

Antibacterial Effectiveness of the 445 nm Diode Laser in the Root Canal System: a Systematic Review

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ABSTRACT

Objectives: Effective root canal disinfection remains challenging due to the complex anatomy of the root canal system and the ability of microorganisms to form resistant biofilms. The 445 nm blue diode laser has recently gained attention as a potential adjunctive disinfection method. This systematic review aimed to evaluate the antibacterial effectiveness of the 445 nm diode laser within the root canal system.

Material and Methods: A literature search was conducted in PubMed, ScienceDirect, and SpringerLink for studies published between 2018 and 2026. A total of 40 papers were identified. Studies meeting predefined inclusion criteria were selected for analysis. Methodological quality and risk of bias were assessed using the Cochrane RoB 2.0 tool for clinical studies and the Joanna Briggs Institute critical appraisal tools for *in vitro* studies.

Results: Five studies met the inclusion criteria: four *in vitro* and one *in vivo* clinical study. All studies demonstrated that the 445 nm diode laser exhibited antibacterial activity against *Enterococcus faecalis* and other endodontic pathogens, although the magnitude of the effect varied depending on laser parameters, dentine thickness, and evaluation methods. *In vitro* studies reported bacterial reductions ranging from 6.9% to 97.6%, and one study demonstrated a 1.0 to 2.5 log₁₀ CFU/mL reduction. In the clinical study, the 445 nm laser alone reduced bacterial load by 58.2%, while its combination with 3% sodium hypochlorite achieved a 92.7% reduction. All included studies demonstrated a low risk of methodological bias.

Conclusions: The 445 nm diode laser shows measurable antibacterial activity within the root canal system. However, its effectiveness depends on irradiation parameters and dentine thickness. As a standalone method, it is less effective than conventional irrigants, but when combined with 2.5 to 3% sodium hypochlorite, a significantly greater antibacterial effect is achieved. More clinical studies are needed to determine its long term clinical relevance.

Keywords: biofilms; endodontics; enterococcus faecalis; lasers; root canal therapy.

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INTRODUCTION

Successful endodontic treatment depends on the effective elimination of microorganisms from the root canal system. Despite significant advances in instrumentation, irrigation protocols, and obturation materials, persistent microbial infection remains one of the primary causes of endodontic treatment failure. This challenge is largely attributed to the ability of microorganisms to survive within the complex anatomy of the root canal system and to form structurally resistant biofilms that limit the efficacy of conventional disinfection methods [1-5].

Endodontic infection is a biofilm-mediated process in which microorganisms colonize complex anatomical areas - such as lateral canals, isthmuses, and dentinal tubules - that cannot be fully reached by mechanical instrumentation alone [5-7]. Bacteria can migrate into dentinal tubules and form intra-tubular colonies at depths reaching several hundred micrometers, depending on dentine structure and tubule morphology [4,6,8]. *Enterococcus faecalis* is particularly associated with persistent and secondary infections due to its ability to withstand harsh environmental conditions, penetrate deeply into dentine, and resist commonly used antimicrobial agents [6,9].

Conventional root canal disinfection relies on chemomechanical preparation using irrigants such as sodium hypochlorite (NaOCl), chlorhexidine (CHX), and ethylenediaminetetraacetic acid (EDTA). Although these agents significantly reduce bacterial load, their penetration into dentinal tubules is limited. NaOCl typically penetrates only 100 to 200 µm into dentine, whereas microorganisms may invade tubules up to 1000 µm, allowing bacteria to persist in deeper layers and potentially contribute to reinfection [5, 10-12].

To improve root canal disinfection, various laser systems have been introduced in endodontics, including diode lasers (405 to 980 nm), neodymium-doped yttrium aluminum garnet (Nd:YAG) lasers (1064 nm), erbium-doped yttrium aluminum garnet (Er:YAG) lasers (2940 nm), and erbium, chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG) lasers (2780 nm). These systems exert antibacterial effects through photothermal, photomechanical, and photoacoustic mechanisms and may enhance irrigant activation. However, their effectiveness varies depending on wavelength, tissue interaction, and energy delivery parameters [13-17].

In recent years, short-wavelength diode lasers - particularly 445 nm blue diode lasers - have gained

attention due to their high absorption in bacterial chromophores and porphyrins, exerting antibacterial effects primarily through photothermal and photochemical mechanisms. These properties suggest that the 445 nm diode laser may offer antibacterial potential in root canal disinfection [18,19].

However, the available evidence regarding the antibacterial effectiveness of the 445 nm diode laser in the root canal system remains limited, heterogeneous, and methodologically diverse. A comprehensive evaluation of current scientific literature is therefore required.

Therefore, the aim of this systematic review was to evaluate the antibacterial effectiveness of the 445 nm diode laser within the root canal system based on currently available scientific evidence.

MATERIAL AND METHODS

Protocol registration

This systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [20] and was prospectively registered in PROSPERO (CRD420261378910). The protocol can be accessed at: <https://www.crd.york.ac.uk/PROSPERO/view/CRD420261378910>

Focus question

The research question of this systematic review was formulated using the Patient, Intervention, Comparison, and Outcome (PICO) framework to ensure a structured and reproducible approach to defining the problem. The focus question was:

“Is the 445 nm diode laser, used alone or in combination with conventional irrigants, effective in reducing bacterial load in the root canal system of permanent human teeth?”

Table 1 summarises the PICO components used to guide the search strategy, study selection, and data extraction.

Information sources and search strategy

A systematic search was performed in the following electronic databases: MEDLINE (PubMed), ScienceDirect (Elsevier), and SpringerLink (Springer Nature). These databases were selected as primary sources because they index the vast majority of peer-reviewed biomedical and dental journals publishing research on laser applications in endodontics. To complement the database search

Table 1. PICO guidelines

Population (P)	Permanent human teeth or dentine samples infected with endodontic pathogens or biofilms
Intervention (I)	445 nm diode laser irradiation
Comparison (C)	Conventional irrigants (NaOCl, CHX), other laser systems, or no treatment
Outcomes (O)	Reduction of bacterial load (CFU, log ₁₀ reduction, qPCR, SEM)
Focus question	Is the 445 nm diode laser, used alone or in combination with conventional irrigants (C), effective in reducing bacterial load in the root canal system of permanent human teeth?

and ensure comprehensive coverage, manual reference screening of relevant reviews and included articles was also performed. The search was conducted between April 22, 2026 and June 4, 2026, and included studies published from 2018 to 2026.

The search strategy included combinations of Medical Subject Headings (MeSH) and free-text terms: “445 nm diode laser”, “blue diode laser”, “endodontic disinfection”, “root canal”, “*Enterococcus faecalis*”, “biofilm”.

Boolean operators (“AND”, “OR”) were used to refine the search. Filters were applied to include only English-language full-text articles published within the selected time frame.

Study selection

The study selection process consisted of three stages:

1. Identification: all retrieved records were combined and duplicates were removed.
2. Screening: titles and abstracts were screened to exclude studies not relevant to the research question.
3. Eligibility assessment: full-text articles were evaluated according to the inclusion and exclusion criteria. Only studies providing sufficient methodological detail and quantitative antibacterial outcomes were included.

Screening and selection were performed by one reviewer (V.M.) and verified through repeated assessment to minimise selection bias. Disagreements between reviewers were resolved through discussion or consultation with a third author. The study selection procedure is shown in the PRISMA flow chart.

Data extraction

Data from the included studies were extracted using a standardized data collection form. The following variables were recorded:

- Study characteristics (authors, year, study design).
- Sample characteristics (type and number of specimens, infection model, dentine thickness).

- Laser parameters (wavelength, power, mode, exposure time, fiber diameter, irradiation technique).
- Control groups (e.g., NaOCl, CHX, other lasers, or untreated controls).
- Outcome measures (colony-forming units [CFU] reduction, log₁₀ reduction, quantitative polymerase chain reaction [qPCR] results, scanning electron microscopy [SEM] findings, percentage reduction).

Eligibility criteria

Studies were selected according to predefined inclusion and exclusion criteria.

Inclusion criteria

- Studies published between 2018 and 2026.
- *In vitro* or *in vivo* studies.
- Studies evaluating the antibacterial effect of a 445 nm diode laser.
- Studies involving human permanent teeth or dentine samples.
- Full-text articles available in English.

Exclusion criteria

- Reviews, meta-analyses, case reports, conference abstracts, and book chapters.
- Studies involving primary teeth.
- Studies evaluating other laser wavelengths without including 445 nm.
- Studies using 445 nm lasers exclusively for photodynamic therapy.
- Studies not related to endodontic infections.
- Non-English publications.

Risk of bias assessment

The methodological quality and risk of bias were assessed according to study design.

The *in vivo* study was evaluated using the Cochrane Risk of Bias 2.0 tool which assesses five domains of potential bias: (1) bias arising from the randomization

process, (2) bias due to deviations from intended interventions, (3) bias due to missing outcome data, (4) bias in measurement of the outcome, and (5) bias in selection of the reported result [21]. Each domain was judged according to the RoB 2.0 criteria as “low risk of bias”, “some concerns”, or “high risk of bias” [21].

In vitro studies were assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for experimental studies [22]. The full list of JBI appraisal questions used in this review is provided in Table 2. According to the JBI methodology, studies scoring ≥ 7 “yes” responses were classified as having a low risk of bias, scores of 5 to 6 indicated a moderate risk of bias, and scores ≤ 4 were considered high risk of bias [22].

Data synthesis

Due to heterogeneity in study design, laser parameters, and outcome measures, a qualitative synthesis of the results was performed.

Statistical analysis

Reference management was performed manually without the use of dedicated reference management software. A meta-analysis was not conducted due to substantial heterogeneity among the included studies, including differences in laser types, irradiation parameters, experimental models, and outcome measures, which prevented quantitative pooling of data. Cohen’s kappa coefficient (κ) was not calculated because all stages of study selection and data extraction were performed by a single reviewer (V.M.).

RESULTS

Study selection

The database search identified 37 records from MEDLINE (PubMed) ($n = 20$), ScienceDirect (Elsevier) ($n = 10$), and SpringerLink (Springer Nature) ($n = 7$). Additional 3 records were identified through manual searching, resulting in a total of 40 records. After removing 1 duplicate, 39 records were screened by title and abstract, of which 34 were excluded for not meeting the inclusion criteria. All five full-text articles assessed for eligibility met the inclusion criteria, and none were excluded at this stage. A total of five studies met the inclusion criteria and were included in the qualitative synthesis (Figure1).

Study characteristics

Five studies met the inclusion criteria: one *in vivo* clinical study [23] and four laboratory-based investigations (three *in vitro* [24-26] and one *ex vivo* model utilizing extracted human teeth [27]). Demographic characteristics such as patient age or sex were not reported because four studies were laboratory experiments, and the single *in vivo* clinical study did not provide demographic data. All studies evaluated the antibacterial effectiveness of the 445 nm diode laser against endodontic pathogens, primarily *Enterococcus faecalis*. Experimental models included dentine slices of varying thicknesses, contaminated extracted human teeth, and infected root canals in clinical patients. Control groups included root canal irrigation with 2.5 to 3% sodium hypochlorite, 2% chlorhexidine, or treatment with Er,Cr:YSGG laser,

Table 2. The Joanna Briggs Institute Critical Appraisal Checklist for Experimental Studies

Question number	Defined question
Q1	Was the assignment to treatment groups truly random?
Q2	Were participants similar at baseline?
Q3	Were participants blind to treatment assignment?
Q4	Were those delivering treatment blind to treatment assignment?
Q5	Were outcome assessors blind to treatment assignment?
Q6	Were treatment groups treated identically other than the intervention?
Q7	Was follow-up complete, and if not, were differences between groups adequately described and analysed?
Q8	Were participants analysed in the groups to which they were randomized?
Q9	Were outcomes measured in the same way for treatment groups?
Q10	Were outcomes measured in a reliable way?
Q11	Was appropriate statistical analysis used?
Q12	Was the trial design appropriate, and were any deviations from the standard RCT design accounted for?

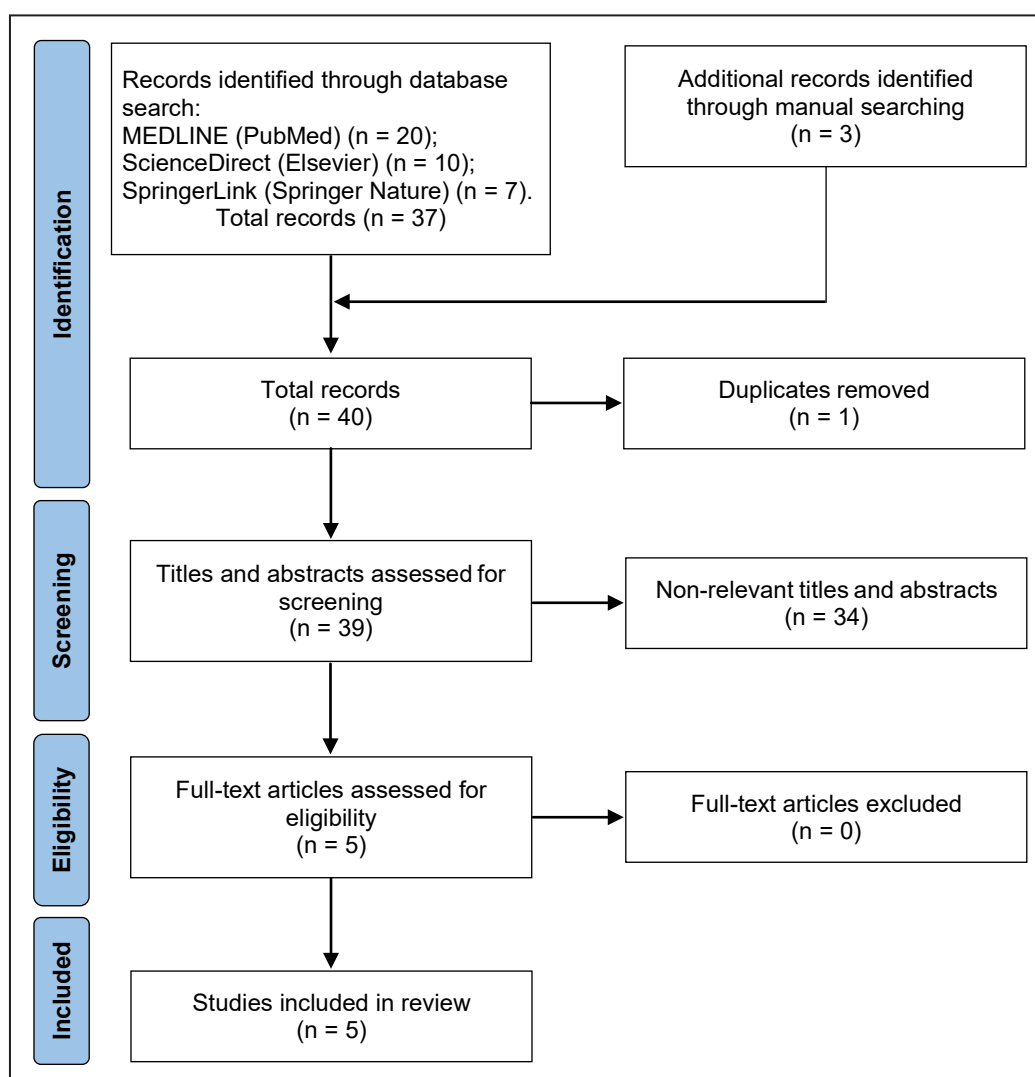


Figure 1. PRISMA 2020 flow diagram of the study selection process.

970 nm diode laser, as well as untreated samples (Tables 3 and 4).

Laser parameters varied considerably across studies, including differences in power output (0.4 to 1.5 W), irradiation mode (continuous wave or chopped), exposure time, fiber diameter (200 µm), and application technique (Table 4).

Antibacterial effectiveness of the 445 nm diode laser

All included studies demonstrated that the 445 nm diode laser exhibited antibacterial activity against *Enterococcus faecalis* [23-27], although the magnitude of the effect varied depending on experimental conditions.

In vitro studies reported bacterial reduction ranging from 6.9% to 97.6% [24-26], depending on laser power, exposure time, and dentine thickness. One study reported a 1.0 to 2.5 log₁₀ CFU/mL reduction [27], indicating a substantial decrease in viable bacterial counts.

Higher energy settings, slower fiber movement, and longer irradiation times were associated with greater antibacterial effects [24,27]. Dentine thickness also influenced outcomes: reductions were highest at 0.3 to 0.5 mm, while markedly reduced effects were observed at 1.0 mm [25].

The only clinical *in vivo* study confirmed that the 445 nm laser also reduced bacterial load under real clinical conditions, achieving a 58.2% reduction when used alone [23] (Table 5).

Comparison with conventional disinfection methods

When used as a standalone method, the 445 nm diode laser generally demonstrated lower antibacterial effectiveness compared with conventional chemical irrigants such as 3% sodium hypochlorite [23]. However, greater antibacterial effects were observed when the laser was combined with 2.5 to 3% sodium hypochlorite [23,26].

Table 3. Characteristics of included studies

Study	Year of publication	Study design	Experimental model	Sample type	Sample size (n)	Microorganisms tested	Control group	Outcome measure
Wenzler et al. [23]	2021	<i>In vivo</i>	Treated root canals	Root canal	57	Polymicrobial flora	NaOCl 3%	qPCR
Gutknecht et al. [24]	2018	<i>In vitro</i>	Infected human dentine samples	Dentine specimen	81	<i>E. faecalis</i>	-	CFU
Hendi et al. [25]	2022	<i>In vitro</i>	Infected human dentine samples	Dentine specimen	105	<i>E. faecalis</i>	Er,Cr:YSGG	CFU
Katalinić et al. [26]	2025	<i>Ex vivo</i>	Instrumented extracted single-rooted teeth	Root canal	62	<i>E. faecalis</i> , <i>C. albicans</i>	NaOCl 2.5%; 970 nm diode laser	CFU
Matthes et al. [27]	2026	<i>In vitro</i>	Biofilm on ceramic discs	Biofilm disc	42	<i>E. faecalis</i> , <i>S. mutans</i> , <i>C. albicans</i>	CHX 2%	CFU

CFU = colony-forming units; qPCR = quantitative polymerase chain reaction.

Table 4. Laser parameters used in the included studies

Study	Wavelength	Power	Mode	Fiber diameter	Exposure	Energy density (J/cm ²)
Wenzler et al. [23]	445 nm	0.6 W	CW	200 µm	4 × 10 s (40 s)	Not reported (total energy: 24 J)
Gutknecht et al. [24]	445 nm	0.4/0.6/1.2 W	Chopped mode/CW	200 µm	4 × 10 s (40 s)	1273.8 - 3821.6 J/cm ²
Hendi et al. [25]	445 nm	0.6 W	CW	200 µm	3 × 10 s (30 s)	Not reported (total energy: 18 J)
Katalinić et al. [26]	445 nm	1.5 W	CW	200 µm	60 s (5 cycles; 1 mm/s)	Not reported (total energy: 90 J)
Matthes et al. [27]	445 nm	1 W	CW	-	1 to 4 mm/s	12.7 - 50.9 J/cm ²

CW = continuous wave.

Table 5. Antibacterial effectiveness of the 445 nm diode laser

Study	Experimental model	Microorganisms tested	Dentine thickness (µm)	445 nm irradiation	Percentage reduction of bacterial colonies (445 nm laser alone)
Wenzler et al. [23]	Treated root canals	Polymicrobial flora	-	0.6 W (CW); 4 × 10 s	58.2%
Gutknecht et al. [24]	Infected human dentine samples	<i>E. faecalis</i>	300	1.2 W (chopped mode); 4 × 10 s	96%
			500	1.2 W (chopped mode); 4 × 10 s	97.6%
			1000	1.2 W (chopped mode); 4 × 10 s	84.9%
			300	0.6 W (CW); 4 × 10 s	82.41%
			500	0.6 W (CW); 4 × 10 s	83.75%
			1000	0.6 W (CW); 4 × 10 s	77.42%
			300	0.4 W (CW); 4 × 10 s	6.90%
			500	0.4 W (CW); 4 × 10 s	32.5%
			1000	0.4 W (CW); 4 × 10 s	-9.68%*
Hendi et al. [25]	Infected human dentine samples	<i>E. faecalis</i>	300	0.6 W (CW); 3 × 10 s (30 s)	48%
			500	0.6 W (CW); 3 × 10 s (30 s)	20%
			1000	0.6 W (CW); 3 × 10 s (30 s)	0%
Katalinić et al. [26]	Instrumented extracted single-rooted teeth	<i>E. faecalis</i> , <i>C. albicans</i>	-	1.5 W (CW); 60 s; 1 mm/s	Standalone 445 nm effect not evaluated (used only in combination with NaOCl)
Matthes et al. [27]	Biofilm on ceramic discs	<i>E. faecalis</i>	-	1 W (CW); 1 to 4 mm/s	Up to 1.8 log ₁₀ (≈ 98.4%) reduction (maximum at 1 mm/s)
		<i>S. mutans</i>	-	1 W (CW); 1 to 4 mm/s	Up to 2.5 log ₁₀ (≈ 99.7%) reduction (maximum at 1 mm/s)
		<i>C. albicans</i>	-	1 W (CW); 1 to 4 mm/s	Up to 1.0 log ₁₀ (≈ 90%) reduction (maximum at 1 mm/s)

*increase in bacterial load/growth relative to control the baseline rather than a reduction.

CW = continuous wave.

In the clinical study, the laser alone resulted in a 58.2% reduction in bacterial load, whereas a 92.7% reduction was achieved when combined with 3% sodium hypochlorite [23]. *In vitro* studies similarly reported higher bacterial reduction when the laser was used as an adjunct to irrigants [26] (Table 6).

Risk of bias within studies

The *in vivo* study [23] demonstrated a low risk of bias across all Cochrane RoB 2.0 five domains (Table 7). Four *in vitro* studies [24-27] were assessed as having low to moderate risk of bias according to the JBI criteria, with generally well-described methodologies and appropriate control groups (Table 8).

DISCUSSION

The present systematic review evaluated the antibacterial effectiveness of the 445 nm diode laser in the root canal system. The findings of this review indicate that the 445 nm diode laser demonstrates measurable antibacterial activity against endodontic pathogens [23-27]. However, its effectiveness varies substantially depending on experimental conditions, laser parameters, and the anatomical characteristics of the root canal system. Across the included studies, the laser consistently reduced bacterial load, but the magnitude of reduction differed widely, ranging from modest effects to reductions exceeding 90% when used in combination with 2.5 to 3% sodium hypochlorite [23,26].

Table 6. Comparison of the antibacterial effectiveness of the 445 nm diode laser with conventional disinfection methods

Study	Experimental model	Dentine thickness	Intervention	Percentage reduction of bacterial colonies
Wenzler et al. [23]	Treated root canals	-	3% NaOCl	80.5%
			445 nm (0.59 W; CW; 4×10 s)	58.2%
			3% NaOCl + 445 nm (0.59 W; CW; 4 × 10 s)	92.7%
Hendi et al. [25]	Infected human dentine samples	300 µm	445 nm (0.6 W; CW; 30 s)	48%
		300 µm	Er,Cr:YSGG	44%
		300 µm	Er,Cr:YSGG + 445 nm	60%
		500 µm	445 nm (0.6 W; CW; 30 s)	20%
		500 µm	Er,Cr:YSGG	28%
		500 µm	Er,Cr:YSGG + 445 nm	62%
		1000 µm	445 nm (0.6 W; CW; 30 s)	0%
		1000 µm	Er,Cr:YSGG	34%
		1000 µm	Er,Cr:YSGG + 445 nm	66%
Katalinić et al. [26]	Instrumented extracted single-rooted teeth	-	2.5% NaOCl	<i>E. faecalis</i> 99.9996%; <i>C. albicans</i> 99.9986%
			2.5% NaOCl + 445 nm (1.5 W; CW; 60 s; 200 µm; 1 mm/s; 5 cycles)	<i>E. faecalis</i> > 99.9999%; <i>C. albicans</i> 99.9998%
			2.5% NaOCl + 970 nm (1.5 W; CW; 60 s; 200 µm; 1 mm/s; 5 cycles)	<i>E. faecalis</i> > 99.9999%; <i>C. albicans</i> > 99.9999%
Matthes et al. [27]	Biofilm on ceramic discs	-	445 nm (1 W; CW); laser beam movement speed 1 / 2 / 4 mm/s	<i>E. faecalis</i> : 1 mm/s 1.78 log ₁₀ (≈ 98.3%); 2 mm/s 1.41 log ₁₀ (≈ 96.1%); 4 mm/s 1.24 log ₁₀ (≈ 94.3%)
		-		<i>S. mutans</i> : 1 mm/s 2.54 log ₁₀ (≈ 99.7%); 2 mm/s 2.02 log ₁₀ (≈ 99.0%); 4 mm/s 2.00 log ₁₀ (≈ 99.0%)
		-		<i>C. albicans</i> : 1 mm/s 1.02 log ₁₀ (≈ 90.5%); 2 mm/s 0.37 log ₁₀ (≈ 57.3%); 4 mm/s 0.42 log ₁₀ (≈ 62.0%)
		-	CHX 2%	<i>E. faecalis</i> : ~3.6 log ₁₀ (≈ 99.97%); <i>S. mutans</i> : ~5.6 log ₁₀ (≈ 99.9997%); <i>C. albicans</i> : ~4.3 log ₁₀ (≈ 99.995%)

CW = continuous wave.

Table 7. Risk of bias assessment of the randomized clinical trial

Study	Random sequence generation and allocation concealment	Deviations from intended interventions	Outcome measurement	Missing outcome data	Selective reporting	Overall risk of bias
Wenzler et al. [23]	Low risk of bias	Moderate risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias

Table 8. Methodological quality assessment of *in vitro* studies

Study	Inclusion criteria	Description of materials	Experimental conditions	Appropriateness of control	Measurement methods	Confounding factors	Reporting of results	Statistical analysis	Score	Risk
Gutknecht et al. [24]	+	+	+	+	+	?	+	+	7	Low
Hendi et al. [25]	+	+	+	+	+	?	+	+	7	Low
Katalinić et al. [26]	+	+	+	+	+	?	+	+	7	Low
Matthes et al. [27]	+	+	+	+	+	+	+	+	8	Low

“+” = yes; “-” = no; “?” = unclear.

Several methodological factors appear to influence antibacterial outcomes. Higher power settings, longer irradiation times, and slower fiber movement were associated with greater bacterial reduction, suggesting a dose-dependent effect [24]. Dentine thickness was another critical determinant: studies using thin dentine slices (0.3 to 0.5 mm) reported markedly higher reductions compared with those using 1.0 mm slices, where the effect was substantially diminished [25]. This aligns with the known optical properties of dentine, where scattering and absorption limit light penetration and reduce the energy reaching deeper bacterial reservoirs. As recently demonstrated by Lusche et al. [28], blue laser light (~ 450 nm) in coronal dentin exhibits a mean attenuation coefficient of 1.22^{-1} , corresponding to an approximate 70% attenuation per millimeter and an apparent optical penetration depth of 0.8 mm. Although the anisotropic structure of dentin induces light guiding effects in thicker layers, the Bouguer-Beer-Lambert law provides a reliable first-order approximation for light penetration in dentin thicknesses up to 2 mm [28].

The clinical study by Wenzler et al. [23] included in this review demonstrated that the 445 nm diode laser alone was less effective than 3% sodium hypochlorite irrigation [23]. Nevertheless, when used as an adjunct, the laser significantly enhanced the antibacterial effect of 2.5 to 3% NaOCl, achieving the highest reduction among all tested protocols [23,26]. This synergistic effect is driven by laser-induced irrigant activation. In this context, “irrigant activation” refers to the transfer of laser energy into the root canal solution, inducing rapid fluid micro-streaming, transient cavitation, and

localized photothermal heating [6,17]. This mechanical agitation forces sodium hypochlorite deeper into complex anatomical structures and dentinal tubules while accelerating its chemical reaction kinetics [6,10]. Consequently, combining physical agitation with enhanced chemical disinfection overcomes the limitations of passive irrigation, yielding superior bacterial eradication [6,17,26]. This synergistic effect may be attributed to improved irrigant activation, increased fluid dynamics, or thermal enhancement of chemical disinfection. A study by Katalinić et al. [26] that included a 970 nm diode laser as a comparator reported similar adjunctive outcomes when both wavelengths were combined with 2.5% sodium hypochlorite [26], suggesting that different diode laser wavelengths may enhance irrigant activation through comparable photothermal mechanisms.

Limitations

Despite these promising results, the heterogeneity of experimental designs limits direct comparison between studies. Differences in sample type, microbial strains, biofilm maturity, irradiation technique, and outcome measures (CFU, $\log_{10}$ reduction, qPCR) complicate the interpretation of pooled antibacterial effectiveness. Furthermore, most available evidence is derived from *in vitro* models, which do not fully replicate the complexity of clinical root canal infections, including anatomical variability, biofilm structure, and host-related factors. Only one clinical study was identified [23], highlighting the need for more robust *in vivo* research to validate laboratory findings.

Another limitation is the lack of standardization in laser application protocols. Parameters such as fiber diameter, movement pattern, irradiation cycles, and energy density varied considerably across studies. Without harmonized protocols, it remains difficult to determine the optimal settings for clinical use or to establish evidence-based guidelines. To account for parameter variability and facilitate dose-dependent comparisons across studies, the reported or calculated applied energy density (J/cm²) values for each protocol have been incorporated into Table 4.

Overall, the current evidence suggests that the 445 nm diode laser has potential as an adjunctive disinfection method rather than a standalone alternative to conventional irrigants. Its ability to enhance the antibacterial effect of 2.5 to 3% sodium hypochlorite is particularly noteworthy and may offer clinical benefits in cases with complex anatomy or persistent infections. However, further well-designed clinical trials are required to confirm these findings, standardize irradiation protocols, and evaluate long-term treatment outcomes.

CONCLUSIONS

This systematic review indicates that the 445 nm

diode laser exhibits measurable antibacterial activity against *Enterococcus faecalis* and other endodontic pathogens. However, its effectiveness is strongly influenced by irradiation parameters and decreases with increasing dentine thickness. As a standalone disinfection method, the 445 nm laser is less effective than conventional root canal irrigants such as 2.5 to 3% sodium hypochlorite and 2% chlorhexidine, although its antibacterial performance is comparable to that of the Er,Cr:YSGG laser. The greatest bacterial reduction was achieved when the 445 nm laser was used in combination with 2.5 to 3% sodium hypochlorite, supporting its potential value as an adjunctive disinfection modality. Given the limited number of clinical studies, further well-designed *in vivo* research is required to determine the long-term clinical relevance and optimal application protocols for this wavelength in endodontic therapy.

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REFERENCES

1. Jeong JW, Silguero Gonzalez E, Makins SR, Kirkpatrick T. Unique root anatomy of mandibular second premolars: clinical strategies for effective disinfection and preservation of dentine structure in root canal treatment—a case report. *Front Dent Med*. 2024;5:1403138. doi: 10.3389/fdmed.2024.1403138. PMID: 39917669.
2. Sule P, Wadhawan T, Carr NJ, Horne SM, Wolfe AJ, Prüss BM. A combination of assays reveals biomass differences in biofilms formed by *Escherichia coli* mutants. *Lett Appl Microbiol*. 2009 Sep;49(3):299-304. doi: 10.1111/j.1472-765X.2009.02659.x. PMID: 19552773.
3. Wang Z, Shen Y, Haapasalo M. Dynamics of Dissolution, Killing, and Inhibition of Dental Plaque Biofilm. *Front Microbiol*. 2020;11:964. doi: 10.3389/fmicb.2020.00964. PMID: 32508783.
4. Kilic Y, Tuglar MM, Karataslioglu E, Turk T. Comparative analysis of dentinal tubule penetration: effects of irrigation activation methods and root canal sealers: in-vitro study. *BMC Oral Health*. 2025;25:991. doi: 10.1186/s12903-025-06419-y. PMID: 40604875.
5. Neelakantan P, Romero M, Vera J, Daoud U, Khan AU, Yan A, Cheung GSP. Biofilms in Endodontics—Current Status and Future Directions. *Int J Mol Sci*. 2017 Aug 11;18(8):1748. doi: 10.3390/ijms18081748. PMID: 28800075.
6. Haapasalo M, Shen Y, Qian W, Gao Y. Irrigation in endodontics. *Dent Clin North Am*. 2010 Apr;54(2):291-312. doi: 10.1016/j.cden.2009.12.001. PMID: 20433979.
7. Hage W, Sarkis DK, Kallasy M, Mallah M, Zogheib C. In vitro evaluation of three engineered multispecies endodontic biofilms on a dentinal disk substrate. *Biomater Investig Dent*. 2023;10(1):2281091. doi: 10.1080/26415275.2023.2281091. PMID: 38204478.
8. Ricucci D, Candeiro GTM, Bugea C, Siqueira JF Jr. Complex Apical Intraradicular Infection and Extraradicular Mineralized Biofilms as the Cause of Wet Canals and Treatment Failure: Report of 2 Cases. *J Endod*. 2016 Mar;42(3):509-15. doi: 10.1016/j.joen.2015.12.014. PMID: 26831049.
9. Mohamed AA, Fayyad DM, El-Telbany M, Mohamed DA. Antibacterial biofilm efficacy of calcium hydroxide loaded on Gum Arabic nanocarrier: an in-vitro study. *BMC Oral Health*. 2024; 24:215. doi: 10.1186/s12903-024-03941-3. PMID: 38341565.
10. Karad KM, Kolhe SJ, Gulve MN, Aher GB, Kolhe PS. Penetration depth of sodium hypochlorite into dentinal tubules influenced by different agitation systems. *Endodontology*. 2021;33(2):81-85. doi: 10.4103/endo.endo_39_2.

11. Arathi G, Rajakumaran A, Divya S, Malathi N, Saranya V, Kandaswamy D. Comparison of penetrating depth of chlorhexidine and chitosan into dentinal tubules with and without the effect of ultrasonic irrigation. *J Oral Maxillofac Pathol.* 2019 Sep-Dec;23(3):389-392. doi: 10.4103/jomfp.JOMFP_194_19. PMID: 31942119.
12. Vidal-Montolió MI, Sanz JL, Ghilotti J, Folguera S, Llena C. Efficacy of Etidronic Acid for Smear Layer Removal: A Systematic Review of In Vitro Studies. *J Funct Biomater.* 2026;17(1):48. doi: 10.3390/jfb17010048. PMID: 38204478.
13. Özbay Y, Özdemir O. Evaluation of laser-activated irrigation on evidence-based endodontology: a bibliometric and scientometric analysis. *G Ital Endod.* 2022;36(2):82-90. doi: 10.32067/GIE.2022.36.02.07.
14. Schoop U, Kluger W, Moritz A, Nedjelik N, Georgopoulos A, Sperr W. Bactericidal effect of different laser systems in the deep layers of dentin. *Lasers Surg Med.* 2004;35(2):111-116. doi: 10.1002/lsm.20026. PMID: 15334613.
15. Gutknecht N, Kaiser F, Hassan A, Lampert F. Long-term clinical evaluation of endodontically treated teeth by Nd:YAG lasers. *J Clin Laser Med Surg.* 1996 Feb;14(1):7-11. doi: 10.1089/clm.1996.14.7. PMID: 9484093.
16. Moritz A, Schoop U, Goharkhay K, Jakolitsch S, Kluger W, Wernisch J, Sperr W. The bactericidal effect of Nd:YAG, Ho:YAG, and Er:YAG laser irradiation in the root canal: an in vitro comparison. *J Clin Laser Med Surg.* 1999;17(4):161-164. doi: 10.1089/clm.1999.17.161. PMID: 11199839.
17. Abaza MM, Harhash TAH, Zaky AA. Comparative analysis of laser and ultrasonic irrigation techniques for smear layer removal in endodontics. *Lasers Med Sci.* 2025;40(1):522. doi: 10.1007/s10103-025-04766-4. PMID: 41389357.
18. Fornaini C, Fekrazad R, Rocca JP, Zhang S, Merigo E. Use of Blue and Blue-Violet Lasers in Dentistry: A Narrative Review. *J Lasers Med Sci.* 2021;12:e31. doi: 10.34172/jlms.2021.31. PMID: 34733754.
19. Johnson NM, Nurmikko AV, DenBaars SP. Blue diode lasers. *Phys Today.* 2000 Oct;53(10):27-32. doi: 10.1063/1.1325190.
20. 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.
21. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, et al, editor(s). *Cochrane Handbook for Systematic Reviews of Interventions version 6.5 (updated August 2024).* Cochrane, 2024. Available from: www.cochrane.org/handbook.
22. Aromataris E, Lockwood C, Porritt K, Pilla B, Jordan Z, editors. *JBIM Manual for Evidence Synthesis.* JBI; 2024. Available from: <https://synthesismanual.jbi.global>. doi:10.46658/JBIMES-24-01
23. Wenzler JS, Falk W, Frankenberger R, Braun A. Impact of Adjunctive Laser Irradiation on the Bacterial Load of Dental Root Canals: A Randomized Controlled Clinical Trial. *Antibiotics (Basel).* 2021;10(12):1557. doi: 10.3390/antibiotics10121557. PMID: 34943769.
24. Gutknecht N, Al Hassan N, Rodrigues Martins M, Conrads G, Franzen R. Bactericidal effect of 445-nm blue diode laser in the root canal dentin on *Enterococcus faecalis* of human teeth. *Lasers Dent Sci.* 2018;2(1). doi: 10.1007/s41547-018-0044-1.
25. Hendi SS, Ahmadyani E, Alikhani MY, Farhadian M, Mirzae A. Antibacterial Effects of the Novel Blue Laser and Erbium Chromium Laser on *Enterococcus Faecalis* in Root Canal Dentin with Different Thicknesses. *Int J Dent.* 2022;2022:6119464. doi: 10.1155/2022/6119464. PMID: 35368314.
26. Katalinić I, Pranjić A, Budimir A, et al. Antimicrobial effect of 2.5% sodium hypochlorite irradiated with the 445 nm diode laser against bacterial biofilms in root canal: in vitro pilot study. *Lasers Med Sci.* 2025;40:202. doi: 10.1007/s10103-025-04463-2.
27. Matthes R, Dittrich L, Schwahn C, Jablonowski L, Kocher T, Welk A. Evaluation of the Inactivation of Microorganisms by a Blue Laser (445 nm)-An In Vitro Study. *Antibiotics.* 2026;15(2):137. doi: 10.3390/antibiotics15020137.
28. Lusche I, Frentzen M, Wierichs R, Meister J. Attenuation behavior of blue (laser) light in dentin: A literature-based evaluation regarding the validity of the Bouguer-Beer-Lambert law for dental applications. *J Dentistry.* 2026;171:106719. doi: 10.1016/j.jdent.2026.106719.

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