Journal of Lasers in Medical Sciences

J Lasers Med Sci 2022;13:e66

Review Article

http://journals.sbmu.ac.ir/jlms

doi 10.34172/jlms.2022.66

# The Effect of High-Power Lasers on Root Canal Disinfection: A Systematic Review

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**Received:** October 6, 2022
**Accepted:** November 20, 2022
**Published online** December 14, 2022

## Abstract

**Introduction:** In root canal therapy, the cleaning and shaping of canals are routinely applied by clinicians in order to remove microorganisms. Eradicating bacteria from the root canal system plays a crucial role in long-term success; however, it is not always easy to disinfect root canals properly because of their complicated anatomy and bacterial load. Achieving an optimally disinfected root canal environment requires adjunctive antibacterial therapeutic methods. High-power laser utilization as an adjunctive strategy to conventional treatment is a relatively new approach that helps clinicians.

**Methods:** This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline. Online databases, namely Web of Science, PubMed/MEDLINE, Scopus, and Cochrane Library, were searched electronically regarding lasers and endodontic treatments. Appropriate studies were included according to the inclusion/exclusion criteria.

**Results:** Among 504 obtained studies by search, 48 were considered for a detailed analysis. Ten articles performed in vivo evaluation, while nine assessed the effect of lasers on artificial models, and 29 conducted *ex vivo* experiments on extracted teeth. When the diode laser, the most frequently used laser, was utilized as an adjunct therapy after NaOCl irrigation, it killed more bacteria than conventional irrigation with NaOCl. Laser-activated irrigation (LAI) with the Er, Cr: YSGG laser and NaOCl disinfects the root canal effectively. Also, photon-induced photoacoustic streaming (PIPS) with Er: YAG and NaOCl exhibited a high bactericidal effect and deep tubular penetration.

**Conclusion:** High-power laser utilization, considering proper case selection and method, can assist in root canal treatment of infected teeth.

**Keywords:** Lasers, Root canal therapy, Root canal preparation, Disinfection

## Introduction

One of the most determining factors in the success of root canal therapy, especially in infected cases, is the quality of disinfection of the root canal system.[1] Disinfection quality is defined as the reduction percentage of pathologic bacteria and microbial biofilm followed by the therapy.[2] Studies have determined a success rate of 95% for teeth with irreversible pulpitis and 85% for teeth with necrotic pulp.[3] The conventional disinfection methods consist of mechanical instrumentation in conjunction with the use of chemical substances.[4] Endodontic files and reamers physically remove microorganisms and infected or inflamed pulp tissue from the root canal system and shape the canal for better and easier obturation. Instrumentation cannot eliminate all the microorganisms from the root canal, although it reduces microbial load[3,5]; therefore, chemical disinfectants are employed to help eradicate the remaining infected pulp tissue and microorganisms in the dentinal tubules, as well as irrigation.[3,5] Sodium hypochlorite (NaOCl) is the gold standard disinfectant in root canal therapy because of its ability to annihilate a wide spectrum of bacteria.[5] Conventional irrigation consists of irrigating root canals during cleaning and shaping with NaOCl, with a concentration between 0.5% and 5.25%, via a syringe.[6] Moreover, even ideal disinfecting solutions cannot eliminate all of the present microorganisms due to the complex anatomy of canals and the limitations of the syringe irrigation technique. The optimal removal of pathogens has substantial significance in the long-term success of root canal therapy (RCT), particularly when treating teeth with anatomical difficulties and also in non-surgical retreatments.[7,8]

Thus, achieving an optimally disinfected root canal environment requires adjunctive antibacterial therapeutic methods and other chemomechanical strategies.[3] Various irrigant agitation techniques have been introduced as

**Please cite this article as follows:** Asnaashari M, Sadeghian A, Hazrati P. The effect of high-power lasers on root canal disinfection: a systematic review. *J Lasers Med Sci.* 2022;13:e66. doi:10.34172/jlms.2022.66.

complementary steps to standard procedures of the cleaning phase. Many studies have indicated that sonically activated irrigation and passive ultrasonic irrigation (PUI) can efficiently remove the bacterium, debris, and smear layer of the root canal system.[5] Laser utilization as an adjunctive strategy to conventional treatment is a relatively new approach that helps clinicians.[3] The effect of the laser used in this process depends on its type, wavelength, power/energy, irradiation duration, and used technique. Various types of lasers could be used in different modalities. Soft tissue lasers, mostly diode, are used to activate photosensitizers or photo-activated substances such as methyl blue, green malachite, and toluidine blue O (TBO), which leads to reactive oxygen species (ROS) formation and subsequent bacterial decrease. The mentioned method is called photodynamic therapy (PDT), also known as photoactivated disinfection (PAD).[4,9] This study discusses the high-power lasers used to disinfect the root canal system. To this end, various lasers such as erbium yttrium aluminum garnet (Er: YAG, 2940 nm), neodymium: yttrium aluminum garnet (Nd: YAG, 1064 nm), erbium, chromium: yttrium scandium gallium garnet (Er, Cr: YSGG, 2780), diode laser with different wavelengths (445-980 nm), and potassium titanyl phosphate (KTP, 532 nm) have been used.[5]

This review study aimed to accomplish a thorough investigation of every study in the last decade (since 2013) on the use of lasers in root canal disinfection and to add up the results and conclusions. This review will augment the knowledge of clinicians and experts investigating lasers in endodontics and help them in their clinical practice.

## Materials and Methods

### *Protocol*

The current systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline.[10]

### *Information Sources and Search Strategy*

Online databases, namely Web of Science, PubMed/MEDLINE, Scopus, and Cochrane Library, were searched electronically according to the terms "Lasers or ray or beam or radiation or photon-induced" and "Root canal or endodontic treatment or pulpectomy" and "Disinfection or decontamination or cleaning or antibacterial effect." The language of studies was limited to English, even though there was no publication status restriction. All relevant studies between 2013 and June 2022 were collected. Collected studies were imported into Mendeley Reference Manager (Elsevier, Amsterdam, Netherlands) where the screening and data extraction were performed.

### *Eligibility Criteria*

#### *Type of Studies*

All *in vivo, ex vivo,* and *in vitro* studies in which the efficacy of high-power laser-assisted disinfection of the root canal system was assessed were included; on the contrary, case reports, case series with less than 10 cases, abstracts, letters, and reviews were not considered.

#### *Type of Participants or Samples*

In vivo studies in which primary or permanent teeth with a necrotic pulp or irreversible pulpitis, whether with or without periapical lesion, were tested were included. For *ex vivo* experiments, extracted human or animal teeth that bacteria were artificially inoculated in their root canal were considered eligible. Additionally, *in vitro* studies that fabricated a rational model resembling the root canal system were deemed suitable.

#### *Type of Intervention*

In this study, lasers with power equal to or higher than 0.5 W were considered high-power; thus, studies that applied lasers with power lower than 0.5 W were not considered. In addition, studies that evaluated the antibacterial effect of PAD were excluded, but studies regarding the antibacterial effect of photon-induced photoacoustic streaming (PIPS) or laser-activated irrigation (LAI) methods were included. Studies that used laser irradiation, either as a sole way of decontaminating root canals or in combination with other methods, were also included.

#### *Type of Outcome*

Studies in which the effect of laser irradiation on decreasing the number of bacteria in the root canal was assessed were included. On the contrary, studies evaluating the impact of laser irradiation on other factors of endodontic treatment, such as periapical lesion healing, smear layer removal, the penetration depth of irrigant, or post-RCT pain, were excluded.

### *Study Selection and Data Extraction*

Two authors (PH and AS) independently screened the title and abstract of the exported citations according to the above-mentioned eligibility criteria. Any conflicts were settled by consulting the third experienced author (MA). Later, the full texts of candidate studies were obtained and underwent further investigation. Finally, the following foremost information was exploited from the articles and was sorted into a designed table:

A) Study characteristics, such as authors and the year of publication.

B) Type of study and sample (sample size was reported only for *in vivo* studies).

C) Type and chief parameters of used laser (wavelength, emission mode, average power, fiber tip diameter, and exposure time).

D) Therapeutic interventions that have been used before or during laser irradiation.

E) Result of the trial.

## Results

### Study Selection

Among 504 obtained studies by search, 99 articles were considered for full-text evaluation. After a thorough appraisal, 51 studies were excluded because of the following excuses: Firstly, employment of PAD; secondly, employment of low-power lasers; finally, examining the effect of laser on smear layer removal, post-RCT pain, and other unintended variables. Subsequently, 48 studies were considered for comprehensive analysis, and their essential information was exported to tables. The flow diagram of this systematic review is illustrated in Figure 1.

### Study Characteristics

Among 48 included studies, ten articles performed in vivo evaluation, nine assessed the effect of lasers on artificial models, and 29 conducted an *ex vivo* experiment on extracted teeth (Table 1). All the *in vivo* studies were accomplished on humans, and there was no animal study. Primary teeth were tested in four trials, both *in vivo*[12] and *ex vivo*.[13-15] Most of the studies performed colony-forming unit (CFU) assessments to evaluate the antibacterial effect of the employed laser.

### Result of Individual Studies

Utilized lasers are summarized in Figure 2. The details of the most commonly employed lasers are provided below.

#### Diode

The diode laser is the most common laser used in disinfecting root canals. Some studies have shown that when the diode laser is used solely, its antibacterial effect is not as good as final irrigation with NaOCl, but when the diode laser is utilized as an adjunct therapy after NaOCl irrigation, it kills more bacteria than conventional irrigation with NaOCl.[14,16-18] However, some studies have reported that merely irradiating the root canal with a diode laser reduces the bacterial load more than traditional irrigation methods.[13,19-25] To achieve higher levels of disinfection, the diode laser has been used coincide with irrigation with distilled water,[26,27] ozonated water,[26] saline,[12,22] chlorhexidine,[27] silver nanoparticles,[27] and another laser application.[28] Additionally, the diode laser has been used in the LAI technique with NaOCl,[13,29,30] and most of these studies have reported that LAI is a more potent tactic to disinfect root canals.

Some studies support the idea that laser irradiation

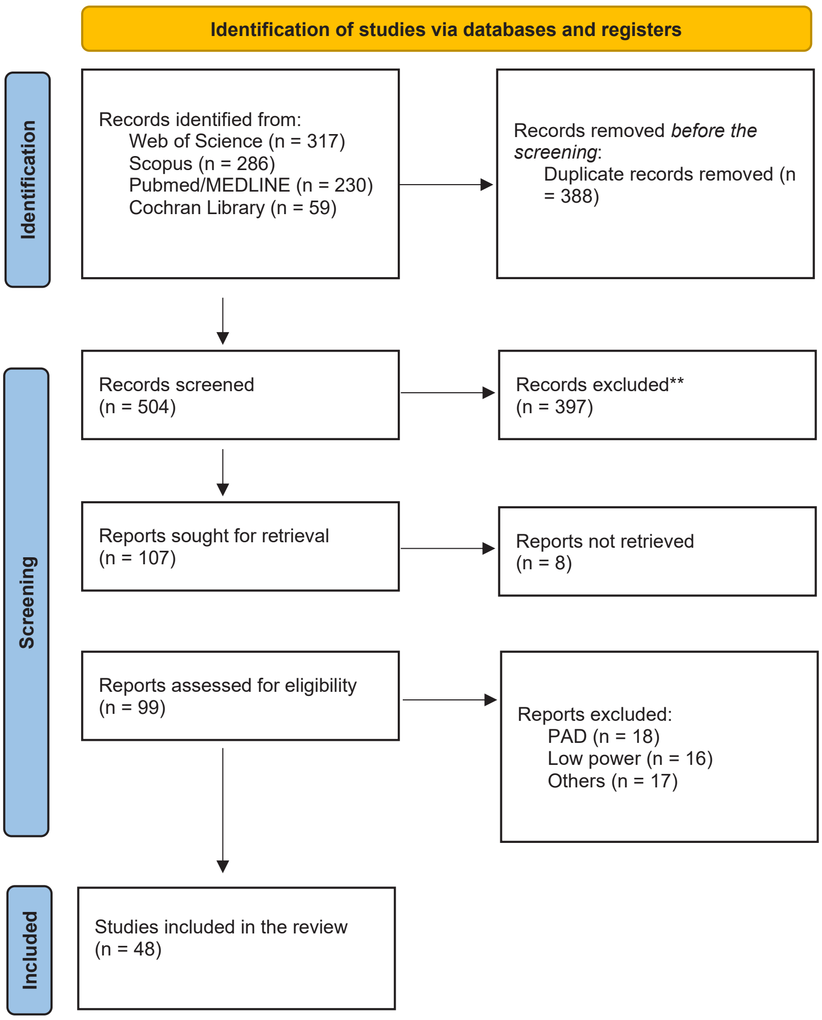


**Figure 1**. Flow Diagram of the Systematic Review According to PRISMA[11]

**Table 1.** A Summary of Studies Utilizing High-Power Lasers

| Author (s), Year | *In vivo/ In vitro* | Sample (size) | Type of Laser | Parameters | | | | | Complementary Methods of Canal Disinfection | Outcomes |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Wave-Length | Emission Mode | Average Power | Fiber Tip Diameter | Exposure Time | | |
| Wenzler et al, 2021[16] | *In vivo* | Human (57) | Diode | 445 nm | CW | 0.59 W | 200µm | 4×10 s | Preliminary conventional chemomechanical preparation | Lower reduction (58.2%) in the bacterial load of the canal compared to conventional NaOCL rinsing (80.5%). |
| | | | | | | | | | Preliminary conventional chemomechanical preparation + prior final irrigation with NaOCl | The highest reduction in the bacterial load of the canal (92.7%) among the experimental groups. |
| Bytyqi et al, 2021[32] | *In vitro* | | Diode | 810 nm | N/A | 1.5 W | 200 µm | 1 m<br>3 m<br>5 m | None | Laser irradiation had a lower antibacterial effect on larger periapical lesions, and increased irradiation time caused better disinfection. |
| Hendi et al, 2021[33] | *Ex vivo* | | Er, Cr: YSGG | 2780 nm | Pulsed | 2.5 W | 200 µm | 4×15 s | None | 47.9% reduction in the colony count |
| | | | | | | | | | Simultaneous irrigation with silver nanoparticles solution | 64.72% reduction in the colony count (NaOCl 100%) |
| Dalaei Moghadam et al, 2021[19] | *In vivo* | Human (98) | Diode | 940 nm | Pulsed | 2 W | 200 µm | 3×20 s | Preliminary conventional chemomechanical preparation | Diode laser utilization significantly reduced the microbial load of root canals and post-RCT pain. |
| Ambalavanan et al, 2021[42] | *In vitro* | | Nd: YAG | 1064 nm | Pulsed | 1.5 W | 200µm | 6 cycles from the bottom of samples to the top | Simultaneous irrigation with silver nanoparticles solution | The Nd: YAG laser in conjunction with silver nanoparticles is an effective protocol against *E. faecalis* |
| Mehta et al, 2020[20] | *In vivo* | Human (48) | Diode | 940 nm | N/A | 1.5 W | 200 µm | 3×5 s | Preliminary conventional chemomechanical preparation | The diode laser significantly reduced the bacterial load. It was more effective than aqueous ozone and garlic extract. |
| Kushwah et al, 2020[26] | *Ex vivo* | | Diode | 980 nm | Pulsed | 3 W | N/A | 4×5 s | Preliminary conventional chemomechanical preparation + Simultaneous irrigation with distilled water | This method is more effective than solely irrigating with NaOCl or ozonated water. |
| | | | | | | | | | Preliminary conventional chemomechanical preparation + Simultaneous irrigation with ozonated water | This method yielded the highest rate of disinfection. |
| Anand et al, 2020[12] | *In vivo* | Human (20) | Diode | 940 nm | CW | 0.5 W | 200 µm | 3 cycles at a speed of 1mm/s | Preliminary conventional chemomechanical preparation + regular saline irrigation | There was no significant difference between NaOCl, photodynamic therapy, laser, and clotrimazole antifungal paste in eliminating *C. Albicans* from the root canal. |
| Suer et al, 2020[34] | *Ex vivo* | | Er, Cr: YSGG | N/A | Pulsed | 2W | N/A | 4×10 s | None | 50% bacterial reduction |
| | | | | | | 0.75 W | | | Simultaneous irrigation with 2.5% NaOCl (LAI) | 100% bacterial reduction similar to irrigation with 5% NaOCl |
| Ghorbanzadeh et al, 2020[51] | *Ex vivo* | | Diode | 810 nm | Pulsed | 2 W | 200 µm | 3 cycles in total 40 s | None | This modality caused lower bacterial disinfection compared to a similar laser with 0.3 W power and indocyanine Green photosensitizer (PDT) |
| Mohamed Abdelgawad et al, 2020[27] | *Ex vivo* | | Diode | 810 nm | CW | 1 W | 200 µm | 5×10 s | Simultaneous irrigation with chlorhexidine<br>Simultaneous irrigation with silver nanoparticles<br>Simultaneous irrigation with distilled water | The laser showed better bacteria disinfection than sonic agitation. Silver nanoparticles were the most potent solution for canal disinfection with the laser. |
| Shehab et al, 2020[35] | *In vivo* | Human (45) | Er, Cr: YSGG | 2780 nm | N/A | 1 W<br>1.5 W<br>2 W | N/A | 4×5 s | Preliminary conventional chemomechanical preparation | Higher power Er, Cr: YSGG laser could destroy *E. faecalis* more effectively, but it cannot wholly eliminate the bacterium. |
| Tokuc et al, 2019[29] | *Ex vivo* | | Er, Cr: YSGG | 2780 nm | Pulsed | 1.25 W | 200 µm | 5×10 s | None | Combination of the Er, Cr: YSGG laser and simultaneous irrigation with NaOCl (LAI) eliminated *E. faecalis* most successfully. Er, Cr: YSGG alone or in conjunction with the diode laser has lower efficiency than conventional irrigation with NaOCl. |
| | | | Diode | 940 nm | Pulsed | 1.5 W - 4.5 W | | | Simultaneous irrigation with NaOCl (LAI) | |

**Table 1.** Continued

| Author (s), Year | In vivo/ In vitro | Sample (size) | Type of Laser | Parameters | | | | | Complementary Methods of Canal Disinfection | Outcomes |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Wave-Length | Emission Mode | Average Power | Fiber Tip Diameter | Exposure Time | | |
| Henninger et al, 2019[44] | *Ex vivo* | | Er: YAG | 2940 nm | CW | 5 W<br>0.5 W | 300 µm<br>600 µm | 3×20 s | Simultaneous NaOCl irrigation (LAI) with or without intermittent irrigation with 0.9% NaOCl | In 3-day biofilms of the root canal, LAI had no significantly different effect than the conventional method. But, in 21-day biofilms, LAI using a 600µm tip showed advantages. |
| Betancourt et al, 2019[36] | *In vitro* | | Er, Cr: YSGG | 2780 nm | Pulsed | 1 W | 200 µm | 60 s | Simultaneous irrigation with NaOCl 0.5% (LAI)<br>Simultaneous irrigation with saline (LAI) | LAI with 0.5% NaOCl and empowered NaOCl 5% had similar antibacterial effects and eliminated all bacteria. |
| Roshdy et al, 2019[52] | *Ex vivo* | | Diode | 980 nm | Pulsed | 2 W | 320 µm | 5×5 s | Prior irrigation with saline, 2.5% NaOCl, or chitosan nanoparticles | Laser irradiation increased the antibacterial effect of either 2.5% NaOCl or chitosan nanoparticles. |
| Katalinić et al, 2019[28] | *In vitro* | | Diode | 445nm<br>970 nm | N/A | 3 W<br>2 W | 200 µm<br>200 µm | 5×12 s<br>5×12 s | The 445-nm laser was used alone or before 970-nm laser irradiation | Combination use of lasers leads to higher bacterial elimination. Using the same 445 nm laser, photo-activated protocol brings about a higher disinfection rate compared to the photo-thermal method. |
| Betancourt et al, 2019[38] | *In vitro* | | Er, Cr: YSGG | 2780 nm | Pulsed | 1 W | 200 µm | 2×30 s | Simultaneous irrigation with 0.5% NaOCl<br>Simultaneous irrigation with saline | LAI with NaOCl had similar effects to conventional irrigation with 2.5% NaOCl |
| Betancourt et al, 2019[37] | *Ex vivo* | | Er, Cr: YSGG | 2780 nm | Pulsed | 0.55 W | 200 µm | 2×30 s | Simultaneous irrigation with 0.5% NaOCl (LAI)<br>Simultaneous irrigation with saline (LAI) | This modality was as effective as conventional irrigation with 2.5% NaOCl.<br>This modality led to less bacterial disinfection compared to laser+ NaOCl, but its effect was comparable to the effect of conventional irrigation with 0.5% NaOCl. |
| Morsy et al, 2018[21] | *In vivo* | Human (56) | Diode | 980 nm | Pulsed | 1.2 W | 200 µm | 4×5 s | Preliminary conventional chemomechanical preparation | Patients treated with adjunctive laser therapy experienced significantly lower pain. There was a statistically significant lower bacterial count in irradiated root canals. |
| Wang et al, 2018[30] | *In vitro* | | Nd: YAG<br>Diode<br>ND: YAP<br>Er, Cr: YSGG | 1064 nm<br>980<br>1340<br>2780 | Pulsed | 1.5 W<br>1.5 W<br>3 W<br>0.75 W | 200 µm<br>200 µm<br>200 µm<br>415 µm | 1 and 3 minutes | None<br>Simultaneous irrigation with NaOCl (LAI) | Bacterial reduction increases with increasing irradiation time. Er, Cr: YSGG had the greatest bacterial reduction and significantly enhanced the efficacy of NaOCl. |
| Dai et al, 2018[13] | *Ex vivo* | | Diode | 810 nm | CW | 2 W | 200 µm | 4×5 s | None / Simultaneous irrigation with 5.25% NaOCl | Combination of NaOCl irrigation with laser activation had the highest antibacterial effect followed by solely laser irradiation. Both of the mentioned methods were superior to NaOCl irrigation. |
| Sonarkar et al, 2018[50] | *In vivo* | Human (32) | Diode | 810 nm | Pulsed | 0.8 W | N/A | 4 times at a speed of 2 mm/s | Preliminary conventional chemomechanical preparation | PDT, diode laser irradiation and NaOCl had similar effects on killing the aerobic bacterium. However, PDT had a statistically significant higher effect on anaerobic bacteria. |
| Ghorbanzadeh et al, 2018[53] | *Ex vivo* | | Diode | 810 nm | Pulsed | 2 W | 200 µm | 4×10 s | None / Prior irrigation with 0.2% chlorhexidine | Solely laser irradiation had the lowest effect, while prior irrigation with CHX 0.2% and subsequent PDT exhibited the highest antibacterial properties. Irrigation with CHX 0.2% followed by laser irradiation was more effective than solely irrigation with CHX 0.2%. |
| Öter et al, 2018[14] | *Ex vivo* | | Diode | 940 nm | Pulsed | 1.5 W | 300 µm | 3×20 s | None | After NaOCl, which caused 0 CFU/ml, laser irradiation had the highest antibacterial effect on the root canals of primary teeth compared to ozone, PAD, or Endosafe. |

**Table 1.** Continued

| Author (s), Year | *In vivo/ In vitro* | Sample (size) | Type of Laser | Parameters: Wave-Length | Emission Mode | Average Power | Fiber Tip Diameter | Exposure Time | Complementary Methods of Canal Disinfection | Outcomes |
|---|---|---|---|---|---|---|---|---|---|---|
| Afkhami et al, 2017[54] | *Ex vivo* | | Diode | 810 nm | CW | 1 W | 200 µm | 4 × 15 s | None | PDT with AgNPs and ICG, diode laser irradiation, irrigation with AgNPs, and irrigation with 2.5% NaOCl have similar effects on the elimination of *E. faecalis* and can be used as an adjunct therapy for root canal disinfection. |
| Kasić et al, 2017[41] | *Ex vivo* | | Nd: YAG<br>Er, Cr: YSGG | 1064 nm<br>2790 nm | Pulsed | 1.5 W<br>1.25 W | 200 µm | 4 times at a speed of 2 mm/s | None | Irradiation with the Nd: YAG laser could not eradicate *E. faecalis* significantly, but Er, Cr: YSGG irradiation eliminated the bacterium significantly, even more than PIPS with 0.3 W- h laser. |
| Schulte-Lünzum et al, 2017[55] | *In vitro* | | Diode | 940 nm | CW | 1 W<br>1.5 W | 200 µm RFT or BFT | 4 × 8 s | None | RFT fiber design exhibits better *E. faecalis* elimination regardless of the power. The highest antibacterial effect was seen in the 1.5 W diode laser with an RFT tip. |
| Cheng et al, 2017[45] | *Ex vivo* | | Er: YAG | 2940 nm | Pulsed | 0.5 W<br>1 W | 300 µm | 20 s | Simultaneous irrigation with NaOCl | Addition of the laser to conventional irrigation with NaOCl enhances disinfection. Smaller prepared apical foramens can be cleansed with lasers. Increasing the power output of the laser is more effective in increasing the antibacterial effect than increasing exposure time. |
| Ozses Ozkaya et al, 2017[46] | *Ex vivo* | | Er: YAG | 2940 nm | Pulsed | 0.5 W | 400 µm | 20 s | Simultaneous irrigation with saline or NaOCl 0.9% (PIPS) | PIPS with NaOCl eliminates more *E. faecalis* compared to conventional NaOCl irrigation. PIPS had higher efficiency in removing biofilm than solely laser irradiation. |
| | | | Nd: YAG | 1064 nm | CW | 1.5 W | 200 m | 4 × 5 s | Prior irrigation with NaOCl 0.9% or saline | The solution used to irrigate the root canal before laser irradiation did not affect biofilm elimination. |
| Granevik Lindström et al 2017[43] | *In vivo* | Human (41 patients, 45 teeth) | Nd: YAG | 1064 nm | Pulsed | 1.5 W | 200 µm | 4 times at a speed of 2 mm/s | Preliminary conventional mechanical preparation + irrigation with saline | Neither laser irradiation nor irrigation with NaOCl and EDTA could completely eliminate the bacterium. There was no significant difference between the antibacterial properties of laser irradiation and irrigation. |
| Christo et al 2016[39] | *Ex vivo* | | Er, Cr: YSGG | 2780 nm | Pulsed | 0.5 W | 415 µm | 4 × 15 s | Simultaneous irrigation with low-concentration (0.5%) NaOCl. (LAI) | Laser activation did not improve the antibacterial effect of the irrigant. |
| Sohrabi et al 2016[17] | *Ex vivo* | | Diode | 980 nm | CW | 2.5 W | 320 µm | N/A | None | Diode laser irradiation had 96.56% bacterial reduction, which is significantly lower than irrigation with 5.25% NaOCl (99.87%). |
| Jyotsna et al 2016[31] | *Ex vivo* | | Diode | 940 nm | CW | 1.5 W | 200 µm | 4 × 5 s | None | Laser irradiation impacted bacteria over the apex, and the smaller apical size led to greater bacteria reduction. |
| Cheng et al 2016[47] | *Ex vivo* | | Er: YAG | 2940 nm | Pulsed | 0.5 W<br>1 W | 300 µm | 20 or 30 s | Simultaneous irrigation with 5.25% NaOCl (PIPS) | PIPS technique disinfected dentinal tubules from 200 to 500µm as time and power increased. Conventional NaOCl eliminated bacteria in lower depth and with less efficiency. |
| Bago Jurič et al 2016[56] | *In vitro* | | Nd: YAG | 1064 nm | Pulsed | 2 W | 300 µm | 4 × 5 s | None | Nd: YAG irradiation had lower bacterial reduction than PDT or irrigation with Qmix. |
| Asnaashari et al 2016[57] | *In vivo* | Human (20) | Diode | 810 nm | CW | 1.2 W | 300 µm | 3 × 10 s | Preliminary conventional chemomechanical preparation | There was no difference in antibacterial effect between solely laser irradiation or PDT with a diode laser with power of 0.2 W. |
| Vatkar et al 2016[22] | *In vitro* | | Nd: YAG<br>Diode | 1064 nm<br>N/A | CW<br>CW | 1.5 W<br>2.5 W | 200 µm | 3 × 5 s<br>3 × 10 s | Simultaneous irrigation with normal saline | In samples disinfected with any of the lasers, no bacteria were found, in contrast to CHX or NaOCl. |

**Table 1.** Continued

| Author (s), Year | In vivo/ In vitro | Sample (size) | Type of Laser | Parameters | | | | | Complementary Methods of Canal Disinfection | Outcomes |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Wave-Length | Emission Mode | Average Power | Fiber Tip Diameter | Exposure Time | | |
| Sarp & Gülsoy 2016[49] | *Ex vivo* | | Er: YAG<br>TFL | 2940<br>1940 | N/A | 0.5 W | 400 µm | 10 × 6 s | Preliminary conventional chemomechanical preparation + Smear layer removal with EDTA 17% | Irradiation with TFL killed 95.15% of bacteria, whereas Er: YAG killed 96.48% of them. However, this difference was statistically insignificant. |
| Grącka-Mańkowska et al 2016[23] | *Ex vivo* | | Diode | 980 nm | CW<br>Pulsed | 1.5 W<br>3 W | 200 µm | One cycle at a speed of 2 mm/s | None | Irradiation with the 1.5-W laser had the highest antibacterial effect. Both laser irradiation methods had a higher antibacterial effect compared to the PDT method. |
| Romeo et al 2015[24] | *Ex vivo* | | KTP<br>Diode | 532 nm<br>980 nm | Pulsed | 2.5 W | 200 µm | 3 × 5 s | None, or preliminary conventional chemomechanical preparation | Both lasers demonstrated a much higher and more significant level of disinfection compared to traditional methods. The KTP laser was slightly more effective than the diode. |
| Licata et al 2015[40] | *Ex vivo* | | Er, Cr: YSGG | 2780 nm | Pulsed | 0.75 W | 200 µm | 30 s<br>60 s | Simultaneous irrigation with 5.25% NaOCl and 17% EDTA | 60 s and 30 s irradiation eliminated 100% and 92.3% of *E. faecalis* respectively. |
| Kapdan et al 2015[15] | *Ex vivo* | | KTP | 532 | Pulsed | 1.5 W | 200 µm | 5 × 5 s | None | The KTP laser reduced the bacterial load of primary teeth root canals significantly, but 2.5% NaOCl illustrated superior disinfection. |
| Grącka-Mańkowska et al 2015[25] | *Ex vivo* | | Diode | 980 nm | CW<br>Pulsed | 0.75 W<br>1 W<br>1.25 W<br>1.5 W<br>3 W | 200 µm | One cycle at a speed of 2 mm/s | None | Irradiation with powers of 1.25 and 1.5 W caused the highest rate of disinfection compared to all experimental groups. |
| Mashalkar et al 2014[18] | *In vivo* | Human (60) | Diode | 980 nm | Pulsed | 2.8 W | N/A | 4 × 5 s | Preliminary conventional chemomechanical preparation | Conventional preparation with NaOCl and hydrogen peroxide is superior to laser irradiation in root canal disinfection. |
| Bago et al 2013[58] | *Ex vivo* | | Diode | 975 nm | Pulsed | 2 W | 320 µm | 4 × 20 s | None | Laser irradiation had a similar bacteriocidal effect to conventional NaOCl irrigation. Both of these modalities left more vital bacteria in the root canal compared to PAD or sonic-activated irrigation. |
| Zan et al 2013[48] | *Ex vivo* | | Er: YAG<br>KTP | 2940 nm<br>N/A | Pulsed<br>Pulsed | 2W<br>2 W | 200 µm | 9 × 5 s | None | Er: YAG laser irradiation destroyed more bacteria compared to KTP, but both laser methods failed to outpoint NaOCl or aqueous ozone. |
| Kaiwar et al 2013[59] | *Ex vivo* | | Diode | 980 nm | N/A | 1.5 W<br>3 W | N/A | 4 × 5 s | None | The 3-W laser caused statistically significantly fewer CFU values than 1.5 W. |

CW: Continuous wave, NaOCl: Sodium hypochlorite, N/A: Not available, s: Second, m: Minute, Er, Cr: YSGG: Erbium, chromium-doped yttrium, scandium, gallium and garnet, RCT: Root canal therapy, Nd: YAG: Neodymium-doped yttrium aluminum garnet

affects the bacteria residing out of the apex, and it could assist in the healing of the periapical lesion by reducing the bacterial load.[31,32] It is mentioned in the literature that smaller periapical lesions and apical foramina would benefit more from laser irradiation.[31,32]

### *Er, Cr: YSGG*

When the Er, Cr: YSGG laser is used solely, it could not effectively destroy bacteria, and its bacterial reduction rate is almost 50%.[29,33,34] However, antibacterial outcomes comparable to gold standard NaOCl irrigation have been reported by studies in which the Er, Cr: YSGG laser was used with the LAI technique with silver nanoparticles,[33] NaOCl,[29,30,34-40] and saline.[36-38] It has been mentioned in the literature that the disinfection potential of the LAI technique with Er, Cr: YSGG significantly improved by increasing irradiation time.[40,41] LAI with the Er, Cr: YSGG laser and NaOCl have frequently been investigated with many powers (ranging from 0.5-1.5 W) and with different NaOCl concentrations (ranging from 0.5-5.25%). Most of these studies have found that LAI with the Er, Cr: YSGG laser and NaOCl effectively disinfects the root canal.[29,30,34,36-38,40]

### *Nd: YAG*

Six out of seven studies in which the Nd: YAG laser was employed have used 1.5 W power output with a 200 µm-thick fiber optic. The Nd: YAG laser has been used only in conjunction with silver nanoparticles[42] and saline.[22,43] The Nd: YAG laser, compared to Er, Cr: YSGG, has a lower


**Figure 2**. The Lasers Utilized to Disinfect Root Canals. Each color represents a type of laser. N/A: Not available; CW: Continuous wave

disinfecting ability when used solely.[30,41] Generally, the majority of studies concerning the Nd: YAG laser in root canal disinfection have not asserted a significant privilege for this modality.

### *Er: YAG*

Er: YAG laser has been utilized in root canal disinfection with various methods, including LAI and PIPS with NaOCl and solely irradiating. LAI with Er: YAG has illustrated considerable bacterial reduction in two studies.[44,45] Similarly, PIPS with Er: YAG and NaOCl exhibited a higher bactericidal effect and deeper tubular penetration compared to conventional irrigation or just laser irradiation.[46,47] Compared to KTP and thulium fiber lasers (TFL), Er: YAG has demonstrated better efficiency when applied alone.[48,49]

### *KTP*

Three studies reported using the KTP laser for disinfecting root canals. In one, the authors affirmed that the diode laser and KTP are more forceful disinfecting agents than conventional irrigation, with KTP being slightly superior.[24] On the contrary, in the other two studies, the authors believed that irradiating root canals with KTP has inferior outcomes compared to conventional irrigation or employing the Er: YAG laser.[15,48] The difference between the findings of the studies could be a result of different incubation periods. Both studies reporting the incompetence of KTP in the disinfection of root canals incubated *Enterococcus faecalis* for 24 hours; however, Romeo et al incubated the same microorganism for 72 hours.[24]

## Discussion

Various high-power lasers have been utilized to disinfect the root canal system. Because PAD is often conducted with lasers whose powers are lower than 0.5 W, and the fact that the efficiency of this technique has been widely investigated in several reviews, we did not consider studies focusing on PAD eligible, in contrast to studies evaluating the effect of PIPS or LAI.[60-62] The diode is the most common laser, followed by Er, Cr: YSGG, Nd: YAG, and Er: YAG, respectively. Some studies concluded that using a diode laser merely is not effective enough in disinfecting root canals, and it must be used as an adjunct therapy after or during NaOCl irrigation.[26,33,34,36] In contrast, some other studies indicated that the diode laser is effective and acceptable when used solely.[12,19,20] Moreover, when Er, Cr: YSGG is utilized solely, it does not eradicate root canal bacteria effectively; however, using this laser with LAI technique with silver nanoparticles, NaOCl or saline showed acceptable outcomes in disinfecting the root canal system.[21,37,45,50] The Nd: YAG laser has been used only in conjunction with silver nanoparticles and saline.[17,35,39] Additionally, using Er: YAG with PIPS or LAI techniques showed a more significant antibacterial effect than using it solely.[44-47]

Different methods and irrigants have been introduced to achieve better and safer root canal disinfection. Among these contemporary modalities, laser utilization is a new approach to activate the irrigation solutions inside the root canal. LAI and PIPS are two techniques used to activate disinfectants.[63,64] In the LAI technique, the absorption of laser energy in the irrigant forms bubbles, which will implode and cause a secondary cavitation effect on the irrigants. This cavitation upshot effectively removes dentin debris and smear layers and has a bactericidal effect.[38] It is reported that a more effective result would be obtained when the LAI technique is operated with Er, Cr: YSGG or Er: YAG in combination with NaOCl.[5,65] PIPS is a newer technique in which intracanal cavitation results from photoacoustic and photomechanical effects caused by low-energy (20 mJ) laser application.[46,63] In this method, the cavitation effect and streaming of irrigants remove the smear layer and dentin debris and lead to effective decontamination of both root canals and lateral canals. The low-power lasers in PIPS cause a minimal thermal effect on the tissue.[64] In this regard, using lasers such as Nd: YAG or diode merely has antibacterial effects based on thermal energy. In this method, heating bacteria and their environment straightly kills the microorganisms. However, this thermal energy may cause undesirable morphological damage and thermal injury to the root canal system.[66,67]

According to Do and Gaudin, some studies indicated that both LAI and PIPS applied by Er: YAG are more effective than conventional syringe techniques or PUI in removing dentin debris from the root canal system and also in canal disinfection. In comparison, some other studies showed no difference between PIPS, LAI, and conventional methods.[63] However, according to Lloyd et al, using Er: YAG as either LAI or PIPS has a better result than conventional methods in sealer and medication removal from the canal.[66] It should be noted that the PIPS technique is more straightforward for the clinician due to the placement of PIPS-specific tips at the orifice of the canals. In the LAI method, a conical-shaped long thin tip is used inside the root canal positioned 5 to 2 mm from the apex. Vertical movements of this tip lead to irrigation solution cavitation.[29] In the PIPS protocol, a large, short-striped, tapered 600 µm wide tip is positioned in the access cavity.[65] Theoretically, PIPS can travel three-dimensionally through the fluids inside the canals and affect the entire root canal system.[46] Due to placing the specific tips in the coronal portion, less canal preparation and enlargement are needed, and also no undesirable thermal effect would be seen.[63] Further studies are necessary to determine the superiority of one of these two techniques.

Using a high-power laser in root canal treatment can be challenging. Clinicians must consider several limitations. Firstly, since the laser light emits in a straight line, it is impossible to have the same disinfection quality on every dentin surface due to the curves and variations in root canal anatomy. Although the tip of the instruments emitting the laser can have a divergence of 18 to 20 degrees, this does not solve the problem of equal and desirable accessibility to the whole dentinal surface of the root canal system.[5] Secondly, the safe use of a laser can be challenging, especially in teeth with an open apex since the emission of the laser through an open apex can cause thermal damage to periapical tissues.[68] Moreover, ledge creation, root perforation, zipping, and over-instrumentation may occur mainly while teeth are treated with curved root canals. Moreover, using high-power lasers in root canal treatment enables the clinician to treat the root canal without using extra photosensitizers or photo-activated substances such as methyl blue, green malachite, and TBO. Indeed, it is required to use mentioned substances in other methods such as PDT. It should be noted that if clinicians use a high-power laser under consideration with accurate case selection, this method can be helpful in root canal treatment of infected teeth.

This review study aimed to provide and present information about the current situation of using high-power lasers in disinfecting root canals so that clinicians can use lasers solely or as a complementary method in their endodontic practice to disinfect the root canal system properly.

### Conflict of Interests

The authors declare that they have no conflict of interest.

### Ethical Considerations

Not applicable

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