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Review Article

Emerging horizons: Applications of laser technology in endodontics and periodontics

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Abstract

The incorporation of laser technology in dentistry has transformed conventional therapeutic approaches, offering distinct clinical advantages over traditional methods. Operating via photothermal, photochemical, and photomechanical interactions, lasers enable precise tissue modification with minimal collateral damage. Their ability to ablate, penetrate, and disinfect has shown promising outcomes in various endodontic procedures, including root canal therapy, vital pulp therapy, management of dentinal hypersensitivity, and control of pulpal and periapical pain. Depending on their wavelength and clinical indication, lasers such as diode, Nd: YAG, Er: YAG, and CO_2 are selectively employed. In periodontics, laser-assisted therapy enhances treatment outcomes through excellent decontamination, reduced bleeding, accelerated healing, and improved patient comfort. This narrative review delves into the underlying mechanisms, current clinical applications, and emerging advancements in laser technology in endodontics and periodontics, highlighting their challenges.

Keywords: Endodontic treatment, Nd: YAG, Er: YAG Lasers, Gingival depigmentation, Periodontal regeneration.

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1. Introduction

The advent of laser technology in medicine dates back to 1960, when Theodore Maiman introduced the first functional laser using a ruby crystal.[1] Initially embraced in specialties such as ophthalmology and dermatology for their precision in delicate surgical procedures, lasers gradually found their place in dentistry by the early 1990s.[2] This transition was driven by the growing demand for minimally invasive techniques that offered both accuracy and enhanced patient comfort. With ongoing advancements, dental lasers have become increasingly refined, featuring specific wavelengths and tailored designs to address the distinct requirements of periodontal and endodontic treatments.[3]

In both endodontics and periodontics, laser technology has opened new avenues for more effective and patient-friendly treatments. In periodontics, lasers are increasingly used as adjuncts to conventional therapy, enhancing the outcomes of both surgical and non-surgical interventions. Their ability to decontaminate periodontal pockets, promote tissue regeneration, and reduce postoperative discomfort has made them a valuable tool in managing periodontal disease. Techniques such as laser-assisted new attachment procedures (LANAP), pocket decontamination, and biostimulation through low-level laser therapy (LLLT) are gaining clinical

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acceptance due to their promising results in improving periodontal health, especially in patients with systemic conditions or advanced disease.[4]

Simultaneously, lasers are gaining prominence in the field of endodontics, where precision and disinfection are crucial. Applications include root canal sterilization, vital pulp therapy (such as pulp capping and pulpotomy), management of dentinal hypersensitivity, and alleviation of pulpal and periradicular pain. Advanced laser systems also facilitate emerging procedures such as stimulation of root development in immature teeth and the removal of fractured instruments or fiber posts within the canal system.[5] These innovations not only enhance the efficacy of endodontic procedures but also contribute to minimally invasive, patient-centred care. This review aims to explore the evolving landscape of laser technology in endodontics and periodontics, examining its mechanisms, current applications.

2. Laser Physics in Dentistry

A laser (Light Amplification by Stimulated Emission of Radiation) is a device that emits a focused beam of light by stimulating atoms to release photons in a controlled manner. It comprises three main components: an energy source, an active medium, and a resonant chamber. The energy source, typically electrical, excites electrons in the active medium to a higher energy state.[6]

Common dental lasers use different mediums:

1. Nd:YAG lasers use neodymium-doped yttrium-aluminum-garnet crystals.
2. CO_2 lasers contain carbon dioxide, nitrogen, and helium gases.
3. Dye lasers use liquid organic dyes as the medium.

When energy excites enough atoms, a population inversion occurs, and more atoms occupy an excited state than the ground state. These atoms then release photons, triggering other excited atoms to do the same, creating a chain reaction. Reflective mirrors within the resonant chamber amplify this light, allowing only a coherent, monochromatic, and directional beam to exit, forming the laser used in dental applications.[7-9]

3. Lasers in Endodontics

3.1. Root canal shaping

Traditionally, root canal shaping is done using hand or rotary instruments, which create a smear layer that must be removed for effective disinfection. Lasers have emerged as a valuable adjunct by enabling smear layer removal and improving canal cleanliness. Laser energy works by vaporizing water within the dentin, thereby ablating surrounding tissue and opening dentinal tubules.[10]

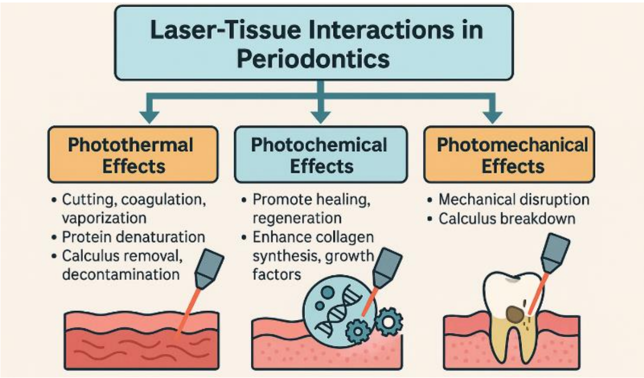

Figure 1: Laser-tissue interactions in periodontics

Studies have shown that the Er: YAG laser effectively removes the smear layer and reduces the risk of dentinal cracks when used at close range.[11] Similarly, Nd: YAG lasers, when combined with rotary NiTi files, have demonstrated superior canal wall cleaning compared to conventional methods, offering enhanced preparation outcomes.[12]

3.2. Root canal irrigation

Effective root canal cleaning relies on both mechanical instrumentation and irrigation. Due to the complex canal anatomy, shaping mainly allows access to the apical region, making irrigation vital for disinfection.[13]

Conventional syringe and needle irrigation (SNI) is widely used but has limitations in reaching intricate canal areas. To overcome this, advanced methods like laser-activated irrigation (LAI) have been introduced. LAI uses laser energy to generate cavitation bubbles, producing rapid fluid motion that dislodges debris and biofilm from canal walls, enhancing overall cleaning efficiency.[14] Laser-assisted irrigation involves the activation of irrigating solutions to improve root canal cleaning and disinfection. Commonly used irrigants such as sodium hypochlorite (NaOCl), ethylenediaminetetraacetic acid (EDTA), and saline are energized by laser systems to enhance their chemical action and mechanical efficacy, resulting in more effective debridement and microbial elimination. According to a study by Zhao J et al., photon-initiated photoacoustic streaming (PIPS) with an Er:YAG laser showed superior antibacterial efficacy compared to conventional needle irrigation (CNI) when used with 1% sodium hypochlorite in root canal treatment. The study reported significantly lower ATP values post-irrigation in the PIPS group ($P < 0.001$), and multivariate analysis revealed that the irrigation method, pre-operative percussion tenderness, and presence of fistula significantly influenced disinfection outcomes.[15] Tong J et al. compared the efficacy of various irrigation activation techniques, including manual dynamic activation (MDA), ultrasonically activated irrigation (UAI), sonically activated irrigation (SAI), photon-induced photoacoustic streaming (PIPS), and shock wave enhanced emission photoacoustic streaming (SWEEPS), in curved root canals. Scanning electron microscopy revealed that both PIPS and SWEEPS achieved significantly better smear layer removal in the middle and apical thirds ($P < 0.05$), whereas no significant difference was observed among the groups in the coronal third ($P > 0.05$). These findings suggest that PIPS and SWEEPS offer superior cleaning efficiency in challenging root canal anatomies.[16]

3.3. Filling material removal

Complete removal of root canal filling materials is crucial during retreatment, as any remnants may harbour bacteria and obstruct the apical area, risking treatment failure. Due to the depth and density of these materials, removal is often challenging. Techniques like sonic irrigation (SNI), passive ultrasonic irrigation, and laser activation are commonly employed. The Er:YAG laser, with a wavelength of 2940 nm, exhibits a high affinity for water and hydroxyapatite, making it highly effective for both hard and soft tissue applications. In endodontic retreatment, it facilitates the removal of root canal filling materials through a mechanism known as photon-induced photoacoustic streaming (PIPS). This technique utilizes a specially designed radial and stripped-tip fiber to deliver laser pulses into the irrigant within the canal. The rapid absorption of laser energy by the irrigant generates powerful photoacoustic shock waves, which produce strong streaming and cavitation effects. These dynamic fluid movements enhance the dislodgement and removal of residual filling materials from the root canal walls, resulting in a cleaner and more efficient retreatment outcome.[17] Studies show that activating 2.5% NaOCl and 17% EDTA with an Er:YAG laser significantly improves the removal of residual iRoot SP and gutta-percha compared to SNI and ultrasonic methods. The Nd:YAG laser has also proven effective in this context.[18,19]

3.4. Lasers in vital pulp therapy

Vital pulp therapy (VPT), including pulp capping and pulpotomy, aims to preserve pulp vitality and is a less invasive alternative to root canal treatment for cariously exposed pulps. While materials like calcium hydroxide and mineral trioxide aggregate (MTA), are commonly used, they have unpredictable outcomes.[20] In vital pulp therapy (VPT), the choice of laser parameters—such as mode, power setting, and duration—varies based on the laser type and the specific procedure being performed, including pulpotomy, pulp capping, or apexogenesis. Diode lasers (940–980 nm) are commonly used in contact mode with a heated tip for pulpotomy, whereas for indirect pulp capping, a defocused mode with parameters like 25 mJ, 10 Hz, and short pulse duration is employed to induce dentin melting. CO_2 lasers can also be applied at low power levels (typically <1 W) for less than one second, often with air cooling, to safely irradiate pulp tissue.[21,22]

Laser-assisted VPT has emerged as a promising alternative. Laser irradiation can accelerate fibrous matrix and dentin bridge formation, enhance collagen expression, and support wound healing. Low-level lasers modulate inflammation and activate growth factors for dentin regeneration, while high-level lasers aid healing by elevating tissue temperature. Research also supports the effectiveness of low-level laser therapy as an adjunct in pulpotomy.[23,24]

3.5. Lasers in dentinal hypersensitivity treatment

Dentinal hypersensitivity is characterized by sharp, short pain triggered by thermal, chemical, or tactile stimuli due to exposed dentinal tubules. Common causes include attrition, abrasion, erosion, abfraction, gingival recession, and tooth decay, which can lead to pulpal inflammation. Conventional treatments aim to block nerve signals or seal tubules using desensitizing agents like fluoride pastes or sealants. In severe cases, root canal therapy may be considered. Lasers offer a non-invasive alternative by sealing tubules through surface modification or protein coagulation. They can be used alone or alongside traditional desensitizing methods to enhance effectiveness.[25,26]

Table 1: Use of different types of lasers in conservative dentistry & endodontics

Laser Type	Wavelength	Tissue Type	Applications
Er:YAG	2940 nm	Hard	Cavity preparation, caries removal, enamel and dentin etching, root canal preparation
Er,Cr:YSGG	2780 nm	Hard and soft	Cavity preparation, caries removal, osseous surgery, endodontic procedures
Nd:YAG	1064 nm	Soft	Root canal sterilization, microbial reduction
Diode	800-980 nm	Soft and hard	Caries detection, desensitization, pulp capping, root canal disinfection
CO_2	10,600 nm	Soft	Cavity sterilization (limited use in hard tissue)
Argon	488-514 nm	Soft	Tooth whitening, composite curing, and caries detection

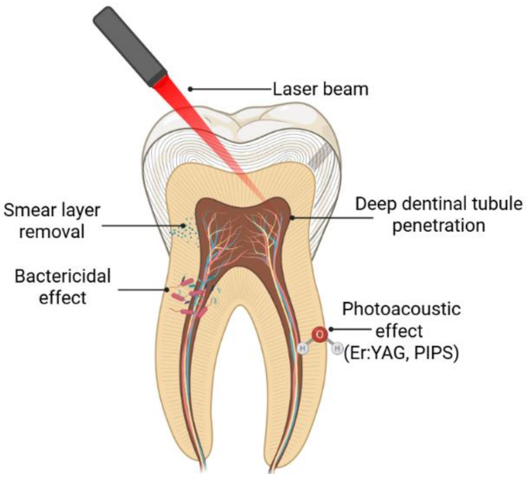

Figure 2: Application of laser in endodontics

4. Lasers in Periodontics

4.1. Non-surgical periodontal treatment

Lasers are playing a transformative role in non-surgical periodontal therapy, particularly when combined with scaling and root planing (SRP). Laser-assisted SRP enhances the removal of plaque, calculus, and pathogenic bacteria from root surfaces, offering a thorough decontamination than conventional methods alone. This approach is especially effective for patients with moderate to severe periodontitis, as it helps reduce periodontal pocket depths, promotes healing, and decreases bacterial load. Additionally, laser treatment may lead to less discomfort, minimal bleeding, and faster recovery, improving overall patient outcomes.[27]

4.2. Laser applications in bone surgery and implantitis treatment

Lasers play a vital role in periodontal procedures, offering precise soft and hard tissue management during surgeries like gingivectomy, gingivoplasty, and bone contouring. They minimize bleeding, reduce postoperative discomfort, and promote faster healing. In managing peri-implantitis, lasers such as Nd:YAG and Er:YAG effectively eliminate bacterial biofilms and enhance tissue regeneration, providing a minimally invasive treatment option.[28]

4.3. Laser-assisted regeneration and diagnostics in periodontics

Laser technology plays a significant role in regenerative periodontal procedures, including bone grafting and guided tissue regeneration. By stimulating cellular metabolism and enhancing tissue response, lasers improve the integration and effectiveness of graft materials, ultimately promoting better healing outcomes. In addition to therapeutic applications, lasers are increasingly used as diagnostic tools in periodontal practice. Techniques such as laser-induced fluorescence and laser Doppler flowmetry help in the early detection of periodontal diseases by identifying subtle changes in tissue properties. This facilitates prompt diagnosis and timely intervention, leading to more effective disease management and improved patient care.[29]

4.4. Gingival depigmentation

Gingival depigmentation is a cosmetic periodontal procedure designed to remove melanin pigmentation from the gingiva, enhancing the aesthetic appearance of the smile. Among various techniques, laser-assisted depigmentation, particularly with diode lasers, has gained popularity due to its precision, minimal bleeding, reduced postoperative discomfort, and faster healing. Diode lasers are especially effective because they operate within the melanin absorption spectrum and can penetrate deeper into the tissue. Their deep thermal effect not only coagulates blood vessels, minimizing bleeding, but also reduces the activity of pigment-producing cells. Additionally, diode lasers may delay melanocyte migration and target pigment-containing cells like melanophages or melanophores that reside in the lamina propria, thereby reducing pigmentation recurrence.[30]

Figure 3: A): Preoperative view. **B**): Immediate postoperative view. **C**): Postoperative view after 1 week

Table 2: Use of different types of lasers in periodontics procedures

Laser Type	Wavelength	Tissue Type	Applications
Diode	800–980 nm	Soft	Gingivectomy, gingival contouring, sulcular debridement, LANAP
Nd:YAG	1064 nm	Soft	Gingivectomy, periodontal debridement, LANAP, microbial elimination
Er:YAG	2940 nm	Hard and soft	Periodontal pocket debridement, calculus removal
Er,Cr:YSGG	2780 nm	Hard and soft	Root planing, scaling, periodontal flap surgery
CO_2	10,600 nm	Soft	Soft tissue ablation, frenectomy, gingivectomy

5. Challenges and Limitations

5.1. Risks and safety considerations

While lasers offer numerous advantages in periodontal treatment, their use is not without risks. One of the most critical concerns is the potential for ocular injury. Without proper eye protection, laser exposure can cause serious retinal damage, leading to vision problems such as cataracts, floaters, diminished night vision, impaired color perception, and in severe cases, permanent blindness. The absence of pain receptors in the retina means damage may go unnoticed until it becomes significant.[31]

Beyond ocular hazards, improper laser settings or mishandling can result in tissue burns, especially in delicate oral areas. Although patients generally report less pain and discomfort compared to conventional methods, thermal damage from lasers may still occur, affecting teeth or bone and potentially leading to sensitivity or structural complications. There is also a minor risk of postoperative bleeding, particularly in patients with bleeding disorders or those on anticoagulants.[32]

5.2. Cost and accessibility

Another significant barrier to the widespread implementation of laser technology in dentistry is its high cost. The initial investment, maintenance expenses, and the additional costs of clinician training and certification limit its accessibility, particularly for smaller practices or those in underserved areas. However, with ongoing technological advancements, the cost of laser equipment is expected to decrease, potentially increasing accessibility and expanding the reach of laser-assisted dental care in the near future.[33]

5.3. Training and skill development

Effective and safe use of laser technology in periodontal treatment demands specialized training and clinical expertise. Dental schools, laser manufacturers, and professional organizations offer structured training programs to help practitioners develop the necessary skills. However, limited access to these programs and the associated costs can pose significant barriers, especially for clinicians in smaller practices or resource-limited settings. Without proper training, there is a heightened risk of procedural complications, reduced treatment efficacy, and potential harm to patients.[34]

6. Discussion

In periodontics, studies have shown mixed outcomes regarding the adjunctive use of lasers with conventional mechanical therapy. While some reports indicate significant improvements in clinical parameters like probing depth, attachment levels, and reduction in gingival inflammation, others found no notable advantage over traditional methods. However, lasers offer precise disinfection and strong coagulative properties that reduce bleeding, minimize the need for sutures, and enhance surgical visibility. Their ability to reduce postoperative pain and swelling also contributes to higher patient comfort and faster healing. Diode and Er:YAG lasers have been particularly effective in improving outcomes in non-surgical peri-implant therapy, significantly reducing clinical attachment loss, pocket depth, and bleeding on probing. Laser-assisted treatments also enhance patient satisfaction in gingival depigmentation due to less trauma and rapid healing.[35-37]

Dubey P et al. conducted a randomized controlled clinical trial comparing conventional and diode laser-assisted root canal treatment in patients with chronic periapical lesions. Ninety patients (98 roots) were divided into two groups, laser and control, with postoperative pain assessed at multiple time intervals using a visual analog scale. Cone beam computed tomography (CBCT) was used to evaluate lesion healing over six months. The study found that diode laser disinfection significantly reduced postoperative pain and demonstrated superior periapical healing outcomes compared to conventional methods.[38] In an in vitro study by Attiguppe PR et al., the efficacy of different diode laser-assisted disinfection techniques in primary teeth was compared, including direct laser irradiation, laser-activated irrigation (LAI) with sodium hypochlorite, and photodynamic therapy (PDT). Sixty extracted primary teeth inoculated with Enterococcus faecalis were treated using one of the three methods. All groups showed a significant reduction in bacterial count ($p < 0.001$). LAI and PDT were significantly more effective than direct laser irradiation, with no significant difference observed between LAI and PDT. The findings suggest that both LAI and PDT are superior laser-assisted techniques for endodontic disinfection in primary teeth.[39] Divya D et al. evaluated the effectiveness of conventional versus laser-assisted disinfection in regenerative endodontic therapy of necrotic immature permanent teeth. Eighteen children were divided into two groups: Group A received standard AAE 2016 protocol disinfection, while Group B underwent diode laser-assisted disinfection (810 nm, 1 W, pulsed mode). Microbial sampling revealed a significant reduction in bacterial load in the laser group ($P = 0.007$). While clinical outcomes remained comparable across time points, the laser group showed significantly enhanced periapical healing between the 3- and 6-month follow-ups ($P = 0.04$). The study supports the adjunctive use of lasers to improve disinfection and accelerate healing in regenerative endodontics.[40]

In endodontics, Er and Er, Cr:YSGG lasers are useful for cavity preparation by accurately removing decayed tissue while preserving healthy structure. These lasers also create micro-retentive surfaces, improving the bonding of restorative materials. Compared to traditional drills, laser-based techniques are less invasive and offer greater precision, making them suitable for pediatric and anxious patients. Additionally, the ability of certain lasers to inhibit bacterial biofilm growth and enhance fluoride uptake points toward promising applications in caries prevention and enamel remineralization. Despite these advantages, ongoing research is necessary to establish standardized protocols and clarify the benefits of different wavelengths in endodontic procedures.[41]

7. Conclusion

Laser technology plays a vital role in modern periodontics and endodontics, offering precise, minimally invasive treatments with faster healing and improved patient comfort. It is effective in both hard and soft tissue applications and serves as a valuable adjunct to traditional methods. Despite challenges like cost, training, and accessibility, ongoing advancements and growing clinical evidence support wider adoption. The choice between laser and conventional techniques should consider the procedure, patient needs, and clinician expertise. As technology progresses, lasers are set to enhance diagnostic, preventive, and therapeutic outcomes, marking a promising future for dental care.

8. Source of Funding

Nil.

9. Conflicts of Interest

There are no conflicts of interest.

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