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Laser systems and current applications in endodontics: A review

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Abstract

Laser technology has gained increasing attention in endodontics due to its potential to enhance disinfection, improve treatment outcomes, and support minimally invasive clinical approaches. The aim of this review was to provide a comprehensive overview of commonly used laser systems in endodontics and to summarize their current clinical applications. Various laser types, including carbon dioxide (CO_2), diode, neodymium-doped yttrium aluminum garnet (Nd:YAG), neodymium-doped yttrium aluminum perovskite (Nd:YAP), erbium-doped yttrium aluminum garnet (Er:YAG), and erbium chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG), have been evaluated in terms of their mechanisms of action and clinical effectiveness. Lasers are used in multiple endodontic procedures, such as root canal disinfection, smear layer removal, pulp capping, pulpotomy, dentin hypersensitivity management, and treatment of pulp and periapical pathologies. In particular, laser-activated irrigation techniques, including photon-induced photoacoustic streaming (PIPS) and shock wave-enhanced emission photoacoustic streaming (SWEEPS), have shown promising results in improving irrigation efficacy and bacterial elimination, especially in complex root canal anatomies. Compared with conventional irrigation methods, these advanced laser techniques enhance the penetration of irrigants into dentinal tubules while minimizing thermal damage to surrounding tissues. Erbium lasers, owing to their high water absorption and photoacoustic effects, appear to be especially effective for smear layer removal and biofilm disruption. Other laser systems, such as diode and Nd:YAG lasers, also contribute to antimicrobial activity and postoperative pain reduction when used appropriately. However, laser parameters, irradiation time, and safety considerations remain critical for successful clinical outcomes. In conclusion, laser systems offer significant advantages in endodontic therapy by improving disinfection, supporting tissue preservation, and enabling minimally invasive techniques. Further well-designed clinical studies are needed to strengthen the evidence regarding their long-term efficacy, safety, and optimal clinical protocols.

Keywords: Laser, endodontics, CO_2, Nd:YAG, Nd:YAP, Er:YAG, Er,Cr:YSGG, PIPS, SWEEPS

1. Introduction

The use of lasers in endodontic applications has been extensively researched and has been shown to offer many advantages over traditional methods (1-3). Depending on the type of laser used, thermal, photochemical, and nonlinear effects may occur during tissue contact; this makes lasers a suitable option for treatment, preventive applications, and aesthetic purposes with excellent tissue tolerance (4). Lasers have become the treatment of choice for eliminating microorganisms in root canals, particularly in the lateral dentinal tubules. This has been achieved through the development of a fiber delivery system. Direct delivery of laser light into the root canal has been proven to have a bactericidal effect (1).

Lasers commonly used in endodontic treatments include erbium-doped yttrium aluminum garnet (Er:YAG), erbium-chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG), neodymium-doped yttrium aluminum garnet (Nd:YAG), neodymium-doped yttrium perovskite (Nd:YAP), carbon dioxide (CO_2), and diode lasers (5).

Currently, the use of laser technology in endodontics is rapidly developing and diversifying. Lasers are effectively used in many endodontic treatment applications, such as root canal treatment, pulp capping, pulpotomy, dentin hypersensitivity treatment, and management of tooth pain associated with pulp and periapical diseases. In addition, laser-based technologies have become the focus of current research in the management of complex clinical situations, such as accelerating root development and removing broken endodontic instruments and fiber posts (Fig. 1) (5).

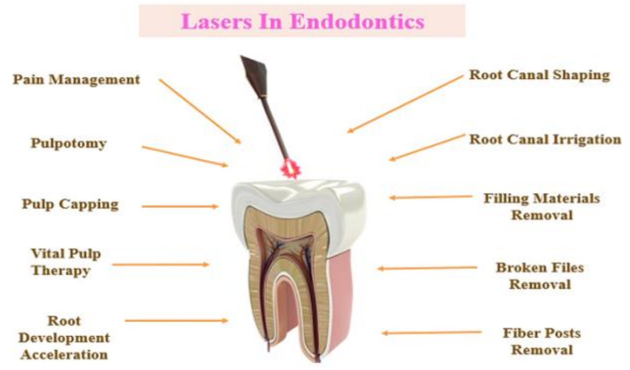

Figure 1. Current and advanced application areas of lasers in endodontic treatment.

2. Types of lasers and their applications in endodontics

2.1. Carbon dioxide (CO_2) laser

Carbon dioxide (CO_2) lasers are the first type of laser used in dentistry and can be operated at wavelengths between 9,000 and 11,000 nm. Carbon dioxide lasers with a wavelength of 10,600 nm are the most commonly used lasers in dental treatment. Because it can control bleeding, the CO_2 laser can be used directly for pulp capping. A study found that a 10,600 nm carbon dioxide laser inhibited biofilm growth and reduced bacterial viability. However, excessive heat buildup and lower operational efficiency limit their clinical application (6, 7). The absorption of hydroxyapatite is at 9,600 nm, and its reflection also peaks at 9,600 nm. Therefore, the 9,300 nm carbon dioxide laser has the highest energy transfer capacity on hydroxyapatite among the existing dental lasers (8). The 9,300 nm wavelength carbon dioxide laser has a shallow heat absorption depth in the enamel and dentin, reducing the risk of thermal damage to the dentin-pulp complex. This laser supports the caries-preventive effect of fluoride and enhances the bonding of resin to the enamel. Furthermore, when used at high power, it allows for the removal (ablation) of caries in restorative treatments (9). However, CO_2 lasers can cause cracks on the enamel surface, which may promote caries development along the cracks (10).

2.2. Diode laser

Diode lasers are a type of laser with low power output and are generally applied in the 810–980 nm wavelength range for treatment purposes. Compared to Nd:YAG lasers, they provide higher water absorption within hard dental tissues and can penetrate as deep as into the dentinal tubules, where they can be effective against microorganisms (11). However, diode lasers exhibit significant beam divergence, which leads to poor optical performance. Despite these limitations, diode lasers can effectively remove microorganisms from root canals and reduce postoperative endodontic pain (12). Studies conducted on rats and dogs have shown that the combination of a Gallium Aluminum Arsenide (GaAlAs) diode laser (810 nm) and mineral trioxide aggregate (MTA) can accelerate dentinogenesis and apical growth in teeth, thereby shortening the treatment time. Similarly, the combined use of calcium hydroxide and laser irradiation has also had positive effects on the apexogenesis process and contributed to supporting root development (13, 14). A low-level Indium Gallium Aluminum Phosphide (InGaAlP) diode (660 nm) laser can be an effective adjunct to revascularization therapy in non-vital immature teeth (15). The GaAlAs diode (810 nm) laser has similar efficacy to potassium oxalate gel in cervical dentin sensitivity, but potassium oxalate gel reduces symptoms immediately (16).

2.3. Neodymium-doped yttrium aluminum garnet (Nd:YAG) laser

Operating at a wavelength of 1064 nm, neodymium-doped yttrium aluminum garnet (Nd:YAG) laser exhibits antimicrobial effects through photothermal interactions and provides localized heat production that penetrates deep into dentin tissues (17). Due to the risk of energy scattering and penetration into adjacent biological tissues, the output power must be correctly adjusted and the irradiation time carefully controlled during clinical applications to protect surrounding tissues (5). The Nd:YAG laser stands out as an effective and attractive option for endodontic disinfection, particularly in resistant cases where standard treatment approaches are insufficient because of its ability to break down bacterial cell walls and biofilm matrices (18). The use of Nd:YAG with sodium hypochlorite (NaOCl) has been shown to improve bacterial clearance and reduce inflammatory markers compared to irrigation alone, leading to improved clinical outcomes (19). However, erbium lasers have been shown to provide more effective bacterial eradication and deeper penetration into dentinal tubules than Nd:YAG lasers. Owing to their photoacoustic and photomechanical mechanisms, they offer higher efficacy in smear layer removal and irrigation activation. In contrast, Nd:YAG relies solely on photothermal interactions, which may be less effective in complex anatomical areas or against mature biofilms (19, 20). It has been reported that an Nd:YAG laser may be useful for removing broken files if precautions are taken to control temperature increases, such as using a combination of pressurized air and water spray (21).

2.4. Neodymium-doped yttrium aluminum perovskite (Nd:YAP) laser

The Neodymium-Doped Yttrium Aluminum Perovskite (Nd:YAP) laser has a wavelength of 1340 nm and exhibits significant absorption capacity for water and hemoglobin. This property enables it to provide effective sterilization within the root canal (22). The mechanism of action involves the high energy of the laser instantly vaporizing water in the root canal, creating micro-explosions, and thus providing effective disinfection against bacteria in the dentinal tubules and the smear layer (23). Furthermore, compared to other high-power laser devices, it offers additional analgesic effects, making it an effective and preferred option for endodontic treatment. The Nd:YAG laser can also be used to treat dentin hypersensitivity. However, it should be used in pulsed mode with rest periods to avoid thermal damage to the surrounding tissues (24, 25). Nd:YAG laser may be an effective alternative to triple antibiotic paste in regenerative endodontic procedures (REP). However, more studies are required to confirm these findings. Additionally, no significant adverse effects of Nd:YAG laser use on the prognosis of REPs have been reported (26).

2.5. Erbium chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser

Erbium chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG) lasers operate at a wavelength of 2780 nm, which is extremely close to the absorption peak of water. Their applications and limitations in endodontic treatment are largely those of similar to Er:YAG lasers, as both belong to the erbium group of lasers. Moreover, applying the Er,Cr:YSGG laser to dental tissue with a water spray almost completely eliminates friction-induced heat generation, keeping the temperature increase to a minimum while increasing the cutting efficiency (27). Er,Cr:YSGG is used in endodontic treatment to remove the smear layer from root canal walls because it has a limited penetration depth of 17 μm into dentin (28). Its bactericidal property is due to the instantaneous vaporization of intracellular water or bacterial dehydration. Furthermore, it has a high affinity for hydroxyapatite; water is vaporized by a photothermal effect, and the expansion of water vapor produces a photomechanical effect that can remove the smear layer on the dentin surface and also fragment intratubular bacteria (29, 30). Er:Cr:YSGG lasers promote intracanal laser operation. In the recommended protocol for the Er:Cr:YSGG laser, the fiber tip is positioned 1-5 mm shorter than the working length. While moving the fiber tip in the coronal direction, a 25 mJ pulse was applied 3-4 times for each canal. The procedure is repeated first with water, then with the preferred irrigant, and applied three times per canal for each irrigant (31). Compared to irrigation with EDTA, Er,Cr:YSGG laser irrigation consistently provides superior smear layer removal efficacy. The Er,Cr:YSGG laser has been shown to be more effective than the diode laser in eliminating bacteria (30). The Er,Cr:YSGG laser can be used as an effective alternative to the traditional ultrasonic method when removing posts from teeth that have undergone endodontic treatment. Lasers have the potential to provide conservative post-removal treatment (32).

2.6. Erbium-doped yttrium aluminum garnet (Er:YAG) laser

Erbium lasers have been introduced in dentistry because their radiation is easily absorbed by water and effectively prepares tissue by creating micro-explosions in hard tissue through the sudden vaporization of water within the tissue (33). The Er:YAG (2940 nm) laser is absorbed by water at a much higher rate than the CO_2, and Nd:YAG lasers (34). This property promotes the formation of strong photoacoustic flow and cavitation effects when the laser interacts with irrigation solutions within the root canal system, creating shock waves powerful enough to penetrate areas that are difficult to reach with standard methods (35). As a result, Er:YAG laser-activated irrigation may support bacterial reduction, enhance smear layer removal, and improve dentin tubule penetration (36). It has been demonstrated that activation with the Er:YAG laser facilitates sealer penetration better than Nd:YAG and provides improved debris and smear layer removal (37).

Due to their shorter penetration depth, built-in cooling systems, and high water absorption, they typically generate less heat than other laser systems (e.g., diode and Nd:YAG lasers) (38). This low thermal effect on the dentin surface reduces the risk of structural damage or deterioration of mechanical properties, making Er:YAG lasers particularly suitable for sensitive or thin-walled root canals. Early studies have also suggested potential advantages in pediatric endodontics, where the preservation of tooth structure is critical, and in regenerative or revascularization procedures aimed at promoting tissue healing within the root canal space (39).

Unlike traditional laser-activated irrigation (LAI) procedures, which require a certain amount of canal enlargement to ensure the laser tip reaches the apical portion of the root, the PIPS and SWEEPS techniques only require placement of the tip in the coronal reservoir of the pulp chamber. This allows for minimally invasive endodontic preparation (Fig. 2) (40).

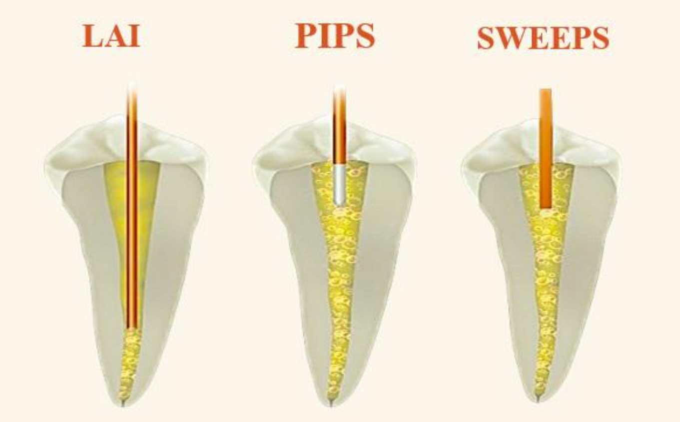

Figure 2. LAI (laser-activated irrigation); PIPS (photon-induced photoacoustic streaming); SWEEPS (shock wave enhanced emission photoacoustic streaming). Figure revised (41).

LAI is produced using pulsed erbium lasers. The root canal irrigant was activated using pulsed lasers. In this case, after shaping, the canals are filled with an irrigant, and pulsed laser irradiation is applied to the irrigant to promote its penetration into the canal system and enhance its cleaning and disinfecting effect. The duration of each laser pulse is in the microsecond range and typically varies between 25 and 250 microseconds. The pulse frequency used in LAI is set to 10 to 20 pulses per second; which means that 10-20 extremely short laser pulses are emitted per second (31).

Photon-Induced Photoacoustic Stream (PIPS, (LightWalker AT; Fotona, Ljubljana, Slovenia) and Shock Wave Enhanced Emission Photoacoustic Stream (SWEEPS) have emerged as promising techniques for improving root canal disinfection. Both improve the removal of the smear layer and disruption of biofilm (38, 39).

PIPS relies on the high absorption of the Er:YAG laser wavelength by water-based irrigants that fill the pulp chamber. When struck in a wet environment, the irrigants are heated beyond the local and instantaneous boiling points. In the PIPS technique, a conical laser tip is placed in the pulp chamber and operated at low pulse energies of 10-20 mJ for 50 μs. The conical tip produces larger cavitation bubbles than flat tips, generating more mechanical energy (Fig. 3). After each pulse, a vapor bubble begins to form at the tip of the fiber. Once this vapor bubble reaches its maximum volume, it collapses, followed by the cavitation effect. This phenomenon produces turbulent photoacoustic agitation of irrigants that flow three-dimensionally throughout the root canal system, leading to effective removal of the smear layer (42, 43). PIPS has surpassed ultrasonic and syringe irrigation by producing stronger shock-wave-like effects (44). PIPS has also demonstrated improved antibacterial outcomes with less postoperative discomfort and complete eradication of Enterococcus faecalis in primary teeth (45, 46).

Figure 3. Representative conical and straight fiber tips.

SWEEPS is a newer Er:YAG laser model introduced to enhance the cleaning and disinfection effectiveness of the PIPS technique. This method relies on the emission of several successive laser pulses, with the second laser pulse applied to the liquid at an optimal delay time during the final stage of collapse of the bubble created by the first laser pulse. The timing of the second bubble is crucial, as the SWEEPS effect does not occur if the second bubble is delivered too early or too late. Experiments have determined that the optimal delay between the two laser pulses is when the second bubble begins to develop near the end of the collapse of the first bubble. This accelerates the collapse of laser-generated bubbles and generates powerful shock waves in narrow root canals (47). Even at lower concentrations, sodium hypochlorite maintained its disinfection efficacy when activated by SWEEPS (31, 44).

Deeb et al. used an endodontic-tipped Er:YAG laser in SWEEPS mode to remove fiber posts in vitro and found that the Er:YAG laser could effectively remove them. Meanwhile, they found that the temperature increases and microcracks caused by lasers were less than those caused by ultrasonic devices. Additionally, the removal rate achieved using lasers was five times faster than that achieved using ultrasonic devices (48).

Er:YAG laser technology has consistently demonstrated superior root canal disinfection compared to traditional methods, particularly with PIPS and SWEEPS. achieving up to 91.03% bacterial reduction and effectively removing biofilms from complex canal regions (49).

In a randomized controlled trial examining postoperative pain and different activation methods, LAI systems were shown to result in significantly lower postoperative pain scores than other activation methods, but no significant difference was found between PIPS and SWEEPS (50).

3. Conclusion

Laser technology in endodontic treatments offers a wide range of applications, from root canal disinfection to smear layer removal, from apexogenesis and dentinogenesis support to fiber post removal, providing significant advantages over traditional methods. Laser systems with different wavelengths and mechanisms of action support both bacterial elimination and tissue-friendly treatment processes. Today, advanced laser-activated irrigation techniques, such as PIPS and SWEEPS, contribute to minimally invasive approaches and increase clinical success. Current findings regarding the role of laser technology in endodontics are promising, and large-scale clinical studies should strengthen the evidence regarding the long-term efficacy and safety of this technology and explore its new areas of application.

Disclosures

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