Emerging Horizons of Laser Applications in Endodontics: A Comprehensive Review

Touheed Ahmad Siddiqui, Lavina Tambe, Aaliya Sheikh, Dr. Nishat Nagaonkar, Dr. Priyanka Bawa, Dr. Vivek Hegde

M.A. Rangoonwala College of Dental Sciences and Research Center, Pune

Abstract - Lasers are increasingly used in endodontics, providing better cleaning, disinfection, and surgical precision than traditional techniques. Methods such as laser-activated irrigation, photon-induced photoacoustic streaming, and shock wave enhanced emission photoacoustic streaming improve root canal debridement and biofilm removal. Low-level laser therapy and photobiomodulation therapy also contribute to pain reduction and tissue regeneration. With continued advancements in laser wavelengths and delivery systems, lasers are expected to further enhance success in endodontic treatment.

Keywords: Endodontics, Laser therapy, Low-level laser therapy, Photobiomodulation, Photodynamic therapy, Root canal disinfection, Postoperative pain, Regenerative endodontics

I.INTRODUCTION

Endodontic Therapy

Microorganisms (MOs) and the byproducts they produce are key contributors to the onset and progression of pulpal and periapical disease. For endodontic therapy to be successful, these microorganisms must be thoroughly removed from the root canal system. (1)

Endodontic treatment, commonly called root canal therapy, focuses on cleaning out diseased pulp tissue, stopping infection, and protecting the tissues around the tooth's root. In cases where lesions are already present, the treatment seeks to reduce infection and encourage tissue repair. (2)

Endodontic Failure

To address the microbial burden during endodontic treatment, local antimicrobial irrigating solutions with tissue-dissolving properties—such as sodium hypochlorite (NaOCl)—are used in conjunction with mechanical instrumentation and are considered the 'gold standard' approach. The penetration of NaOCl into root dentin reaches approximately 130 µm. However, the intricate three-dimensional architecture of the root canal system restricts the depth and distribution of irrigating solutions within this complex network. (2)

Systemic antibiotics are not considered reliable for routine endodontic outcomes and should be reserved for cases involving spreading infections or medically compromised patients. Reported failure rates in the literature range from 7% to 16%, largely due to the intricate anatomy of the root canal system. When treatment fails, retreatment is often required. For this reason, additional strategies have been explored to enhance the cleaning and antimicrobial effectiveness of irrigating solutions. (2)

Lasers

LASER stands for "Light Amplification By Stimulated Emission of Radiation." Light is a form of electromagnetic energy that moves at a constant speed in wave form. Normally, light waves are noncoherent and composed of multiple wavelengths (polychromatic). When an already excited atom absorbs an additional quantum of energy, it releases two identical photons. These photons travel in phase as a coherent wave and can stimulate neighboring atoms to emit more identical photons, resulting in an amplification of light energy, which generates a laser beam.

The production of a laser beam requires an active medium made up of atoms or molecules, which may be solid, liquid, or gas, usually contained in a glass or ceramic tube. This medium is energized by an electric current or flash lamp, triggering stimulated emission of radiation. When the number of excited atoms exceeds those in the ground state, a condition called "population inversion" occurs. The photons are then guided and focused with the help of mirrors, producing a coherent, collimated laser beam that can be directed to target tissues.(3)

Various types of lasers have been explored for use in endodontics. These include near-infrared lasers—such as diode lasers (810, 940, 980, and 1,064 nm) and Nd:YAG (1,064 nm)—as well as medium-infrared lasers like Erbium, Chromium: YSGG (Er,Cr:YSGG; 2,780 nm) and Erbium:YAG (2,940 nm).

Among these, near-infrared lasers such as Nd:YAG (wavelength range 803–1,340 nm) were the first applied in root canal therapy using optical fibers. Because this wavelength is not absorbed by hard dentinal tissues, it does not produce an ablative effect on the dentin surface. Instead, the thermal action penetrates up to 1 mm into the dentinal walls, producing a decontaminating effect in deeper layers of dentin.

Medium-infrared lasers, including the Erbium family (2,780 nm and 2,940 nm), have also been introduced with the advantage of flexible and fine delivery tips. These wavelengths are strongly absorbed by the water within dentinal tissues, resulting in a superficial ablative effect along with decontamination of the canal walls.

The far-infrared CO2 laser (10,600 nm) was initially employed in endodontics for canal disinfection and apical dentin fusion during retrograde surgery. However, its use in endodontics has now been largely discontinued, except in procedures involving vital pulp therapy such as pulpotomy and pulp coagulation. (4) Classification of Lasers (10)

Laser Device	Wavelength Characteristics	Application
Er:YAG Laser 2940 nm	1. Readily taken up by hydroxyapatite crystals 2. Causes mild heating and micro-explosions due to water evaporation 3. Leads to ablation and removal of hard tissue	1. Root canal treatment 2. Pulpotomy
Er,Cr:YSGG Laser 2780 nm	1. Comparable in function to Er:YAG lasers 2. Produces minimal heat while maintaining high cutting efficiency when used with water spray	Similar to Er:YAG laser
Nd:YAG Laser 1064 nm	1. Dispersion of energy with penetration into surrounding biological tissues	1. Root canal irrigation
Nd:YAP Laser 1340 nm	1. Rapidly taken up by dark-colored substances, metals, and water 2. Delivers energy effectively within curved root canals	1. Eliminates smear layer on root canal walls
CO_2 Laser 10,600 nm	1. Rapidly absorbed by enamel and dentin 2. Promotes blood clotting (hemostasis)	1. Widely used in medicine and dentistry such as direct pulp capping
Diode Laser 810–980 nm	1. Deep tissue penetration 2. Targets microorganisms within dentinal tubules	1. Eliminates microorganisms in root canals 2. Reduces post-operative endodontic pain

Lasers In Root Canal Treatment (4,6)

- Caries management.
- Vital Pulp Therapy
- Access cavity preparation.
- Root canal wall preparation.
- Sterilization or disinfection of infected canals.
- Obturation with gutta percha or resin.
- Removal of temporary cavity sealing materials, root canal sealing materials, and fractured instruments in root canals.

I Application of Lasers for Caries Management

Dental caries is the localized breakdown of hard dental tissues caused by acids produced during bacterial fermentation of free sugars. Lasers provide a precise and minimally invasive approach for managing caries. By altering the chemical composition or solubility of dental tissues, lasers can modify tooth structure in a way that helps prevent caries formation. For preventive purposes, however, the laser energy must be effectively absorbed and converted without harming adjacent or underlying tissues.

The Erbium family of lasers, including Er:YAG and Er,Cr:YSGG (2780 nm), are particularly suited for hard tissue ablation because of their strong affinity for water. Since carious dentin contains more water than healthy tissue, these lasers can be set to an ablation threshold that allows selective removal of only the decayed portion while preserving intact tooth structure. This conservative approach maintains the tooth's strength and reduces the extent of restorative intervention.

In addition, Erbium lasers disinfect the treated site, lowering the risk of reinfection and recurrent caries. Their ability to act on both hard and soft tissues also makes them useful for exposing subgingival cavity margins, enhancing cavity preparation. A newer option, the short-pulsed CO2 laser (9300 nm), is available in the dental market—though not yet globally distributed—and has demonstrated efficient ablation along with the creation of smooth cavity margins.(6)

II Treatment of Vital Pulpal Tissue Pulp Capping

The pulsed Nd:YAG laser is applied in combination with black ink placed on the tooth surface, and air spray cooling is required to prevent thermal injury to the pulp from laser energy. CO2 laser irradiation is typically carried out at 1–2 W following irrigation with sodium hypochlorite and hydrogen peroxide solutions for at least five minutes. After laser application, calcium hydroxide paste should be placed as a dressing on the exposed pulp. (4)

Vital Pulp Amputation

The lasers commonly employed include CO2, pulsed Nd:YAG, He-Ne, low-power semiconductor diode lasers, and medium-power semiconductor diode lasers. The use of CO2 lasers is relatively time-consuming, and repeated exposures may cause damage to pulp tissue. Similarly, pulsed Nd:YAG lasers have been associated with pulpal injury and low success rates; therefore, their application should be limited to purposes such as pulp hemostasis, pain reduction, anti-inflammatory effects, and stimulation of residual pulpal cells. (4)

III Access Cavity Preparation

For access cavity preparation, root canal shaping and cleaning lasers like Er,Cr:YSGG (2780nm) and Er:YAG (2940nm) can be used. (4)

IV Root Canal Wall Preparation

Lasers including Er,Cr:YSGG (2780 nm), Er:YAG (2940 nm), and Nd:YAG (1064 nm) are utilized for the preparation of root canal walls. In cases where the laser fiber cannot be introduced into the canals, mechanical instruments such as reamers and files should be employed first, followed by laser application. (4)

V Sterilization or Disinfection of Infected Canals

Disinfection or sterilization of infected root canals can be achieved using lasers such as pulsed Nd:YAG, argon, semiconductor diode, CO2, and Er:YAG. Owing to their specific energy and wavelength properties, these lasers are effective in eliminating microorganisms. (4)

In addition, diode lasers are favored for disinfection because in vitro studies have demonstrated their strong antimicrobial effectiveness against microorganisms from the root canal system.(7)

Effective root canal disinfection is essential for treatment success, as persistent inflammation and infection may compromise regenerative outcomes. Several types of high-power lasers can be employed for this purpose, including the neodymium-doped yttrium aluminum garnet (Nd:YAG) laser (1064 nm), neodymium-doped yttrium aluminum perovskite (Nd:YAP) laser (1340 nm), various high-power diode lasers (780–980 nm), erbium-doped yttrium aluminum garnet (Er:YAG) laser (2940 nm), and erbium, chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG) laser (2780 nm).(9)

VI Laser Assisted Obturation

Because of their thermal properties, lasers such as the Nd:YAG have been explored for thermo-softening gutta-percha. However, they offer little benefit compared with the commercially available thermoplasticized gutta-percha obturation systems. The Nd:YAG laser has also been applied for trimming excess gutta-percha remaining after lateral compaction techniques. (4)

VII Removal of Temporary Cavity Sealing Materials, Root Canal Sealing Materials, and Fractured Instruments in Root Canals

Lasers have made it possible to remove temporary cavity sealers, root canal filling materials, and even fractured instruments from canals. However, in narrow or sharply curved canals, the use of laser tips has frequently led to canal wall perforations. (4)

Broken Files Removal

Separated instruments lodged in the apical region can be removed in two ways: either by directly irradiating the instrument with a laser to melt it, or by applying laser energy to the surrounding dental tissue to create a bypass that allows removal with conventional tools. Both techniques, however, present significant limitations. Melting metal instruments requires high-energy lasers, which risk causing thermal injury to adjacent tissues. Conversely, ablating the surrounding tissues requires less energy but carries a high risk of lateral perforation in curved or thin-walled canals. The Nd:YAG laser may be useful for fractured file removal, provided that temperature increases are controlled with adjunctive measures such as pressurized air and water spray.(10) Fiber Posts Removal

In clinical practice, glass fiber posts are typically removed using mechanical or ultrasonic methods. However, these approaches often lead to considerable loss of tooth structure, and the heat generated during the procedure may also damage dental tissues. More recently, lasers have been introduced for fiber post removal. Compared to ultrasonic instruments, lasers produce less temperature rise and fewer microcracks, while achieving removal up to five times faster. Studies using micro-CT have shown that the Er,Cr:YSGG laser (2.5 W, 20 Hz, MZ5 endodontic tip) can efficiently remove glass fiber posts while preserving a greater amount of healthy tooth structure. (10)

Lasers in Pain Management in Endodontics Post-operative Endodontic Pain management

Postoperative pain (POP) after root canal treatment usually lasts between 24 and 48 hours, though in some cases it may persist for up to three days. Recommended management strategies include the use of non-steroidal anti-inflammatory drugs, paracetamol, or corticosteroids. More recently, photobiomodulation therapy (PBMT) has been suggested as an effective option for pain control.(2)

Different laser-based approaches are used in endodontics to help reduce postoperative pain. These include external laser application to the root apex, as in photobiomodulation (PBM) or low-level laser therapy (LLLT); canal disinfection via photosensitizer activation with a wavelength-specific laser, as in photodynamic therapy (PDT); or direct laser use, such as Er:YAG or diode lasers, for root canal disinfection and activation of irrigating solutions.(8)

Photobiomodulation (PBM)

Photobiomodulation therapy (PBMT) involves the use of light energy at wavelengths within the optical window of 650–1350 nm to trigger biological responses through energy transfer. This non-ablative light energy influences cellular processes within the targeted tissue and, in turn, affects the broader biological system it belongs to. By modulating cellular metabolism, PBMT can alter cellular activity, producing beneficial effects such as anti-inflammatory, analgesic, and therapeutic outcomes. When the appropriate dose is applied, PBMT does not generate significant heat in the irradiated tissues. In vivo studies have demonstrated that PBMT can temporarily inhibit nerve function. Other observed effects include localized conduction block, interference with axonal transport, and selective inhibition of nociceptors. These mechanisms collectively contribute to pain relief, which is reversible and free from adverse side effects.(2)

The pulsed Nd:YAG laser is commonly employed for analgesia in endodontics. Its wavelength affects the sodium pump mechanism, modifies cell membrane permeability, temporarily alters sensory nerve endings, and inhibits depolarization of C and A nerve fibers.(4)

Photodynamic Therapy

Photodynamic therapy (PDT), also known as photo-activated disinfection (PAD), is a modern technique increasingly applied in medicine and dentistry to eliminate microorganisms and tumor cells. The method involves introducing a light-sensitive compound, called a photosensitizer (PS), into the target site and activating it with a low-intensity light of a specific wavelength range. This activation generates reactive oxygen species (ROS), which effectively destroy microorganisms while sparing healthy cells from toxicity. The success of PDT largely depends on the proper interaction between the photosensitizer and the chosen light source.(9)

II.LASERS IN DENTINAL HYPERSENSITIVITY

Low Level Laser Therapy (LLLT) for Reducing Dentin Hypersensitivity

Laser therapy offers an effective option for managing dentin hypersensitivity, a condition characterized by short, sharp pain in exposed dentin triggered by external stimuli. While various desensitizing agents are traditionally used, low-level laser (LLL) irradiation directed at the cervical and apical regions of sensitive teeth has proven to be a reliable approach. The effectiveness of this treatment is largely attributed to its influence on pulpal nerve activity. At the cellular level, the laser acts by interfering with the transmission of pain signals from peripheral nerves to central pathways and by blocking depolarization in sensory C fibers.(5)

Lasers in Endodontic Surgeries

Soft tissue lasers such as Nd:YAG, diode, and CO2 can be used to create precise incisions, providing direct access to the periradicular area. Additionally, replacing aerosol-generating handpieces with lasers during periapical surgery helps lower the risk of contamination from blood-borne pathogens. Hard tissue lasers like Er:YAG and Er,Cr:YSGG are suitable for bone cutting, sectioning of the apical third during apicoectomy, and have also been investigated for retrograde preparation. The distinct advantages of laser light in endodontic surgery include high precision, hemostasis, reduced postoperative pain and swelling, minimized scarring, sterilization, and selective absorption.(4)

Future Directions for the Use of Lasers In Endodontics

Laser-Activated Irrigation: Laser-activated irrigation (LAI) is performed using erbium family lasers, which act primarily through photoablation. In this process, the water content of dental tissues is converted to steam, causing micro-explosions that fracture portions of the tooth structure. During LAI, laser energy is transmitted to the irrigant via specialized fiber tips, including lateral-emission tips. The resulting vapor bubbles collapse, producing secondary cavitation effects and generating rapid movement of the irrigant within the canal. Thus, erbium lasers aid in canal cleaning through two main mechanisms: increasing irrigant flow velocity and exerting physical forces on canal walls that help disrupt biofilms. However, the antibacterial action of erbium lasers is limited to areas adjacent to the canal lumen(9)

Photon-induced photoacoustic streaming (PIPS): Photon-induced photoacoustic streaming (PIPS) is an advanced form of laser-activated irrigation that has shown promising results in eliminating biofilms and removing the smear layer. This method relies on the photomechanical effects of erbium lasers at low energy settings to generate cavitation and acoustic streaming within intracanal fluids. Unlike earlier techniques, PIPS places the laser tip in the coronal portion of the root canal, reducing the risk of damage to canal walls and periapical tissues while enhancing the efficiency of canal wall cleaning compared to conventional approaches. (9)

The Shock Wave Enhanced Emission Photoacoustic Streaming (SWEEPS): The SWEEPS technique has been recently introduced for the Er:YAG laser to enhance root canal cleaning and disinfection in endodontics. Unlike the PIPS mode, which delivers a single 50 µs super-short pulse, SWEEPS employs double pulses of 25 µs each. The reduced pulse duration results in twice the peak power at the same energy, producing a more powerful bubble collapse. Furthermore, the second pulse is released at an optimal moment—when the first bubble is close to completing its collapse—thereby maximizing the effect. These sequential pulses generate shock waves, intensify fluid dynamics, and increase photoacoustic streaming, ultimately leading to more effective canal cleansing and disinfection. (9)

III.REGENERATIVE ENDODONTIC TREATMENT

Regenerative endodontic treatment (RET) generally consists of two clinical phases. The first phase involves disinfecting the root canal and sealing the tooth temporarily for a period of 1 to 4 weeks. During this stage, both high-power and low-power lasers, particularly through photodynamic therapy (PDT), may be used to eliminate microorganisms. (9)

The second phase of regenerative endodontic treatment (RET) relies on the presence of adult stem cells within the tooth and oral tissues, including stem cells of the apical papilla, dental pulp stem cells, stem cells from exfoliated deciduous teeth, periodontal ligament stem cells, and bone marrow stem cells. A scaffold (matrix) is introduced to support these cells, either by creating a blood clot through intentional over-instrumentation or by introducing platelet-rich plasma (PRP) or platelet-rich fibrin (PRF) into the canal. The scaffold plays a vital role by directing cell alignment, organization, and proliferation while facilitating nutrient and gas exchange. Equally important for root regeneration are growth factors—signaling proteins that regulate cell division, differentiation, and maturation. Dentin is recognized as a major natural reservoir of these signaling proteins. (9)

The second stage of regenerative endodontic treatment (RET) follows the principles of tissue engineering, which involve the triad of dental stem cells, scaffolds, and growth factors. These components can be further stimulated by the application of low-power lasers (also known as cold or soft lasers) to improve regenerative outcomes. This approach, termed low-level laser therapy (LLLT), low-power laser therapy, or photobiomodulation therapy (PBMT), uses energy from low-intensity, non-ionizing light sources—such as lasers or light-emitting diodes—within the visible and near-infrared spectrum (600–1000 nm). Absorption of this energy induces photochemical changes, leading to modifications at molecular, cellular, and tissue levels. Research has shown that LLLT can improve cellular activity and ATP production, reduce pain, alleviate inflammation, and accelerate healing. Various lasers, including GaAlAs, GaAlInP, GaAs, and helium-neon lasers, are used for LLLT. By enhancing blood supply and stimulating seeded stem cells, LLLT is often considered a fourth element of tissue engineering. Moreover, it may activate growth factors, thereby promoting cell proliferation and differentiation. (9)

IV.CONCLUSION

Lasers have introduced new possibilities in endodontics by improving disinfection, facilitating smear layer removal, enhancing surgical precision, and supporting regenerative approaches. While they offer significant advantages over conventional methods, lasers should currently be considered as valuable adjuncts rather than complete replacements for traditional instrumentation and irrigation. With ongoing technological advancements and further clinical validation, lasers are expected to play an increasingly important role in achieving safer, more predictable, and more effective endodontic treatment outcomes.

REFERENCES

[1] Ioana Roxana Bordea and Reem Hanna and Nasim Chiniforush and Elena GrÄƒdinaru and Radu Septimiu CÃ¢mpian and Adina Sãrbu and Andrea Amaroli and Stefano Benedicenti. Evaluation of the outcome of various laser therapy applications in root canal disinfection: A systematic review, Photodiagnosis and Photodynamic Therapy, Volume 29, pages 101611, 2020, issn 1572-1000

[2] Anagnostaki, Eugenia, Valina Mylona, Steven Parker, Edward Lynch, and Martin Grootveld. 2020. "Systematic Review on the Role of Lasers in Endodontic Therapy: Valuable Adjunct Treatment?" Dentistry Journal 8, no. 3: 6

[3] https://doi.org/10.3390/dj8030063

[4] Gopikrishna V, editor. Grossman's Endodontic Practice. 14th ed. New Delhi: Wolters Kluwer; 2021.

[5] Pandit, V. S., Ingale, V. P., Chavan, S., Deshpande, Y. D., Sharma, A. S., & Jadhav, A. B. (2022). Lasersin endodontics review. International Journal of Health Sciences, 6(S6), 10574–10583

[6] Mankar N, Burde K, Agrawal P, et al. (October 30,

2023) Application of Low-Level Laser Therapy in Endodontics: A Narrative Review. Cureus15(10): e48010. DOI 10.7759/cureus.48010

[7] Usta, S.N., Betancourt, P., Ceylan, A. et al. The cutting-edge roles of lasers in endodontics: A bibliometric and scientometric analysis of the 100 most-cited articles. Lasers Med Sci 39, 219 (2024).

[8] Elmsmari, F., Shujaie, H., Alzaabi, R. et al. Lasers efficacy in pain management after primary and secondary endodontic treatment: a systematic review and meta-analysis of randomized clinical trials. Sci Rep 14, 26028 (2024). https://doi.org/10.1038/s41598-024-74998-x

[9] Ahrari F, Akhondian S, Shakiba R, Tolouei A, Salehi A, Valizadeh M, Hosseini K. Laser Applications in Regenerative Endodontics: A Review. J Lasers Med Sci. 2024 Feb 4;15:e1. doi: 10.34172/jlms.2024.01. PMID: 38655047; PMCID: PMC11033860

[10] Huang Q, Li Z, Lyu P, Zhou X, Fan Y. Current Applications and Future Directions of Lasers in Endodontics: A Narrative Review. Bioengineering (Basel). 2023 Feb 26;10(3):296. doi:10.3390/bioengineering10030296. PMID: 36978686; PMCID: PMC10044917.