, potentially lowering overall treatment costs. The time savings associated with laser procedures, which often reduce treatment duration and improve clinical efficiency, further support the economic benefits of incorporating lasers into endodontic practice (35).

7.3. Social equity and access

While laser therapy has clear benefits, its widespread adoption remains a challenge, particularly in low-resource settings (34). The high initial cost of laser devices and the need for specialized training can limit access to laser technology in certain clinical environments (5). Efforts to reduce costs and increase access to laser devices are essential to ensure that laser therapy becomes more widely available. As social equity remains a priority in global healthcare, making laser-assisted endodontic treatments more accessible will align with global health initiatives such as the Sustainable Development Goals 10 (SDGs), ensuring equitable access to advanced dental care for all populations (36).

7.4. Ethical and professional considerations

As with any technological advancement, laser therapy raises ethical and professional considerations. First, informed consent is essential, as patients should be fully informed about the benefits and risks associated with laser-assisted treatments (37). Additionally, the competence of clinicians using lasers must be ensured through proper training to avoid iatrogenic damage and ensure patient safety (38). As Fahim et al. (2024) (13) and Arslan et al. (2017) (26) emphasized, proper training is crucial for the safe and effective use of laser devices, ensuring that clinicians are capable of achieving optimal results without causing harm to the patient.

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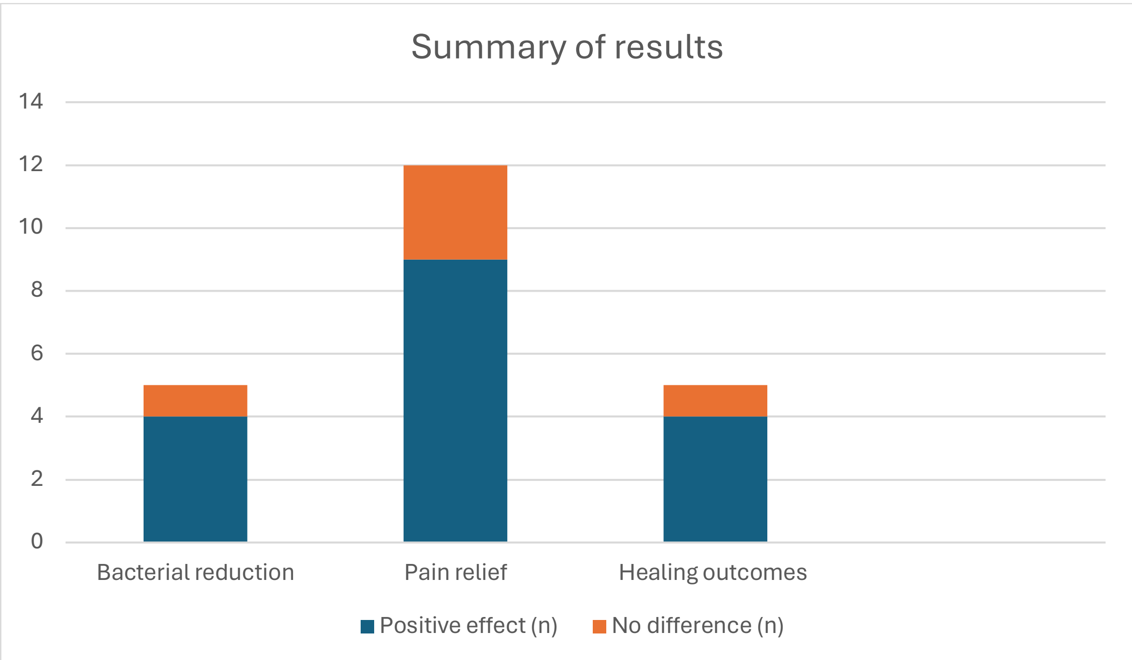
9. ANNEXES

9.1. Summary of result table

Figure 2. Visual representation of the percentage of studies reporting positive outcomes across the three main categories: bacterial reduction, pain relief, and healing outcomes. The graph illustrates that laser therapy demonstrated consistent effectiveness in over 75% of the studies analyzed. Based on data summarized in Table 1.



9.2. Abbreviation's list

Abbreviation	Meaning
BI	Buccal Irradiation
BLI	Buccal-Lingual Irradiation
CBCT	Cone Beam Computed Tomography
CFU	Colony-Forming Units
CHX	Chlorhexidine
CMD	Conventional Mechanical Disinfection
EDTA	Ethylenediaminetetraacetic Acid
Er:YAG	Erbium-doped Yttrium Aluminum Garnet Laser (used for hard/soft tissue treatment, 2940 nm)
Er,Cr:YSGG	Erbium, Chromium-doped Yttrium Scandium Gallium Garnet Laser (used for hard/soft tissue applications, 2780 nm)
GaAlAs	Gallium Aluminium Arsenide (infrared laser diode, ~808 nm)
ICG	Indocyanine Green
InGaAlP	Indium Gallium Aluminium Phosphide (red laser diode, ~660 nm)
LLLT	Low-Level Laser Therapy *(also called PBM)*
LAI	Laser-Activated Irrigation
LD	Laser Disinfection
MB	Methylene Blue
NaOCl	Sodium Hypochlorite
PAI	Periapical Index
PBM	Photobiomodulation

Abbreviation	Meaning
PDT	Photodynamic Therapy
PLD	Pseudo-Laser Disinfection
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PICO	Population, Intervention, Comparison, Outcome
PUI	Passive Ultrasonic Irrigation
RCT	Randomized Controlled Trial Root Canal Treatment
SDG	Sustainable Development Goal
UAI	Ultrasonic Activated Irrigation
VAS	Visual Analogue Scale (for pain assessment)