folia medica

Folia Medica 67(5)
DOI: 10.3897/folmed.67.e153378

Review

The role of laser technology in modern endodontics: a literature review

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Received: 19 March 2025 ♦ **Accepted:** 20 May 2025 ♦ **Published:** 22 October 2025

Citation: Zaneva-Hristova D, Borisova T, Svetlozarova S, Kirova M, Valkov B. The role of laser technology in modern endodontics: a literature review. Folia Med (Plovdiv) 2025;67(5):e153378. doi: 10.3897/folmed.67.e153378.

Abstract

Introduction: Primary endodontic treatment and retreatment involves a number of stages and materials which are all crucial for the final result. Irrigation and the reduction of the microbial count in the root canal system represent a critical phase of the treatment process, contributing significantly to the overall success of the procedure. It was found that conventional methods and irrigants do not show satisfactory results. For this reason, different lasers are entering endodontics to combine with traditionally accepted materials.

Aim: This literature review aims to examine the various aspects of laser applications in endodontics and their clinical significance.

Materials and methods: In this literature review, related articles and publications are reviewed and research findings on the topic are summarized.

Results: Review of all included articles and publications indicates that most types of lasers can be used in the course of endodontic treatment. Lasers are also used to remove pins, fractured instruments and old root canal filling.

Conclusion: In this review, we have provided an overview of the emerging applications of lasers in endodontics and various common dental procedures, highlighting laser-based therapy as a promising approach in dental treatment.

Keywords

diode laser, Er:YAG laser, irrigation, LAI, lasers, Nd:YAG laser, PDT, PIPS

Introduction

A laser is a type of quantum-optical device that uses the phenomenon of stimulated emission of radiation to produce a monochromatic, coherent, and collimated beam of light with a high spectral brightness.[1]

Since its introduction in the 1960s, laser technology has been widely used in a variety of medical specialties, including general surgery, ophthalmology, and dermatology.[2]

The rapid advancement of laser technology has the potential to usher in a new era in the diagnosis, prevention, and treatment of various diseases. Increasingly, focus is being placed on the application and future potential of laser technology in the field of dentistry.

Laser therapy has quickly advanced to become a leading technology in maxillofacial surgery, implantology, periodontics, and endodontics, playing an important role in modern dental treatment. Due to the limitations of some of the traditional materials and protocols used in endodontics, it has been necessary to seek alternatives. As a result, lasers are becoming more widely used in endodontics. They have a number of advantages over conventional materials.[3] The integration of lasers into endodontic practice and research has seen a substantial rise in recent years.[4]

Lasers have become widely used in dental offices due to their numerous undeniable benefits, including powerful hemostatic action, the absence of bacterial contamination, postoperative reduction of patients' inflammation, and a significant decrease in their pain level.[2]

The laser beam in dental applications is delivered through handpieces that are designed to resemble contra-angle handpieces. These handpieces allow dentists to reach even the most difficult areas of the oral cavity and can be adjusted for adequate and adjustable water jets. Dental lasers provide a menu with a selection of programs in which the manufacturer has pre-entered the parameters required for the specific manipulation. Setting up the parameters the dentist needs for a particular case allows for the creation of new programs.[5]

The unique and intricate anatomy of the root canal system, as well as the characteristics of endodontic infection, which is based on a diverse polymicrobial flora, are the two main factors that determine the obstacles that endodontic therapy presents. Because microorganisms can penetrate as deep as 200 μm into the dentinal tubules, sterilizing the endodontic system can be challenging. Research has shown that following medical and chemical therapy for the root canal, the number of germs decreased by about 70%.

Lasers have proven a positive effect on lowering the bacteria count in the root canal system, which is one of the primary tasks and goals in routine endodontic therapy. Lasers are effective even in hard-to-reach regions where conventional irrigation methods would fail. They also perform well in reducing postoperative sensitivity, which has been observed in the treatment of deep cavities and root canals.[6]

All of this shows that lasers can help improve clinical outcomes when used properly. In recent years, lasers have also been applied to other clinical settings, including the extraction of fractured tools and old root canal posts and fillings.

However, there are drawbacks to lasers in addition to their benefits. Laser devices are an expensive investment that not every dentist can afford. It is necessary to know the specifications of each laser and to be able to correctly select the laser according to the individual clinical situation. Inappropriate laser parameters can cause adverse effects such as thermal damage to periradicular tissues, perforations, and over-instrumentation, jeopardizing the success of endodontic treatment.[7-9] For these reasons, a tailored laser approach is required for various clinical situations.

Since the late 1970s, endodontics has employed a variety of laser devices. Conflicting findings have come from a number of studies on the potential use of lasers for irrigation in endodontic treatment. Regarding the use of laser energy in the root canal, there exist some uncertainties and unsolved issues. How effective at disinfection the different laser systems are in comparison to traditional irrigants.[10]

According to a position statement by the American Association of Endodontists, laser-based root canal disinfection shows greater potential compared to traditional instrumentation and shaping techniques.[4]

Aim

The purpose of this literature review was to analyze the many aspects of endodontic laser applications and the therapeutic relevance of each.

Materials and methods

A series of articles, publications, and results of various studies from renowned international journals published by foreign and Bulgarian authors are summarized in order to provide an overview of the application and limitation of lasers in endodontics, as well as their advantages and disadvantages. The main databases used for the search were PubMed and ScienceDirect with the following keywords: diode laser, Er:YAG laser, irrigation, LAI, lasers, Nd:YAG laser, PDT, PIPS.

Results

According to their physical properties, lasers are classified into three categories. The first category comprises solid-state lasers. This group of lasers includes the Nd:YAG, Er:YAG, and Er,Cr:YSGG lasers. Another major class of lasers includes the carbon dioxide (CO_2) lasers. The third category comprises diode lasers, which emit wavelengths within the visible spectrum.

In therapeutic dentistry, lasers have a number of applications: in dentine hypersensitivity, in treatments aimed at preserving the vitality of teeth, in teeth whitening, and in endodontic surgery. Lasers are used at all stages of endodontic treatment, including root canal access, preparation, disinfection, and obturation, as well as the removal of old fillings, pins, and fractured instruments. The lasers most commonly used in therapeutic dentistry are the Nd:YAG, diode, Er:YAG, Er,Cr:YSGG, and He:Ne lasers.

Er:YAG lasers use a wavelength of 2940 nm. They can be used for hard dental tissue preparation because their radiation is easily absorbed in water, which can lead to evaporation of water and micro-explosions that can blast off tiny particles of hard substance.[11]

The Er,Cr:YSGG lasers have a wavelength of 2780 nm. They are similar to the Er:YAG lasers, as they are both erbium-type lasers.[12]

Nd:YAG lasers have lower absorption in water with a wavelength of 1064 nm.[13]

They can be used during root canal irrigation.[14] Their ability to cut hard dental tissues is not so good.[15]

One kind of low-power-output laser is the diode laser. It is often applied at a wavelength between 810 and 980 nm when used for therapeutic purposes.[16]

Compared to the Nd:YAG laser, the diode laser can absorb more water inside the dental hard tissues, which allows it to penetrate deeper and target the germs inside the dentinal tubules.[17]

The first laser intended for use on hard dental tissues was the Er:YAG laser, which received FDA approval in 1997. When laser light interacts with tissue, it may undergo reflection, scattering, absorption, or transmission to adjacent structures. In biological tissues, absorption primarily occurs due to the presence of free water molecules, proteins, pigments, and other macromolecules. The extent of absorption is highly dependent on the wavelength of the incident laser radiation.[18] The longer the wavelength, the greater the absorption. Absorption is most significant with CO_2 lasers (860), with a wavelength of 10 600 nm, and with an Er:YAG laser (12 000), with a wavelength of 2940 nm.[19]

Application of lasers in endodontics

For vital pulp therapy

Bleeding control is important to the success of vital pulp therapy. Biological methods of treatment using lasers have been reported to have a high success rate, thanks to the efficient bleeding control, disinfection, and stimulating effects on dental pulp cells.[18]

The CO_2 laser is used in direct pulp capping because of its hemostatic properties, which allow for effective bleeding control.[20]

Er:YAG and Nd:YAG lasers exhibit significant healing potential, promoting the formation of a dentin bridge and the regeneration of reparative dentin.[21]

For trepanation of the pulp chamber

After reaching the dentin, the laser can be used to open the pulp chamber (hard tissue mode). An advantage of the Er:YAG laser for pulp chamber access is that it provides a clean operative field, removing bacterial debris and necrotic pulp tissue to obtain a cleaner pulp chamber, aiding in the identification of root canal orifices (operating mode on soft tissue).[22]

For root canal preparation

Only lasers capable of removing dentin from the root canal wall can serve as an alternative to traditional files. Wang et al. found that diode laser treatment efficiently eliminates the smear layer, resulting in less apical extrusion after obturation compared to traditionally treated root canals.[23] Nd:YAG laser treatment of dentin effectively eliminates the smear layer while facilitating its recrystallization, consequently decreasing dentin permeability.[24]

The Er:YAG laser has been demonstrated to be highly effective in the ablation and removal of hard dental tissues during root canal treatment and pulpotomy. By opening the dentinal tubules, it facilitates deeper penetration of the filling material into the canal walls, thereby enhancing the quality of the seal.[25]

For endodontic irrigation

At present, Er:YAG, Nd:YAG, Er,Cr:YSGG, CO_2, and diode lasers have been demonstrated to be effective in achieving root canal disinfection.

Enterococcus faecalis and *Porphyromonas gingivalis* are the main pathogens responsible for persistent periradicular inflammation. They have a penetration limit of 500 microns in the dentinal tubules.[26] In order for the irrigant to penetrate deeper, it is necessary to use additional equipment, such as ultrasonic activation or lasers. They are of utmost importance, as they increase the effectiveness of irrigants.[27] In addition to *E. faecalis*, lasers have also been shown to be effective in reducing *Candida albicans*.[28]

The effectiveness of alkaline NaOCl and EDTA solutions in endodontics can be significantly enhanced through agitation by ultrasonic energy or pulsed laser activation. This process induces fluid movement, facilitating improved contact between the irrigating solutions and root canal wall areas that are inaccessible to rotary instruments. Additionally, it raises the temperature of the irrigants, thereby enhancing their chemical efficacy on both soft and hard tissues.[29]

The use of a laser in the endodontic space is subject to a number of restrictions. Laser light is emitted in a linear trajectory from the tip of an optical fiber. The unidirectional nature of the laser beam poses a challenge in ensuring uniform and comprehensive treatment of the dentin surface within the root canal.[30] Moreover, root canal preparation and the removal of old canal fillings using laser technology pose a significant risk in curved root canals due to the potential for perforation.[31] Erbium lasers have the disadvantage of causing thermal damage to periapical tissues due to their large apical opening.[32] The ablative action of the lasers can cause overinstrumentation and perforations in the root canal walls. Another major disadvantage of laser treatment is the apical extrusion of the irrigation solution. Research has indicated that irrigation activated by an Er:YAG or Nd:YAP laser results in a greater extrusion of debris compared to conventional needle irrigation.[33]

Consequently, the photon-induced photoacoustic streaming tip (PIPS tip), a new erbium laser tip, was released in 2010.[34] Studies have demonstrated that the PIPS system exhibits superior efficacy in the removal of calcium hydroxide and the smear layer compared to sonic and ultrasonic systems.[35]

The Er:YAG laser equipped with PIPS technology has been shown to achieve greater tissue dissolution efficiency compared to Er,Cr:YSGG lasers.[36]

Laser-activated irrigation (LAI) utilizes photon-induced photoacoustic streaming (PIPS), delivering energy to the irrigant through low-energy pulses while causing only a minimal temperature increase. This technique has been shown to enhance the antibacterial efficacy of low-concentration sodium hypochlorite, enabling the use of safer concentrations for patients.[37]

Photon-induced photoacoustic streaming (PIPS) represents an innovative advancement within laser-activated irrigation (LAI) techniques. Additionally, this approach effectively minimizes the risk of thermal injury to both the root canal dentinal walls and surrounding periapical tissues.[38] Photoacoustic emission of a shock wave (SWEEPS) was designed to increase the efficiency and limit the drawbacks of the PIPS method.[39]

Although SWEEPS and PIPS function similarly, SWEEPS delivers pulse pairs into the liquid via a distinct mechanism.[40] Compared to the typical PIPS irrigation process, which produced a single Er:YAG pulse, SWEEPS increased the amplification of pressure waves.[41]

A significant limitation associated with laser-activated irrigation (LAI) is the heightened risk of apical extrusion. The extrusion of debris, pulp remnants, irrigants, bacteria, and bacterial by-products through the apex is known to provoke postoperative inflammation and discomfort, potentially prolonging the healing period of periapical tissues.

Coronary Laser Activated Irrigation (CLAI)

The detrimental impact of sodium hypochlorite (NaOCl) on dentin has been well-documented, with higher concentrations exacerbating its adverse effects. Specifically, a 5.25% NaOCl solution markedly decreases dentin strength compared to a 0.5% solution. This phenomenon occurs due to the enlargement of dentinal tubules and subsequent degradation of intertubular dentin.[42]

CLAI is capable of removing biofilm independent of chemical action, avoiding the risks associated with high concentrations of NaOCl. Therefore, this root canal irrigation technique ensures safety and effectiveness, contributing to new treatment strategies designed to remove the intraradicular biofilm.[43]

Because the fiber tip is positioned in the pulp chamber to guarantee pressure wave propagation within the root canal, the CLAI process is technically simpler than the traditional LAI, which involves inserting a fiber into the root canal. Nevertheless, the Er:YAG laser's agitation of the irrigant may result in irrigant extrusion from the apex, harming the apical periodontal tissue.[44]

Certain studies indicate that Nd:YAG laser therapy should not be considered as a replacement but rather as a supplementary method to conventional root canal irrigation procedures, primarily because the laser's characteristics enable an antibacterial effect extending approximately 1 mm into dentinal tissues.[45] Nevertheless, the application of Nd:YAG and carbon dioxide lasers has been associated with undesirable carbonation effects on dentin. Thus, the application of these lasers for root canal disinfection necessitates strict adherence to established protocols, aiming to limit potential adverse outcomes and mitigate thermal stress on radicular dentin.[46]

The formation of filings can reduce the bond strength of root canal obturation materials to dentin by obstructing the dentinal tubules.[47] The Nd:YAP laser has demonstrated efficacy in removing debris adhered to the dentinal walls within the root canal system.[48]

Photodynamic therapy (PDT)

Laser energy can be used alone or in conjunction with a photosensitive medication that, once bound to pathogenic microorganisms, is activated by low-energy laser light. By this mechanism, bacteria are removed from the root canal system. Propagation of the acoustic waves emitted by the low-energy pulsed laser can help to distribute disinfectant solutions more efficiently in the root canal system.[4]

Photoactivated disinfection (PAD)

Photoactivated disinfection (PAD) represents an alternative laser-based method for eliminating microorganisms within the root canal system. This technique utilizes low-power lasers, typically visible red diode lasers with an output power not exceeding 100 mW, applied for a duration of approximately 60–120 seconds. PAD functions by inducing photochemical reactions, particularly the generation of reactive oxygen species, oxygen molecules, and free radicals from photosensitizing agents, such as tolonium chloride. These reactive species effectively eradicate intracanal bacteria, including resistant strains such as *Enterococcus faecalis*. Several studies have reported up to a 98% reduction in the bacterial counts of *E. faecalis* following PAD treatment.[49]

To achieve optimal effectiveness, laser energy during PAD should be administered via a photodynamic diffuse tip, generating a cylindrical radiation pattern tailored to the geometry of the root canal system. A notable advantage of the low-energy laser levels utilized in PAD is their capacity to deliver antimicrobial effects without causing tissue damage, thereby minimizing optical risks for both clinician and patient.[50]

Photodynamic therapy (PDT) is a promising technology for reducing microbial counts in patients undergoing endodontic treatment. One of the advantages of PDT is the lack of heat in the periradicular tissues.[51] Photodynamic therapy functions primarily through photochemical mechanisms rather than thermal effects, differentiating it from numerous other laser-based techniques. However, tooth discoloration has been identified as a potential adverse consequence, particularly due to the application of methylene blue (MB) as a photosensitizing agent, which can exacerbate staining of dental tissues.[52]

Antimicrobial photodynamic therapy (APDT) involves a sequential two-step process characterized by the activation of a biocompatible photosensitizing agent through exposure to low-energy laser irradiation.[53]

Garcez et al. reported that conventional root canal therapy independently achieved a bacterial reduction of approximately 90%, while antimicrobial photodynamic therapy alone resulted in a 95% reduction. Notably, the combined application of both methods produced an even greater bacterial elimination, exceeding 98%.[54] The efficacy of antimicrobial photodynamic therapy is influenced by multiple variables, including the specific photosensitizing agent employed, its concentration, the bacterial species targeted, the characteristics of the light source, and the parameters applied during irradiation.[55]

Compared to the Nd:YAG laser, the diode laser demonstrates enhanced water absorption in hard dental tissues, allowing deeper penetration into dentinal tubules and thereby effectively targeting microorganisms residing within them.[56] Conversely, the diode laser demonstrates considerable beam divergence, leading to suboptimal optical precision. Despite this limitation, it remains effective in eradicating microorganisms within root canal systems and in reducing postoperative endodontic discomfort.[57] Research has demonstrated that diode laser-assisted root canal irrigation achieves a disinfection efficacy comparable to that obtained with conventional irrigation using a 5% sodium hypochlorite solution.[58]

For root canal obturation

The utilization of the Nd:YAG laser has been shown to effectively decrease apical extrusion. Additionally, the application of an Er:YAG laser beam at settings of 200 mJ and 4 Hz for a duration of 60 seconds enhanced the adhesion properties of epoxy-based sealers in comparison to zinc oxide-eugenol-based materials.[59]

For removing a root canal filling material

Activation of 2.5% sodium hypochlorite (NaOCl) and 17% EDTA using an Er:YAG laser substantially enhanced the efficiency of removing residual iRoot SP and gutta-percha following instrumentation with nickel-titanium (NiTi) files.[60] Furthermore, alongside the Er:YAG laser, the Nd:YAG laser has also demonstrated efficacy for ablation procedures.[61]

The Nd:YAG laser, employed at three distinct power settings (1 W, 2 W, and 3 W), successfully facilitated the removal of filling materials in over 70% of cases and enabled retrieval of fractured instruments in approximately 55% of cases.[62]

For fractured instruments removal

Two methods are available for removing fractured instruments lodged within the apical region of the root canal. The first method is by directly treating the fragment itself with the laser to melt the material. The other method is to irradiate the tooth tissue around the instrument with a laser to create a bypass, then use another instrument to remove the fractured segment. A notable limitation of the first method is the necessity of employing high-energy lasers to melt metallic instruments, which poses a risk of thermal injury to surrounding dental tissues. Although tissue fusion around the instrument requires comparatively lower energy, this technique still carries an elevated risk of perforating the canal walls, particularly when applied to curved, narrow, or delicate root canals.

For radicular posts removal

Radicular posts can be effectively removed from root canals by using an Er:YAG laser (2 W, 15 Hz, 135 mJ, 50 μs) in conjunction with an endodontic handpiece that is in the SWEEPS mode. Furthermore, the associated temperature elevation and formation of microcracks resulting from laser irradiation are notably lower compared to those observed with the use of ultrasonic instruments.[63]

For influencing postoperative pain

Recent advancements in laser technology have facilitated the development and clinical implementation of novel laser-based treatment modalities aimed at alleviating endodontic pain.[64] Results showed that photodynamic therapy significantly alleviated postoperative pain in teeth with necrotic pulp tissue.[65] Laser treatment has demonstrated effectiveness in reducing concentrations of pain-mediating substances, including substance P and inflammatory mediators such as specific prostaglandins. Concurrently, laser therapy facilitates the synthesis of immunological factors, such as lymphokines, immunoglobulins, beta-endorphins, and certain prostaglandins, thereby contributing to analgesic and anti-inflammatory effects.[66]

Conclusion

This review provided an overview of recent advancements in laser applications within endodontics and various routine dental procedures, highlighting the potential of laser-based therapy as an alternative therapeutic approach in dentistry. The purpose of this study was to analyze earlier research and assess the effectiveness of lasers in endodontics. The findings demonstrated that the application of lasers greatly enhanced root canal system disinfection, dentinal sludge removal, and sealing material penetration into the dentinal tubules. Laser treatments have distinct characteristics and inherent limitations, so dental practitioners must become thoroughly acquainted with these aspects, including the proper application of various laser modalities, in order to effectively integrate this technology into clinical practice.

Funding

The authors have no funding to report.

Competing interests

The authors have declared that no competing interests exist.

Acknowledgements

The authors have no support to report.

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