Sadony and Moharam
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REVIEW

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Laser applications in endodontics: a review article

Doaa M. Sadony[1] and Lamiaa M. Moharam[1*]

Abstract

Background Different types of dental laser can be used instead of the traditional hand and rotary files in root canal treatment with highly acceptable performance. Laser devices emit an intense and focused light energy, which interacts with biologic tissues, for pulp removal, shaping and cleaning the dentinal walls to be finally sealed with gutta-percha. Various laser devices with different wavelengths such as CO_2, Er:YAG, Nd: YAG and Diode present the best laser–tissue interaction. Lasers in root canal treatment show more advantages than traditional treatment. Laser is more accurate than conventional root canal treatment that allow minimal removal of healthy dentinal tissue. Lasers have anti-bacterial effect by reduction of more than 99.7% bacterial counts for root canal sterilization. Laser provides less bleeding, inflammation, pain, discomfort and infection than conventional procedures. Laser treatment of root canals results in a good sealing of gutta-percha to root canal walls to prevent infections.

Conclusions Laser application is comfortable to the patients by removing the disturbing sounds of drills and decreasing the need for local anesthesia. It decreases the need for suturing in endodontic surgery due to better hemostasis, thus getting clean and well-sealed surgical wounds.

Keywords Laser, Applications, Endodontics

Background

Endodontic treatment is an important procedure used to maintain the function of the pulp-affected teeth through cleaning, sterilization and obturation of root canals (RCs) (Neha et al. 2023). Different traditional root canals treatment (RCT) techniques are commonly performed to treat damaged pulp tissues including mechanical methods using hand files and chemical disinfection with NaOCl, frequent irrigation of RCs to remove smear layer. These methods are step-by-step technique, followed by GP condensation to seal RCs. Contemporary methods are now applied using rotary NiTi files, and RCs irrigation with chlorhexidine (CHX), NaOCl, and Ethylenediaminetetraacetic acid (EDTA), followed by warm lateral condensation. These methods of RCT can be accomplished using surgical microscope, electronic apex location, ultrasonic instrumentation and digital X-ray for much easier process. However, there was not much difference between the two methods of treatments in RCT (Neha et al. 2023). Laser is "Light Amplification by the Stimulated Emission of Radiation." It can be used instead of the traditional hand and rotary files in RCTs with highly acceptable performance. Laser can 'boil away' the damaged tissue with greater accuracy. Therefore, less bleeding is encountered during RCT and RCs are cleaner. Some patients who had conventional RCTs in the past then endodontic laser treatment recently reported much lesser pain and no discomfort immediately after laser treatment. Laser devices emit an intense and focused light energy, which interacts with biologic tissues, for pulp removal, shaping and cleaning the dentinal walls to be finally sealed with gutta-percha (GP) (Mohapatra 2019). Various laser devices with different wavelengths such as CO_2, Er:YAG, Nd: YAG and

*Correspondence:
Lamiaa M. Moharam
lamia.moharam@gmail.com
[1] Restorative and Dental Materials Department, National Research Centre, El-Bohouth Street, Dokki, Giza, Egypt

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Diode present the best laser–tissue interaction (Cristiane et al. 2020).

Main text

Mechanism of laser action

Laser device consists of three parts: energy source, active medium, and optical cavity that include two or more mirrors. For laser light amplification, the electrical current is pumped into the active medium that contains the optical resonator to produce photons spontaneously. Then, the stimulated photons are reflected back and forth by the mirror before exiting the laser cavity. The laser light is delivered to the target tissues by a fiberoptic or articulated arm.

Laser tissue interaction

The monochromatic laser beam has a selective reaction with the target tissues through transmission, reflection, scattering and absorption by the tissues. In laser absorption by tissues, the temperature elevates and produces photochemical effects depending on the tissue water content. Pulp hyperthermia occurs when the temperature is below 50 °C, while coagulation and protein denaturation without vaporization of the underlying tissues, when temperature reaches 60–100 °C. Then, ablation occurs when temperature is at 100 °C where water vaporization within the tissues occurs. When temperature exceeds 200 °C, the tissue dehydration and burning occur, resulting in carbonization (Qin et al. 2023). Five important types of biological effects might occur once the laser photons enter the tissues; fluorescence, photothermal, photoacoustic, photochemical, and photo-biomodulation. Laser absorption depends on its wavelength and the tissue characteristics (pigmentation and water content). The effect of absorbed laser light on the tissues can be controlled by: energy mode (continuous or pulsed); laser beam size; pulse length and repetition rate; and the presence of water coolant. When laser is applied at low power, laser-tissue interactions might have an optical, optical and photochemical or photo-biomodulative effect, while photothermal interactions occur in high power lasers (Pradnya et al. 2017; Coluzzi 2000).

Lasers in endodontics

The physical effect of laser in endodontic treatment depends on the absorption of its wavelengths in chromophores as water, minerals and pigmentation. However, Nd:YAG and diode lasers are badly absorbed in H_2O and minerals yet they have high bactericidal effect on dentin. Nevertheless, CO_2, Er:Yag and Er,Cr:YSGG lasers are highly absorbed in water and minerals (Stabholz et al. 2003).

Laser types in endodontics and their uses

CO_2 laser: CO_2 laser is primarily soft tissues laser of 10.600 nm. It is absorbed by water, while 9.300 nm CO_2 laser is absorbed by tooth minerals, its hard tissue applications as cavity preparation, and apicectomies. Using scanning electron microscope (SEM) images in vitro study, showed cleaner dentinal surface with melted, fused and re-crystallized dentin after apicectomy and root treatment using pulsed 9.600 nm CO_2 laser. SEM images investigated the marginal permeability and dentinal surface texture after apicectomy with conventional burs and laser, they observed roughly root surface after conventional treatment while, smooth surface and high marginal adaptation after CO_2 laser treatment in continuous mode, using cooling agent (Vicky et al. 2021). There are different types of laser that can be used in the field of endodontics with several applications (Table 1).

Nd: YAG laser: Nd: YAG (1.064 nm) is widely used for endodontic disinfection. It is highly absorbed by the pigmentation, to be very effective for cutting, soft tissues coagulating, good hemostasis and antibacterial effect. Its mechanism of action depends on thermal heating of the bacteria, showing 99.16% decrease in bacterial accounts (*Enterococcus faecalis* and *Escherichia coli*) in root canal treated by Nd:YAG. For good dentin root canal irradiation and to prevent heat damage to the periapical tissues; a thin fiber tip of

Table 1 Laser types in root canal treatment

Type	Construction	Uses	Wave length	Delivery system
Diode	Semiconductor	Soft tissue laser, Diagnosis	445 nm, 405 nm, 655 nm	Optical fiber
Nd:Yag	Solid state	Soft tissue laser	1.064 nm	Optical fiber
CO_2	Gas state	Hard tissue laser	10.600 nm	Articulated arm
Er,Cr:YSGG	Solid state	Hard tissue laser	2.790 nm	Optical fiber
Er:YAG	Solid state	Hard tissue laser	2.940 nm	Optical fiber, Articulated arm

Nd:YAG (diameter 200 μm) was placed 1–2 mm less than the apex with slow circular movements upwards the crown, where the irradiated root dentin showed changes as melting, fusion and re-crystallization of dentinal tubules (Taher et al. 2022).

Diode laser: Diode lasers have visible (660 nm) and infrared (810–980 nm) spectrum. They are highly absorbed in water, therefore, diode lasers have significant antimicrobial effectiveness in root canal treatment against common bacterial root canal (*E. coli* and *E. faecalis*, when irradiated at 4 W at 6 °C. Application of diode laser (810 nm) at 3 W for 30 s against intracanal *E. faecalis* showed substantial antibacterial effect. Moreover, multiple morphological changes were observed in the root dentin walls such as removal of the smear layer and fused dentinal tubules, after irradiation by diode laser and Nd:YAG laser. Diode laser has thermal mechanisms of action through destruction of cell wall integrity and denatured of protein. It also has photoacoustic effect by occluding dentinal tubules via dentin melting to prevent bacterial entrapment (Sara et al. 2024).

Photoactivated disinfection (PAD): It is sterilization of hard and soft dental tissues by a photochemical effect through activation of a photosensitizer low laser energy, leading to single oxygen formation that damages the bacterial cell membrane and its DNA. PAD effectiveness depends on photosensitizer type and concentration, bacteria type, the light source and its parameters. Recently, combining diode laser (at 630, 660 and 670 nm) with methylene blue dye is giving better results than conventional RCT and irrigation. High bacterial reduction (99.9%) was shown after RCT using toluidine blue O (TBO) + diode laser (660 nm/50 mW), and a high reduction in bacterial account after RCT using diode laser (665 nm, 1 W/30 J/cm^2/2.5 min/twice) with methylene blue. Many studies recommended PAD as an alternative method for RC sterilization (Lei-Lei et al. 2023).

Er:YAG and Er,Cr:YSGG lasers: Er,Cr:YSGG (2790 nm) and Er:YAG (2940 nm) lasers are well absorbed in water and hydroxyapatite, causing ablation removal of hard and soft dental tissues. In last few years, Erbium lasers were used for cleaning RC by laser activated irrigation (LAI) action based on specific acoustic streaming in intra-canal fluids and cavitation phenomena due to photothermal and photomechanical effects. Erbium laser absorbs water leading to vaporization and formation of large vapor bubbles expansion > 1.600 times than main volume of traditional irrigant with high pressure to drive the irrigant out of the canal and the smear layer removal occurs. In root canal preparation, these bubbles cause pressure to suck fluid back into the root canal leading to secondary cavitation effect (Kosarieh et al. 2021).

Lasers application in endodontics

Lasers have multiple applications in endodontics (Sofia et al. 2023) including:

Pulp diagnosis: Laser Doppler flowmetry (LDF) is used to diagnose blood flow of dental pulp with low power at 1–2 mW, by directing laser beam to the blood vessels within the pulp through the crown, so that red blood cells move, which is observed by a photocell on the crown surface where the output reading indicates the number and velocity of the blood cells. LDF method has several advantages over traditional electric pulp testing methods (Thermal Test, Electric Pulp Tester and percussion test) including; painless sensation in determining the tooth vitality, can be used with uncooperative patients, detection of pulp vitality in traumatized or immature teeth, reproducible results, and noninvasive. However, LDF has some limitations, as in the anterior teeth with thin enamel and dentin, molars with thicker enamel and different pulp position within the tooth that might cause changing in pulpal blood flow. Yet, these limitations can be overcome by using multiple probes for accurate assessment (Liao et al. 2017).

Laser in Analgesia: Pulsed Nd:YAG laser is widely used as local anesthesia (LA) agent, via interfering of laser wavelengths with tissues sodium-pump mechanism, changing cell membrane permeability and sensory neurons endings leading to nerves fibers block (Qin et al. 2023).

Pulp capping and pulpotomy: Small pulp exposures (1.0 mm or less) in adult patients require pulp capping to maintain the vitality of the teeth. Materials like Ca $(OH)_2$, mineral trioxide aggregate (MTA), that is highly soluble in body fluids, and glass ionomer (GI), which causes chronic pulp inflammation and lack of dentin bridge formation in some cases, are traditionally used for pulp capping treatment. Recently, lasers were used to obtain a bloodless area and sterile wound by action of vaporization, coagulation and closing small blood vessels. CO_2 laser was compared with Ca $(OH)_2$ application, after 12 months for direct pulp capping effectiveness, the results showed 90% success rate with CO_2 and 68% with Ca $(OH)_2$. Er:YAG and Nd:YAG lasers recorded significant results in pulp capping procedures in several different studies, with good pulp tissues healing and formation of a reparative dentin and dentin bridge (Hilton 2009; Eugenia et al. 2020). Pulpotomy treatment is needed for the exposed pulp in teeth with not fully formed roots. The traditional materials are Ca $(OH)_2$ which is applied for dentin bridge formation; however, temporary pain and peri-radicular inflammation will be observed when follow-up period increased, leading to decreased success rates, while MTA showed favorable results when applied to exposed pulp, but it needs long time for complete setting (Rajendran et al. 2019). CO_2 and Nd:YAG are recommended for this purpose, as CO_2 is well-absorbed by enamel and dentin, leading to ablation, removal, melting, and solidification of dental tissue; so, it is an effective tool with 91–98% success rates in primary teeth pulpotomy (Mert and Tuğba 2023). Pulsed Nd:YAG laser applied in 1 W for 10 s at 10-Hz in repetition rate did not elevate the intra-pulpal temperature, so it can be useful in anti-inflammatory and anti-bacterial effects and pulp hemostasis procedures (Kathari and Ujariya 2014).

Access cavity and root canal preparation: Laser is widely used in RCT starting from first step of the procedure. Er:YAG (2,940 nm) and Er,Cr:YSGG (2,780 nm) can be used for access cavity preparation, shaping and cleaning of the root canal. Pulsed Nd:YAG (1,064 nm) at 15 Hz and 1.5 W can be used to remove pulp tissue remnants, completely remove the smear layer, seal dentinal tubules, debris removal and control of hemorrhage. Using traditional RCT instruments for convenient access to canals orifices leads to removal of more sound tooth structure creating thick smear coating, its disadvantageous as it blocks dentinal tubules, decreases penetration of sealer into the dentinal tubules, limits optimum penetration of disinfecting RC irrigants and reduces dentine permeability (Ruaa 2019). Due to these defects, laser removal of the smear layer and sealing the dentine surface has become a priority. Therefore, the application of CO_2 laser was found to have a positive effect on root dentin, which became harder and more acid resistant than non-lased dentin. Moreover, the melted surface layer increased the bond strength by 300% (De-Meyer et al. 2017).

Root canal disinfection and irrigation: Comparing the efficacy of LAI of root canals with conventional irrigation showed favorable results for the laser technology. LAI for removing bacteria and preventing new bacterial growth was found more effective than conventional irrigation delivered by a syringe, as lasers provide a superior dentin seal and high success rates than conventional techniques (Chandrashekar et al. 2023). Traditional endodontic instrumentation followed by laser application has become a goal in dentistry (Dagher et al. 2019). Different laser systems are used and delivered into the root canal system by a thin optical fiber (Nd:YAG, Er:YAG diode and Er,Cr:YSGG) or by a hollow tube (Er:YAG and CO_2). Laser irradiation used in dentistry has the ability to kill bacteria; this effect is directly related to the energy level and amount of laser irradiation. It was reported that Er:YAG, Nd:YAG, Er,Cr:YSGG, and CO_2 laser can remove smear layer from the canal walls, RC disinfection preserving an adequate part of the pulp chamber roof and dentin. Similar results were obtained using Nd:YAG lasers on dentin surfaces infected with Candida species and diode laser (980 nm) to decrease *E. faecalis* up to 97% from infected dentin walls (Sarda et al. 2019). Traditional root canal irrigation has several drawbacks such as accidental NaOCl pushing into periapical tissues and surrounding vital structures such as maxillary sinus, resulting in emphysema and dentin erosion; chlorhexidine (CHX) was found to be unable to remove biofilm layer or dissolve necrotic tissue remnants and has lesser effect on gram-ve than gram + ve bacteria; EDTA has no antibacterial activity, reduces RC dentin hardness, and demineralized intertubular dentin; MTAD adversely affects dentin physical properties causing reduced bond strength of calcium-hydroxide-based and resin-based RC sealers due to precipitate formation (Azhar et al. 2022). Antimicrobial photodynamic therapy (APDT) is a two-step procedure, where photosensitizer is first applied on target tissues, then irradiated by laser to kill the bacteria. Nowadays, a new formula of photosensitizers is introduced to improve the antibacterial efficacy of APDT in RCT and increase the penetration into dentinal tubules and anatomical complexities. Garcez et al. (María-José et al. 2021) compared APDT, conventional root irrigants and a combination of both to remove bacteria found in the infected root; they showed that conventional treatment decreases bacteria by 90%, APDT by 95% and combination treatment by 98%. Comparing the antibacterial efficacy of (Er:YAG) with APDT systems and NaOCl action on *E. faecalis* showed that Er:YAG and APDT reported great decrease in bacterial counts than NaOCl irrigant. PDT using TBO and (LED) as an adjunctive antimicrobial procedure with conventional endodontic treatment (Divyangana 2020). An endodontic tip (PIPS-tip) was developed to ensure complete laser irradiation of RC walls. It's a specific tapered firing fiber tip for erbium laser that can be introduced to canal orifice, instead of inserted inside the canal. Its pulsed irradiation has photoactive effect on irrigants, causing irrigants to travel through RC with 3D movement, for complete debris removal with no thermal damage to the surrounding dentinal tissues. Thus, PIPS system has a superior effect in debris removal compared to the sonic and ultrasonic systems (Mandras et al. 2020). PIPS technique had been compared to NaOCl and EDTA irrigation procedures; the results showed complete removal of the bacterial account and debris in RC. Today, there are two methods used for root canal sterilization, first: fiber inserted in a dry root canal, with straight laser beam in a spiral movement to expose all RC walls and complete removal of smear layer depending on photothermal interaction of laser; and second: the fiber used with the irrigant inside pulp chamber at the level of the orifice (Mandras et al. 2020).

GP removal and sealing: Laser-assisted obturation using Nd:YAG has been used for thermo-softening GP, removal of excess GP after obturation due to their thermal effect. Moreover, it showed better results over the thermo-plasticized GP obturation systems commercially available today (Altamash et al. 2022; Paneliantong et al. 2023). 3D laser canal obturation prevents leakage from the apical foramen, so increasing the success rate of RCT. It was demonstrated that Nd:YAG and diode were useful in preventing the apical leakage. Er,Cr:YSGG was useful in shaping, cleaning, and RC obturation. Er:YAG laser beam (200 mJ/4 Hz/60 s) was reported to increase the adhesion of resin-based sealers compared to ZOE-based sealers, leading to increased adhesion of the sealer to canal walls with less voids (Paneliantong et al. 2023). Nd:YAG laser at 1–3 W removed GP and broken instruments in more than 70% and 55% of cases, respectively. Nd:YAG in pulsed mode was used to remove two types of obturation materials from the root canal, and the time need for the removal of obturation materials by laser ablation was shorter than that of conventional procedures (Bernardo et al. 2023; Violeta and Emilia 2022). Post-operative pain after conventional re-treatment may develop. It was demonstrated that low-level laser therapy (LLLT) is a practical, non-pharmacologic technique for reducing pain in RCT cases (Arslan et al. 2017).

Endodontic surgery: Soft tissue lasers such as CO_2, Diode and Nd:YAG are used to obtain clean incision for direct access to the periapical area and replace infection of hand pieces in periapical surgery to decrease the contamination of the surgical area. Er:YAG and Er,Cr:YSGG lasers are used for apicoectomy and retro-preparations, showed less contamination of surgical site, and no smear layer. The main advantages of laser endodontic surgery are: sterilization, precision, coagulation, selective absorption, no scarring, excellent wound healing, bloodless area, decrease bacteria numbers in the surgical field, no need for sutures, less pain and good hemostasis (Anuradha et al. 2020). Nd:YAG laser showed sterilization and less permeability in the lased resected root due to the changes in dentin structure as melting, solidification, and re-crystallization of the hard tissues than non-glazed roots. However, better healing is achieved with laser (Rotundo et al. 2010).

Laser disadvantages

At the wrong wavelength or power level, lasers can damage oral and ocular tissues:

1. Hard lasers can sometimes damage the tooth and burn the surrounding soft tissues.
2. Eye tissue damage could happen when lasers are powerful, to avoid eye damage the dentists should use special goggles for eye protection.
3. Avoid shining metal surfaces when using lasers because the light may reflect back and cause eye damage; instead, use high-speed suction pipes or evacuation to avoid inhalation of bad vapors that may cause respiratory disease (Saima and Farzeen 2023).

Conclusions

It can be concluded that using lasers in RCT showed more advantages than traditional treatment. Laser is more accurate than conventional RCT that allow minimal removal of healthy dentinal tissue. Lasers have anti-bacterial effect by reduction of more than 99.7% of RC bacterial counts. Laser provides less bleeding, less post-operative inflammation, pain, discomfort and infection than conventional procedures. Laser can reach inaccessible accessory lateral canals for better root sealer diffusion, resulting in good GP sealing to RC walls to prevent infections. Laser is much comfortable to patients by omitting the disturbing sounds of drills and decreasing the need for LA. It helps performing RCT in single-root teeth. It decreases the need for suturing in endodontic surgery due to better hemostasis and reduced bleeding by getting clean and well-sealed surgical wounds.

Recommendations

The future looks for using lasers in the dentistry field. More clinical research is required to evaluate effectiveness of laser compared to traditional methods, to help develop standard clinical guidelines for practicing dentists.

Abbreviations

RC	Root canal
RCT	Root canal treatment
GP	Gutta-percha
CO_2	Carbon dioxide
Er:YAG	Erbium-doped yttrium aluminum garnet
Nd: YAG	Neodymium-doped yttrium aluminum garnet
NaoCl	Sodium hypochlorite
NiTi	Nickel Titanium
CHX	Chlorhexidine
EDTA	Ethylene-diamine-tetra-acetic acid
H_2O	Water
PAD	Photoactivated disinfection
DNA	Deoxyribonucleic acid
TBO	Toluidine blue
Er,Cr:YSGG	Erbium, Chromium Co-doped Yttrium Scandium Gallium
MTA	Mineral trioxide aggregate
LAI	Laser-activated irrigation
$Ca (OH)_2$	Calcium hydroxide
APDT	Antimicrobial photodynamic therapy
LDF	Laser Doppler flowmetry
SEM	Scanning electron microscope
GI	Glass ionomer
MTAD	Mixture of Doxycycline, citric acid and a detergent
LLLT	Low-level laser therapy
LA	Local anesthesia

Laser Light amplification for stimulated radiation

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DS collected the data and wrote the original manuscript. LM modified the manuscript, wrote, and revised the final manuscript. All authors have read and approved the final manuscript.

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