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Lasers as a Therapeutic Tool in Endodontics: Mechanisms, Clinical Applications, and Current Evidence — A Comprehensive Review

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ABSTRACT:

Successful endodontic therapy depends on effective microbial elimination from the complex root canal system and prevention of reinfection. Despite advancements in chemomechanical preparation, conventional instrumentation and irrigation techniques exhibit limitations in accessing intricate canal anatomy and achieving complete disinfection. In recent years, laser technology has emerged as a promising adjunctive tool in endodontics due to its unique photothermal, photochemical, and photoacoustic properties.

This narrative review evaluates the mechanisms of action, therapeutic applications, advantages, and limitations of commonly used laser systems in endodontics, including diode, Nd:YAG, Er:YAG, Er,Cr:YSGG, and CO_2 lasers. Applications discussed include root canal disinfection, smear layer removal, laser-activated irrigation, photodynamic therapy, vital pulp therapy, postoperative pain control, and enhancement of periapical healing. Evidence suggests that erbium-based lasers are particularly effective for irrigant activation and smear layer removal, whereas diode and Nd:YAG lasers demonstrate deeper dentinal penetration and enhanced antimicrobial effects. Low-level laser therapy has shown potential in modulating inflammation and reducing postoperative discomfort.

Although encouraging results have been reported, variability in clinical protocols, concerns regarding thermal safety, and the absence of standardized guidelines limit widespread adoption. Current evidence supports the role of lasers as adjunctive modalities that enhance conventional endodontic procedures rather than replace them. Further well-designed clinical trials are required to establish standardized protocols and long-term clinical outcomes.

1. Introduction:

Successful endodontic therapy is fundamentally dependent on the effective elimination of microorganisms from the complex root canal system and the prevention of reinfection.(1,2) Despite significant advancements in instruments, materials, and techniques, persistent microbial infection remains the primary cause of endodontic failure. Traditional chemo-mechanical preparation relies on hand or rotary instruments in combination with irrigating solutions such as sodium hypochlorite and ethylenediaminetetraacetic acid (EDTA). While these methods are indispensable, they exhibit inherent limitations. Mechanical instruments are unable to contact all areas of the canal walls, and irrigants demonstrate restricted penetration into dentinal tubules and inaccessible anatomical regions.(3,4) Additionally, concerns regarding irrigant extrusion, cytotoxicity, and incomplete smear layer removal continue to challenge predictable disinfection outcomes.

To overcome these limitations, adjunctive technologies have been explored to enhance the efficacy of root canal treatment. Among these, laser technology has emerged as a promising therapeutic tool in modern endodontics.(5) Lasers offer unique physical and biological properties, including high energy concentration, wavelength-specific tissue interaction,

and the ability to induce photothermal, photochemical, and photoacoustic effects.(6) These properties enable lasers to interact with both hard and soft tissues in a controlled manner, making them suitable for various endodontic applications.

Over the past two decades, different types of lasers—such as diode, neodymium-doped yttrium aluminum garnet (Nd:YAG), erbium-doped yttrium aluminum garnet (Er:YAG), and erbium, chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG)—have been investigated for use in endodontic therapy. Their applications extend beyond root canal disinfection to include smear layer removal, laser-activated irrigation, photodynamic therapy, vital pulp therapy, postoperative pain reduction, and enhancement of periapical healing.(7) Low-level laser therapy (LLLT), in particular, has gained attention for its biostimulatory and anti-inflammatory effects, contributing to improved patient comfort and tissue healing.(8)

Laser-activated irrigation techniques, such as photon-induced photoacoustic streaming, have further expanded the therapeutic potential of lasers in endodontics. By generating cavitation and acoustic streaming within irrigating solutions, these techniques enhance irrigant penetration and debris removal from complex canal systems without the need for deep tip insertion.(9) Such advancements highlight the evolving role of lasers as adjuncts rather than replacements for conventional endodontic procedures.

Despite encouraging laboratory and clinical findings, the routine clinical use of lasers in endodontics remains a topic of debate. Variations in laser types, power settings, application protocols, and outcome measures have resulted in heterogeneous evidence. Concerns related to thermal damage to periodontal tissues, cost, technique sensitivity, and the absence of standardized clinical guidelines further necessitate a cautious and evidence-based approach to laser implementation in endodontic practice.(10)

Given the growing body of literature and increasing clinical interest, a comprehensive evaluation of lasers as a therapeutic tool in endodontics is warranted. This narrative review aims to assess the mechanisms of action of commonly used dental lasers, their therapeutic applications in endodontic procedures—particularly in root canal disinfection and biological healing—their advantages and limitations, and their clinical implications based on current evidence.

Laser Basics & Mechanisms

Lasers are devices that generate a focused beam of light through the process of light amplification by stimulated emission of radiation. The emitted laser light is characterized by unique properties such as monochromaticity, coherence, and collimation, which distinguish it from conventional light sources. These properties allow laser energy to be delivered precisely to target tissues, making lasers suitable for a wide range of diagnostic and therapeutic applications in dentistry, including endodontics.

The clinical behaviour of a laser is primarily determined by its wavelength, which governs how the laser energy interacts with biological tissues. Laser–tissue interaction occurs when the emitted light is absorbed, reflected, transmitted, or scattered by the target tissue.(11) In endodontics, absorption is the most clinically relevant interaction, as it determines the therapeutic effects produced within dentin, pulp tissue, microorganisms, and irrigating solutions.(12) Different tissues exhibit varying absorption characteristics based on their water content, pigmentation, and mineral composition, emphasizing the importance of wavelength selection in laser-assisted procedures.

Several mechanisms of laser–tissue interaction are relevant to endodontic therapy. Photothermal effects occur when absorbed laser energy is converted into heat, leading to temperature elevation within the tissue. This effect is responsible for the bactericidal action of certain lasers, as elevated temperatures can disrupt bacterial cell walls and denature proteins and serves various other purposes incision, excision, ablation, vaporization, hemostasis, and coagulation.(13) Adjustments in the Laser setting can generate different photothermal interactions: Maintaining a smaller spot size aids in incision/excision, enlarging the spot size allows ablation by letting the laser interact with a broader area of tissue, while haemostasis and/or coagulation happens if the laser beam is positioned out of focus.

Photochemical effects, particularly in photodynamic therapy, involve the activation of a photosensitizing agent by laser light, resulting in the production of reactive oxygen species that exert antimicrobial

effects.(14) Photoacoustic and photomechanical effects are observed when laser energy interacts with irrigating solutions, generating shock waves and cavitation bubbles that enhance fluid movement and debris removal within the root canal system.(15)

The depth of laser penetration into dental tissues varies according to the wavelength and tissue composition. Lasers with shorter wavelengths and high affinity for water, such as erbium lasers, exhibit superficial penetration and are effective for hard tissue interaction and smear layer removal. In contrast, lasers with longer wavelengths, such as diode and neodymium-doped yttrium aluminium garnet (Nd:YAG) lasers, demonstrate deeper penetration into dentinal tubules, making them suitable for intracanal disinfection and bacterial reduction.(16,17) Understanding these penetration characteristics is critical to optimizing clinical outcomes while minimizing the risk of thermal injury to surrounding periodontal tissues.

In addition to their antimicrobial potential, lasers have been shown to exert biological effects on host tissues. Low-level laser therapy operates at sub-ablative energy levels and induces cellular responses without causing thermal damage. These responses include enhanced mitochondrial activity, increased adenosine triphosphate production, modulation of inflammatory mediators, and stimulation of tissue repair processes. Such biostimulatory effects form the basis for the use of lasers in postoperative pain control, pulp therapy, and the promotion of periapical healing in endodontic practice.(18)

From a clinical perspective, the therapeutic efficacy and safety of lasers depend on multiple parameters, including power output, pulse duration, energy density, mode of emission, and exposure time. Inappropriate settings may result in excessive heat generation and undesirable tissue damage, underscoring the need for adequate training and adherence to evidence-based protocols.(19) When used judiciously and as an adjunct to conventional chemo-mechanical preparation, lasers offer a versatile therapeutic modality that complements existing endodontic techniques.

Types of Lasers Used in Endodontics

Several laser systems have been investigated and applied in endodontic therapy, each characterized by a specific wavelength that determines its interaction with dental tissues, microorganisms, and irrigating solutions. The choice of laser depends on the intended therapeutic application, including disinfection, smear layer removal, irrigation activation, and biostimulation.

Diode Lasers

Diode lasers operate in the near-infrared spectrum, typically between 810 and 980 nm. These lasers demonstrate relatively deep penetration into dentinal tubules due to low absorption by water and hydroxyapatite. As a result, diode lasers are commonly used for intracanal disinfection, where their photothermal effects contribute to significant bacterial reduction, including microorganisms located deep within dentinal tubules.(20) Additionally, diode lasers are frequently employed in low-level laser therapy for postoperative pain control and enhancement of tissue healing.(21) Their compact size, ease of use, and cost-effectiveness make them one of the most widely adopted laser systems in endodontic practice.

Neodymium-Doped Yttrium Aluminum Garnet (Nd:YAG) Lasers

Nd:YAG lasers emit light at a wavelength of 1064 nm and are characterized by deep tissue penetration and strong affinity for pigmented tissues. These properties contribute to their pronounced bactericidal effects, particularly against resistant microorganisms such as *Enterococcus faecalis*.(22) Nd:YAG lasers have been studied extensively for root canal disinfection and dentinal tubule sterilization.(23) However, due to their potential for heat generation, careful control of power settings and irradiation protocols is essential to minimize the risk of thermal damage to periodontal tissues.

Erbium-Doped Yttrium Aluminum Garnet (Er:YAG) Lasers

Er:YAG lasers operate at a wavelength of 2940 nm and exhibit high absorption in water and hydroxyapatite. This makes them particularly effective for hard tissue applications, including smear layer removal and dentin modification.(24) In endodontics, Er:YAG lasers are commonly used in laser-activated irrigation techniques, where their interaction with irrigating solutions generates photoacoustic effects that enhance canal cleanliness. These lasers are widely used in laser-activated irrigation protocols such as photon-induced photoacoustic

streaming and shock wave-enhanced emission photoacoustic streaming. Due to their superficial penetration, erbium lasers offer effective cleaning with minimal thermal risk when used appropriately.(25)

Erbium, Chromium-Doped Yttrium Scandium Gallium Garnet (Er,Cr:YSGG) Lasers

Er,Cr:YSGG lasers emit light at a wavelength of 2780 nm and share similar properties with Er:YAG lasers, including strong absorption by water.(26) When Er,Cr:YSGG laser radiation is combined with water spray, frictional heat generation is reduced and cutting efficiency increases, resulting in a low temperature increase on tooth tissue.(27,28)

Carbon Dioxide (CO_2) Lasers

CO_2 lasers emit light at a wavelength of 10,600 nm and demonstrate strong absorption by water, resulting in superficial tissue interaction. Certain morphological changes, such as carbonization, hemocoagulation, and protein denaturation in the target tissue, are brought about by CO_2 laser energy, which also causes the water to evaporate.(29) This property of hemocoagulation makes CO_2 Laser suitable for use in direct pulp capping procedures.(30) Although their use in endodontics is limited, CO_2 lasers have been investigated for surface sterilization and soft tissue procedures related to endodontic surgery. Their role in conventional root canal therapy remains minimal due to limited penetration and risk of excessive surface heating.

Therapeutic Applications

Vital Pulp Therapy

Following injury from trauma, caries, or restorative operations, vital pulp therapy (VPT) approaches are used to maintain the vitality and function of the pulp within the tooth. Advances in the understanding of pulpal biology have reshaped contemporary concepts of vital pulp therapy. Evidence now suggests that the dental pulp possesses a greater capacity to tolerate and respond to microbial insults arising from deep carious lesions than was previously believed.

As caries progresses and dentin undergoes demineralization, the pulpo-dentinal complex releases a variety of biologically active signaling molecules, including transforming growth factor-β, adrenomedullin, and insulin-like growth factors. These mediators contribute to favorable pulpal outcomes by stimulating cellular events associated with tissue repair and regeneration.(31) As a result, clinical conditions once routinely diagnosed as irreversible may still have the potential for recovery when managed using biologically sound treatment strategies, thereby challenging traditional boundaries between reversible and irreversible pulpal disease.

Recently, laser-based interventions have emerged as a biologically oriented, non-drug alternative for vital pulp therapy. Despite the availability of multiple materials and clinical techniques for VPT, variability in treatment outcomes continues to raise questions regarding long-term success. Subsequently, lasers have been investigated as an adjunctive modality in VPT due to their ability to reduce microbial load, enhance cellular activity, achieve effective hemostasis, and support tissue repair and healing.

The use of laser energy on exposed pulpal tissue was initially explored with carbon dioxide lasers by Melcer et. al., primarily to stimulate reparative dentin formation. The CO_2 laser exhibits a high affinity for water, leading to rapid vaporization within the target tissue and resulting in distinct thermal alterations such as tissue carbonization, coagulation of blood components, and protein denaturation. However, histological observations from studies evaluating its use in vital pulp therapy have revealed the presence of an uneven fibrous dentin framework adjacent to areas of thermal damage, along with delayed formation of a reparative dentin bridge.(32)

A clinical and radiographic investigation assessing direct pulp capping in permanent teeth reported improved treatment outcomes when the Er:YAG laser was used in conjunction with Biodentine, with higher success rates observed compared to the use of either the laser or Biodentine alone.(33) The Er,Cr:YSGG laser demonstrates biological effects comparable to the Er:YAG laser. Nevertheless, both erbium-based laser systems exhibit inferior hemostatic performance when compared with carbon dioxide and diode lasers.

Several investigators have observed improved outcomes in direct pulp capping when Er,Cr:YSGG or Er:YAG lasers were used in combination with calcium hydroxide or TheraCal. In contrast, the adjunctive use of the same laser systems with mineral trioxide aggregate did not demonstrate any additional benefit, as comparable results

were obtained when MTA was applied without laser assistance.(28,34–36)

The Nd:YAG laser has the ability to occlude dentinal tubules, creating a sealed layer with a depth of approximately 4 µm. This characteristic has been evaluated for its potential role in minimizing or preventing discoloration associated with materials placed within the pulp chamber. Findings indicate that Nd:YAG laser irradiation can reduce the risk of discoloration when blood contamination is absent; however, it does not effectively prevent or limit discoloration when blood is present.

Despite their ability to penetrate dentinal tissues effectively, diode lasers have not demonstrated a clear clinical advantage over conventional materials such as mineral trioxide aggregate (MTA) or formocresol in primary teeth.(37,38) Additionally, diode laser application before indirect pulp capping using resin-modified glass ionomer or Biodentine did not result in a statistically significant enhancement in dentinal bridge formation.(39) When evaluated against HMG CoA reductase inhibitor (simvastatin), a newer biologically active regenerative agent, diode laser irradiation likewise failed to show superior outcomes.(40)

However, Mir et al. documented a successful management of a pulp polyp using a diode laser by employing different energy settings. A high-power diode laser was utilized for excision of the hyperplastic pulp tissue and to achieve effective hemostasis, while low-level laser therapy (LLLT) was subsequently applied to enhance tissue repair and support the healing response.(41)

Root Canal Shaping

Root canal shaping constitutes a critical phase of endodontic therapy, as it facilitates the removal of residual pulp tissue, dentinal debris, and microbial by-products while simultaneously providing sufficient space for the effective action of irrigating solutions and intracanal medicaments in disinfecting the root canal system. Moreover, an adequately prepared canal geometry is indispensable for achieving a hermetic, three-dimensional obturation.

The use of lasers for the ablation of dental hard tissues can be traced back to the 1960s, with the introduction of ruby lasers operating at a wavelength of 693.4 nm. Despite their initial promise, these early laser systems were eventually abandoned in clinical practice due to undesirable effects, including the induction of microcracks within hard tissues, surface carbonization, and excessive thermal damage.

In root canal shaping, laser action is primarily mediated by the rapid vaporization of water within dental hard tissues, leading to ablation of the surrounding dentin. Among available systems, erbium lasers exhibit high ablation efficiency and, when used within appropriate parameters, are associated with minimal thermal side effects.(42)

The introduction of fine-diameter Er:YAG laser fibers has allowed efficient dentin ablation and root canal enlargement, predominantly through photoablative processes driven by the strong absorption of laser energy by water molecules. (43) In addition, Ando et al. proposed that laser irradiation may inhibit bacterial proliferation or eradicate viable microorganisms within the treated zone through mechanisms such as explosive photoablation, micro-explosive events, and rapid vaporization, which collectively lead to mechanical disruption of bacterial cell structures. (44)

Laser-Assisted Root Canal Disinfection and Smear Layer Removal

Inadequate disinfection of the root canal system is a leading cause of persistent periapical disease and endodontic failure. The complex micro-anatomy of root canals allows microorganisms to persist within organized biofilms that are inherently resistant to conventional chemomechanical procedures. Consequently, while instrumentation mainly provides access to the apical region, effective infection control relies largely on irrigation. Owing to the limitations of syringe-and-needle irrigation, advanced activation techniques such as ultrasonic, sonic, and laser-assisted irrigation have been introduced to enhance disinfection efficacy.

Multiple laser wavelengths have been explored for root canal debridement and disinfection, including neodymium:yttrium aluminum garnet (Nd:YAG, 1064 nm), erbium:yttrium aluminum garnet (Er:YAG, 2940 nm), carbon dioxide (CO_2, 9600 and 10,600 nm), erbium, chromium:yttrium scandium gallium garnet (Er,Cr:YSGG, 2780 nm), diode lasers (635–980 nm), and potassium titanyl phosphate (KTP, 532 nm). Yavagal et.

al. reported complete eradication of *Enterococcus faecalis* from primary tooth root canals was achieved using 5.25% sodium hypochlorite gel activated by an 810-nm diode laser.(45)

Lasers, particularly diode and Nd:YAG systems, possess the ability to penetrate dentinal tubules to depths far exceeding those achieved by conventional chemical irrigants, thereby facilitating microbial reduction in areas inaccessible to mechanical instrumentation.Using a 940-nm diode laser in combination with sodium hypochlorite and EDTA irrigation, Saraswathi *et al.* demonstrated improved smear layer removal without inducing additional reduction in the mineral content of root dentin.(46)

Earlier approaches to laser-assisted root canal disinfection predominantly employed wavelengths within the visible and near-infrared spectrum, as these could be efficiently delivered through flexible, small-diameter optical fibers, enabling access to the majority of prepared root canals. Nevertheless, the inherent antimicrobial efficacy of these wavelengths was limited. In addition, challenges related to uniform energy distribution and inconsistent contact with the canal walls restricted their cleaning effectiveness, ultimately resulting in suboptimal and unpredictable disinfection outcomes.(47,48)

These limitations prompted the development of laser-activated irrigation (LAI), a technique that employs short laser pulses to energize intracanal irrigants, thereby enhancing their penetration into the complex root canal anatomy and improving both cleansing and antibacterial efficacy. Meire et al. reported that diode lasers are unsuitable for cavitation-based LAI. In contrast, erbium-based systems, including Er:YAG and Er,Cr:YSGG lasers, and to a lesser extent the Nd:YAP laser (1340 nm), were identified as appropriate for this application. Furthermore, they suggested that optimal cavitation performance is achieved when erbium lasers are equipped with conical fiber tips and operated at ultra-short pulse durations with sufficiently high pulse energy.(49)

Laser energy transmitted through optical fiber tips induces the formation of cavitation bubbles within the intracanal irrigant. The subsequent expansion, oscillation, and collapse of these bubbles generate vigorous fluid dynamics and shear forces along the canal walls. This hydrodynamic activity disrupts microbial biofilms and dislodges debris adherent to the dentinal surfaces, which is then transported coronally and evacuated from the root canal system.(50)

Photon-induced photoacoustic streaming (PIPS) is an advanced irrigant activation technique that uses an erbium laser at sub-ablative settings (20 mJ, 15 Hz) with ultra-short pulse durations (~50 µs). PIPS fiber tips are positioned coronally, unlike conventional laser-activated irrigation methods that require fiber tip to be positioned approximately 5 mm short of the apex, thereby eliminating the need for excessive apical enlargement.

Laser–irrigant interaction generates cavitation and shock waves through photoacoustic and photomechanical effects. Koch et al. demonstrated that PIPS produces fluid velocities approximately ten times greater than passive ultrasonic irrigation (PUI), with enhanced hydrodynamics observed throughout the entire root canal system up to 20 mm.(51)

Shock wave–enhanced emission photoacoustic streaming (SWEEPS) is an advanced laser-activated irrigation modality that employs temporally paired Er:YAG laser pulses. The precisely timed second pulse intensifies the collapse of the primary cavitation bubble, generating shock waves that significantly enhance irrigant dynamics within confined regions of the root canal system.

The evolution of laser-activated irrigation has thus shifted from intracanal fiber placement using flat-ended tips and higher pulse energies to coronal fiber positioning within the pulp chamber with conical tips and lower energy settings. Importantly, laser use serves as an adjunct rather than a substitute for conventional irrigation, augmenting overall canal disinfection when applied with appropriate parameters.

Photodynamic Therapy in Endodontics

Photodynamic therapy involves the activation of a photosensitizing agent by a specific wavelength of laser light, resulting in the generation of reactive oxygen species that exert antimicrobial effects. This technique has gained attention as an adjunctive disinfection strategy, particularly against antibiotic-resistant microorganisms.

Photodynamic therapy is advantageous due to its minimal thermal effects and selective microbial targeting. However, its effectiveness depends on adequate photosensitizer penetration, light activation parameters, and oxygen availability within the canal system. While promising, photodynamic therapy is currently considered an adjunct rather than a primary disinfection modality.

Post Endodontic Pain Management

Pain related to dental treatment is anticipated before the procedure, experienced intraoperatively, remembered afterward, and often shared by patients during the preoperative, operative, and postoperative phases. Pharmacological management with analgesics remains the most commonly employed approach for pain control; however, these medications are frequently associated with adverse gastrointestinal effects, hepatotoxicity and renal impairment.

Consequently, low-level laser therapy (LLLT) with laser parameters as 600–1000 nm wavelength; ≤ 500 mW output, most commonly delivered using diode lasers, has gained prominence as a noninvasive alternative. The analgesic effects of LLLT are attributed to its ability to modulate pain thresholds, reduce the release of inflammatory mediators such as bradykinin and histamine, enhance endogenous endorphin production, and alter prostaglandin synthesis.

Ismail et al. reported that low-level laser therapy (LLLT) provided superior reduction of immediate postoperative pain at 24 hours when compared with laser-activated irrigation (LAI) and the control group; however, at 48 hours, both LLLT and LAI demonstrated comparable analgesic efficacy.(52)

In contrast, Tunc et al. observed no statistically significant reduction in postoperative pain with either Nd:YAG or diode laser application in non-vital teeth. However, in vital teeth diagnosed with symptomatic irreversible pulpitis, the use of Nd:YAG laser was associated with a moderate degree of pain reduction.(53)

The analgesic effects of laser irradiation have been attributed to multiple biological mechanisms, including decreased levels of prostaglandin E_2, interleukin-1β, and tumor necrosis factor-α, along with reduced neutrophil infiltration, oxidative stress, tissue edema, and bleeding. With ongoing advances in laser technology, various laser-based modalities such as conventional laser applications, photobiomodulation therapy, and antimicrobial photodynamic therapy, have been increasingly incorporated into endodontic practice to enhance pain management.

Periapical Healing and Surgical Applications

The most common cause of failure following apicoectomy with retrograde filling is bacterial ingress resulting from microleakage, which subsequently initiates periradicular inflammation. Exposure of dentin during root-end resection facilitates leakage pathways, allowing irritants from the root canal system to diffuse into the surrounding periapical tissues.

The application of laser energy at the root apex during apicoectomy offers several clinical advantages, including enhanced hemostasis, minimal or contact-free tissue interaction, improved visibility of the surgical field, and accurate apical root-end resection. Reduced mechanical vibration during laser use contributes to decreased postoperative pain and patient discomfort, while also lowering the risk of inadvertent injury to adjacent tissues. Additionally, laser irradiation may exert a disinfecting effect on the infected apical region.

In an experimental study, surface modification of resected root ends using Er:YAG (2.94 µm) and CO_2 (9.6 µm) lasers was evaluated. The laser-treated specimens demonstrated significantly reduced permeability to methylene blue dye when compared with untreated control samples, indicating improved sealing of the dentinal surface.(54) Wong and co-workers observed no statistically significant difference in bacterial leakage when comparing root-end surfaces treated with an Nd:YAG laser to those restored with retrograde amalgam.(55)

In their assessment of endodontic surgical sites treated with adjunctive low-level laser therapy, Metin et al. demonstrated improved healing of both soft and hard tissues. Additionally, the use of LLLT was associated with reduced postoperative discomfort and enhanced patient-reported quality of life, with the most pronounced benefits observed during the early healing phase.(56)

Photobiomodulation

Photobiomodulation therapy (PBMT) refers to the use of low-energy light exposure delivered via an electromagnetic radiation source in the visible and near-infrared spectra that acts through photochemical pathways. The Arndt–Schultz principle applied to photobiomodulation states that low levels of energy stimulate physiological activity, whereas excessive energy exposure can suppress cellular responses

Low-intensity laser therapy operates within a safe energy range that does not generate harmful thermal effects in biological tissues. During laser application, photon energy is absorbed at the cellular level, triggering a stimulatory response referred to as photobiostimulation, which has been shown to confer multiple therapeutic benefits, including pain modulation, antimicrobial action, decreased dentinal hypersensitivity, facilitation of disinfection within infected dentin, and stimulation of dentin formation along the root canal walls.

Limitations & Safety Concerns

Despite their promising therapeutic benefits, the clinical application of lasers in endodontics is associated with several limitations and safety concerns that warrant careful consideration. One of the primary concerns is the risk of thermal damage to periodontal tissues and surrounding structures. Excessive energy delivery, inappropriate power settings, or prolonged irradiation may result in undesirable temperature elevation, potentially compromising periodontal ligament vitality and alveolar bone health.

Another limitation relates to the lack of standardized clinical protocols for laser use in endodontics. Variability in laser types, wavelengths, power settings, fiber placement, and irradiation duration across studies has contributed to heterogeneous outcomes in the literature. This variability complicates direct comparison between studies and limits the ability to establish universally accepted clinical guidelines.

The cost of laser equipment and the associated learning curve also pose practical challenges, particularly in routine clinical settings. Effective and safe laser application requires adequate training and a thorough understanding of laser–tissue interactions. Without proper training, the benefits of laser-assisted endodontics may not be fully realized, and the risk of procedural errors may increase.

Future Directions

Despite the growing body of evidence supporting laser-assisted endodontics, several areas require further investigation. Future research should focus on well-designed randomized controlled trials with standardized laser parameters, clearly defined outcome measures, and long-term follow-up to assess treatment success and periapical healing. Comparative studies evaluating different laser systems under uniform conditions would also aid in establishing evidence-based clinical guidelines.

Emerging laser-activated irrigation techniques and advancements in photodynamic therapy warrant further exploration, particularly in relation to biofilm disruption and antimicrobial resistance. Additionally, the role of lasers in regenerative endodontic procedures and vital pulp therapy represents a promising area of future research. As technology evolves, integration of laser systems with digital workflows and enhanced imaging modalities may further refine precision and therapeutic efficacy in endodontic practice.

Conclusion

Lasers have emerged as valuable adjunctive therapeutic tools in modern endodontics, offering benefits that extend beyond conventional mechanical and chemical approaches. Their ability to enhance root canal disinfection, improve irrigant dynamics, and modulate biological healing responses underscores their growing clinical relevance. However, the therapeutic success of lasers depends heavily on appropriate case selection, adherence to evidence-based protocols, and proper operator training.While current evidence supports improved antimicrobial action and potential benefits in pain modulation and tissue repair, heterogeneity in protocols and limited long-term clinical data necessitate cautious integration. Lasers should be viewed as complementary tools rather than replacements, with future research focused on standardization, safety optimization, and evidence-based clinical guidelines.

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