



Diode Lasers in Dentistry: A Comprehensive Review of Clinical Applications and Future Perspectives

Mobina Sadat Boskabadi

Department of Optical Engineering and Laser, Faculty of Engineering, Khayyam University, Mashhad,
Iran

boskimobina@gmail.com

Fatemeh Sadat Hosseini

Department of Optical Engineering and Laser, Faculty of Engineering, Khayyam University, Mashhad,
Iran

fatemeh.sadattt.hosseini@gmail.com

Abstract

Diode lasers have become valuable tools in modern dentistry due to their minimally invasive nature, precise tissue interaction, portability, and versatility. Operating mainly within the 600–980 nm wavelength range, diode lasers are widely used in soft tissue surgery, periodontal therapy, endodontic disinfection, antimicrobial procedures, aesthetic treatments, and photobiomodulation. Their effects are primarily based on photothermal and photobiomodulatory mechanisms, which can promote tissue management, microbial reduction, and cellular repair. This review summarizes the principles of diode laser technology, mechanisms of laser–tissue interaction, clinical applications, advantages, limitations, and safety considerations. The performance of diode lasers is also compared with other dental laser systems, including Nd, Er, and CO₂ lasers. Although diode lasers offer promising clinical benefits, challenges related to treatment standardization, thermal safety, and long-term clinical evidence remain. Future advances in digital dentistry, artificial intelligence, and intelligent laser systems may further enhance their role in personalized and minimally invasive dental care.

Keywords: Diode laser; Laser dentistry; Soft tissue surgery; Periodontology; Endodontics; Photobiomodulation; Minimally invasive dentistry.



Introduction

The continuous development of dental technologies has significantly changed modern clinical practice by introducing treatment approaches that aim to improve precision, reduce biological trauma, and enhance patient outcomes. Among these technologies, laser systems have become increasingly important because they provide controlled delivery of optical energy and allow selective interaction with biological tissues. Since the first introduction of lasers into dentistry, different wavelengths have been investigated for surgical, diagnostic, antimicrobial, and regenerative applications [1], [2]. Dental lasers are categorized according to their active medium into gas lasers, solid-state lasers, and semiconductor lasers. Common systems used in dental applications include carbon dioxide (CO₂), neodymium-doped yttrium aluminum garnet (Nd:YAG), erbium-doped yttrium aluminum garnet (Er:YAG), and diode lasers. Each laser system possesses specific optical characteristics that determine its absorption behavior, penetration depth, and biological effects within oral tissues [3].

Among these technologies, diode lasers have gained extensive acceptance due to their practical advantages, including compact size, portability, high energy efficiency, and relatively lower equipment cost. Their compatibility with flexible optical fibers enables accurate energy delivery into anatomically complex areas of the oral cavity, making them suitable for periodontal pockets, root canal systems, and soft tissue procedures [4]. Most dental diode lasers operate within the wavelength range of approximately 600–980 nm. At these wavelengths, laser energy is mainly absorbed by tissue chromophores, particularly hemoglobin and melanin. This selective absorption enables effective soft tissue management with simultaneous coagulation and hemostasis, which explains their widespread application in periodontal surgery and oral soft tissue procedures [5].

Unlike erbium lasers, which demonstrate strong absorption by water and hydroxyapatite and are therefore suitable for hard tissue procedures, diode lasers have limited ability to remove mineralized dental structures. Consequently, their primary clinical applications are focused on soft tissue modification, microbial reduction, and biological stimulation rather than enamel or dentin ablation [6]. The biological effects produced by diode lasers depend on several operational parameters, including wavelength, output power, emission mode, exposure duration, energy density, and tissue characteristics. Appropriate selection of these parameters is essential to achieve therapeutic benefits while avoiding excessive thermal accumulation and unwanted tissue damage [7].

In addition to high-power surgical applications, diode lasers have received increasing attention because of their photobiomodulatory effects. Low-level diode laser irradiation can stimulate cellular activity through mitochondrial mechanisms, resulting in increased adenosine triphosphate (ATP) production, regulation of inflammatory responses, and enhancement of tissue repair processes [8]. Despite the increasing application of diode lasers in dentistry, several challenges remain, including variability in treatment protocols, limited long-term clinical evidence, and the absence of universally accepted guidelines for many applications. Therefore, critical evaluation of current scientific evidence is necessary to define the appropriate role of diode lasers in contemporary dental practice. The aim of this review is to provide a comprehensive analysis of diode laser technology, including fundamental principles, mechanisms of tissue interaction, clinical applications, comparative characteristics, limitations, safety considerations, and future developments.

II. Fundamentals of Diode Laser Technology and Laser–Tissue Interaction Mechanisms

Diode lasers are semiconductor-based optical devices that generate coherent light through the process of stimulated emission. The active medium of these lasers consists of semiconductor materials, commonly



including gallium arsenide (GaAs), aluminum gallium arsenide (AlGaAs), and related compounds. When electrical energy is applied to the semiconductor junction, electrons and holes recombine and release photons. These photons are amplified inside the optical cavity, resulting in laser emission at a specific wavelength determined by the semiconductor composition and device structure [9]. The semiconductor structure of diode lasers provides several advantages compared with conventional laser systems. Their small size, high electrical efficiency, low maintenance requirements, and relatively simple construction allow the development of portable and user-friendly devices suitable for clinical dentistry. Furthermore, the integration of flexible optical fibers enables accurate delivery of laser energy to restricted anatomical regions, improving accessibility during periodontal, surgical, and endodontic procedures [10].

The interaction between diode laser radiation and biological tissues depends on several optical phenomena, including reflection, scattering, transmission, and absorption. Among these mechanisms, absorption is the most clinically relevant because it determines how optical energy is converted into biological effects. The degree of absorption depends primarily on laser wavelength and the concentration of specific tissue chromophores [11]. Biological tissues contain different molecules capable of absorbing laser radiation. In dental tissues, hemoglobin, melanin, and intracellular photoreceptors are considered important chromophores responsible for diode laser interaction. The absorption of diode laser energy by hemoglobin explains its effectiveness in vascular soft tissues, where controlled thermal effects can produce coagulation, hemostasis, and tissue incision [12].

When absorbed optical energy is converted into heat, photothermal effects occur. The biological response depends on the temperature reached and the duration of exposure. Moderate temperature elevation may result in protein denaturation and coagulation, whereas higher temperatures may lead to tissue vaporization and ablation. Controlled photothermal interactions form the basis of many diode laser applications, including gingival surgery, frenectomy, periodontal procedures, and soft tissue lesion removal [13]. Laser parameters play a critical role in determining treatment outcomes. Factors such as output power, continuous-wave or pulsed emission mode, irradiation time, energy density, fiber tip movement, and distance from the target tissue influence the amount of energy delivered. Inappropriate parameter selection may result in excessive heating, carbonization, delayed healing, or injury to adjacent tissues [14].

In addition to photothermal effects, diode lasers can induce photobiomodulation when applied at lower energy levels. Photobiomodulation is a biological process in which photons are absorbed by intracellular chromophores, particularly cytochrome c oxidase within mitochondria. This interaction enhances mitochondrial function, increases ATP synthesis, regulates reactive oxygen species production, and activates cellular signaling pathways associated with tissue repair [15]. The cellular effects of photobiomodulation include stimulation of fibroblast proliferation, increased collagen synthesis, enhanced angiogenesis, modulation of inflammatory cytokines, and improved cellular migration. These biological responses explain the growing interest in low-level diode laser therapy for postoperative healing, pain control, regenerative procedures, and tissue recovery [16].

Another important mechanism associated with diode lasers is antimicrobial activity. High-power diode irradiation can reduce microbial viability through thermal disruption of bacterial membranes, protein denaturation, and structural damage to microbial components. Furthermore, diode lasers can be combined with photosensitizing agents in antimicrobial photodynamic therapy (aPDT), in which laser activation produces reactive oxygen species capable of damaging microbial cells [17]. Although diode lasers provide valuable therapeutic effects, thermal management remains a fundamental safety consideration. Because heat can diffuse beyond the targeted area, excessive energy delivery may cause unwanted tissue

injury. Appropriate selection of laser parameters, controlled fiber movement, adequate cooling strategies, and clinician training are essential for achieving safe and predictable outcomes [18].

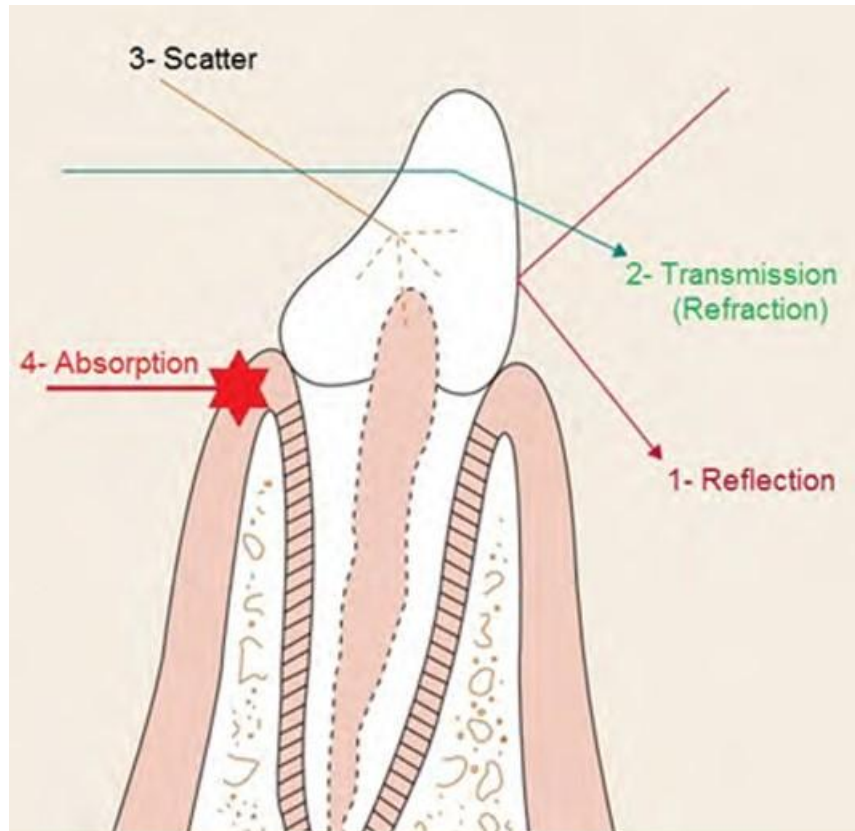


Figure 1. Schematic Representation of Diode Laser Interaction With Biological Tissues

III. Clinical Applications of Diode Lasers in Dentistry

A. Soft Tissue Surgery Applications

Soft tissue surgery represents the most established and widely accepted application of diode lasers in dentistry. Due to their absorption by hemoglobin and melanin, diode lasers interact efficiently with vascularized oral tissues and provide controlled tissue modification with simultaneous coagulation. This characteristic improves surgical visibility, minimizes bleeding, and may contribute to improved patient comfort compared with conventional surgical methods [19]. Diode lasers are commonly used for gingivectomy, gingivoplasty, frenectomy, soft tissue lesion removal, crown lengthening procedures, and esthetic gingival contouring. Their ability to perform precise tissue modification with limited mechanical trauma has increased their importance in minimally invasive dental procedures [20]. One of the major advantages of diode laser-assisted soft tissue surgery is improved hemostasis. During laser incision, thermal sealing of small blood vessels occurs simultaneously with tissue cutting, reducing intraoperative bleeding and improving visualization of the surgical field. This effect is particularly beneficial in highly vascular oral tissues where conventional surgery may present greater bleeding challenges [21].



In esthetic dentistry, diode lasers have become valuable tools for modifying gingival architecture. Procedures such as correction of uneven gingival margins, treatment of excessive gingival display, and gingival reshaping can be performed with high precision. When appropriate treatment planning and clinical protocols are applied, diode laser procedures may provide predictable aesthetic outcomes. Another important application is gingival depigmentation. Since melanin-containing cells absorb diode laser energy effectively, controlled irradiation can selectively remove excessive pigmentation while maintaining surrounding tissue integrity. Clinical studies have reported favorable healing responses and patient satisfaction following diode laser-assisted gingival depigmentation procedures [22].

III-B. Periodontal Applications of Diode Lasers

Periodontal diseases are among the most prevalent chronic inflammatory disorders affecting oral tissues and are primarily associated with bacterial biofilms and host immune responses. Conventional periodontal therapy, particularly scaling and root planing (SRP), remains the standard approach for controlling periodontal infection. However, complete elimination of microorganisms from deep periodontal pockets, furcation regions, and anatomically complex areas may be difficult because of limitations in mechanical accessibility [23]. The application of diode lasers as adjunctive periodontal tools has gained increasing attention due to their antimicrobial properties and selective interaction with pigmented tissues. Because diode laser wavelengths are absorbed by hemoglobin, melanin, and bacterial pigments, laser irradiation can produce localized photothermal effects that contribute to bacterial reduction and modification of inflamed periodontal tissues [24].

The antimicrobial mechanism of diode lasers is mainly related to thermal disruption of microbial structures. Increased temperature within the irradiated region may cause bacterial membrane damage, protein denaturation, and alteration of intracellular components. Several studies have demonstrated reductions in periodontal pathogens, including *Porphyromonas gingivalis*, *Prevotella intermedia*, and *Aggregatibacter actinomycetemcomitans*, following diode laser application [25]. An important advantage of diode lasers in periodontal treatment is their ability to combine microbial reduction with soft tissue management. Laser-assisted periodontal procedures may improve access to periodontal pockets, reduce inflammatory granulation tissue, and provide improved control of bleeding during surgical interventions. In addition, reduced mechanical trauma associated with laser procedures may support improved postoperative healing responses [26].

Antimicrobial photodynamic therapy (aPDT) represents another important periodontal application of diode lasers. In this technique, a photosensitizing compound is introduced into the periodontal environment and activated by laser irradiation. The activated photosensitizer produces reactive oxygen species, including singlet oxygen and free radicals, which can selectively damage bacterial cells without depending solely on thermal mechanisms [27]. Clinical studies evaluating diode laser-assisted periodontal therapy have reported improvements in periodontal parameters, including reduction in probing depth, decreased gingival inflammation, and improved clinical attachment levels. However, systematic reviews have indicated that the clinical benefits vary among studies because of differences in laser parameters, treatment protocols, patient characteristics, and follow-up periods [28]. Therefore, diode lasers should currently be considered complementary technologies rather than replacements for conventional periodontal treatment. Mechanical biofilm removal remains the foundation of periodontal therapy, while diode lasers may provide additional benefits in selected clinical situations when applied according to evidence-based protocols.



III-C. Endodontic Applications of Diode Lasers

Successful endodontic therapy depends on effective elimination of microorganisms from the root canal system and prevention of reinfection. Despite improvements in mechanical instrumentation and irrigation methods, complete disinfection remains challenging because root canals contain complex anatomical structures such as lateral canals, isthmuses, and dentinal tubules that may harbor persistent microorganisms [29]. Diode lasers have been investigated as supplementary technologies for improving root canal disinfection. Their flexible optical fibers allow delivery of laser energy into narrow and irregular canal spaces, providing access to areas that may be difficult to reach through conventional instrumentation and irrigation alone [30].

The antimicrobial action of diode lasers in endodontics is primarily based on photothermal effects. Absorption of laser energy by microbial structures causes localized temperature elevation, leading to bacterial membrane disruption, protein denaturation, and reduction of microbial viability. Several studies have demonstrated antimicrobial effects of diode lasers against *Enterococcus faecalis*, a microorganism frequently associated with persistent endodontic infections [31]. The effectiveness of diode laser application in root canal therapy depends on multiple factors, including wavelength, output power, exposure duration, irradiation technique, and canal anatomy. Excessive energy delivery may increase heat transmission through dentin and potentially affect surrounding periodontal tissues. Therefore, controlled movement of the optical fiber and appropriate energy selection are essential for maintaining biological safety [32].

Combination approaches involving diode lasers and antimicrobial photodynamic therapy have also been investigated. This strategy enhances antimicrobial activity through oxidative mechanisms generated by activated photosensitizers. Research suggests that photodynamic therapy may provide additional microbial reduction, particularly in cases involving resistant microorganisms and persistent infections [33]. Although diode lasers demonstrate promising antimicrobial effects, they cannot replace conventional endodontic procedures. Mechanical preparation, chemical irrigation, and appropriate obturation remain essential components of successful root canal treatment. The role of diode lasers is therefore considered an adjunctive approach intended to enhance disinfection rather than replace established treatment principles [34].

IV. Diode Lasers in Esthetic Dentistry and Tooth Whitening

The increasing demand for aesthetic dental treatments has stimulated the development of technologies designed to improve smile appearance and treatment efficiency. Tooth discoloration is one of the most common aesthetic concerns, and professional bleaching procedures using hydrogen peroxide or carbamide peroxide remain among the most frequently performed cosmetic treatments [35]. Light-assisted bleaching techniques have been introduced with the objective of accelerating chemical reactions involved in tooth whitening. Diode lasers have been investigated as potential activation sources because of their controlled energy delivery, compact design, and ability to interact with specific chromophores present in bleaching materials [36]. The proposed mechanism of diode laser-assisted bleaching involves acceleration of peroxide decomposition and increased production of reactive oxygen species. These molecules penetrate dental structures and oxidize organic pigment molecules responsible for tooth discoloration, potentially improving whitening efficiency and reducing treatment duration [37].

Despite these theoretical advantages, the clinical superiority of laser-assisted bleaching remains controversial. Some investigations have reported enhanced whitening effects following laser activation,



whereas others have demonstrated no significant improvement compared with conventional bleaching techniques. Differences in bleaching agents, laser parameters, and evaluation methods contribute to inconsistent findings among clinical studies [38]. Thermal safety is an important consideration during laser-assisted bleaching procedures. Excessive temperature elevation within the pulp chamber may increase the risk of tooth sensitivity and pulpal irritation. Therefore, appropriate selection of laser power, exposure duration, and cooling methods is necessary to prevent adverse biological effects [39]. Beyond tooth whitening, diode lasers are increasingly used in aesthetic soft tissue procedures. Gingival reshaping, correction of irregular gingival contours, and management of excessive gingival display can be performed with high precision, allowing diode lasers to become an important component of comprehensive aesthetic treatment planning.

V. Photobiomodulation, Pain Management, and Tissue Regeneration

In addition to surgical applications, diode lasers have attracted considerable interest because of their ability to induce photobiomodulation (PBM), a non-thermal biological process that stimulates cellular activity through controlled exposure to low-intensity light. Unlike high-power laser applications, which primarily depend on thermal tissue interactions, photobiomodulation produces biological effects without significant temperature elevation or structural damage to tissues [40]. The molecular mechanism of photobiomodulation is mainly associated with photon absorption by intracellular chromophores, particularly cytochrome c oxidase located in the mitochondrial respiratory chain. Absorption of laser photons enhances mitochondrial activity, leading to increased adenosine triphosphate (ATP) production, modulation of reactive oxygen species, and activation of cellular signaling pathways involved in metabolism, inflammation control, and tissue repair [41].

At the cellular level, diode laser-induced photobiomodulation may stimulate fibroblast proliferation, collagen synthesis, endothelial cell activity, and angiogenesis. These effects contribute to improved wound healing and tissue regeneration, supporting the use of diode lasers after periodontal surgery, implant placement, tooth extraction, and other invasive dental procedures [42]. Pain management is one of the most extensively investigated applications of photobiomodulation in dentistry. Postoperative pain and inflammation are common complications following many dental interventions, and low-level diode laser therapy has been proposed as a non-pharmacological approach for reducing patient discomfort. The analgesic mechanisms are associated with modulation of inflammatory mediators, reduction of edema, improvement of local circulation, and alteration of neural activity [43].

Clinical studies have demonstrated potential benefits of diode laser photobiomodulation in reducing pain following surgical extraction, periodontal procedures, implant placement, and endodontic treatment. However, variations in laser wavelength, energy density, irradiation protocols, and treatment timing have resulted in differences among reported outcomes [44]. In implant dentistry, photobiomodulation has been investigated for its possible influence on osseointegration. Experimental and clinical studies suggest that low-level diode laser irradiation may enhance osteoblast activity, increase expression of bone-related markers, and improve early biological responses around implant surfaces. These effects may contribute to improved implant stability during the healing phase [45].

Orthodontic applications of diode laser photobiomodulation have also been explored. Some investigations suggest that laser stimulation may influence bone remodeling processes, potentially accelerating orthodontic tooth movement and reducing treatment-associated discomfort. However, additional well-designed clinical studies are required before standardized clinical recommendations can be established [46]. A major challenge in photobiomodulation therapy is the determination of optimal treatment dosage. The biological response to laser exposure follows a biphasic pattern, meaning that



insufficient energy may result in limited biological effects, whereas excessive energy may inhibit cellular activity. Therefore, accurate selection of wavelength, power density, exposure duration, and energy dose is essential for predictable therapeutic outcomes [47].

VI. Comparative Analysis of Dental Lasers

Although diode lasers have become increasingly common in dental practice, other laser systems, including Nd:YAG, Er:YAG, and CO₂ lasers, continue to play important clinical roles. Differences in wavelength, chromophore absorption, penetration depth, and thermal characteristics determine their specific applications and biological effects.

TABLE I -Comparison of Diode Lasers With Nd:YAG, Er:YAG, and CO₂ Lasers

Parameter	Diode Laser	Nd:YAG Laser	Er:YAG Laser	CO ₂ Laser
Active medium	Semiconductor diode	Neodymium-doped yttrium aluminum garnet crystal	Erbium-doped yttrium aluminum garnet crystal	Carbon dioxide gas
Typical wavelength	600–980 nm	1064 nm	2940 nm	10600 nm
Main chromophore	Hemoglobin, melanin, cytochrome oxidase	Hemoglobin, melanin	Water and hydroxyapatite	Water
Primary applications	Soft tissue surgery, periodontal therapy, antimicrobial therapy, photobiomodulation	Periodontal treatment, coagulation, soft tissue surgery	Hard tissue ablation, cavity preparation, bone procedures	Soft tissue cutting and vaporization
Hard tissue capability	Limited	Limited	Excellent	Limited
Fiber delivery system	Excellent	Excellent	Limited	Usually articulated arm
Hemostatic capability	Excellent	Excellent	Moderate	Excellent
Thermal penetration	Moderate	High	Low–moderate	High
Portability	Excellent	Moderate	Moderate	Low
Equipment cost	Low–moderate	High	High	High

The major advantage of diode lasers compared with many other dental laser systems is their simplicity and practicality. Their compact design and flexible fiber delivery system allow easy integration into routine dental procedures. These features make diode lasers particularly suitable for soft tissue management and minimally invasive applications. Nd:YAG lasers exhibit similar absorption characteristics because of their interaction with pigmented tissues. They provide excellent coagulation and antimicrobial effects; however, their deeper thermal penetration requires careful control of energy parameters to minimize unwanted tissue effects [48].

Er:YAG lasers represent one of the most effective laser systems for hard tissue applications because of their strong absorption by water and hydroxyapatite. This property allows efficient removal of enamel, dentin, and bone with relatively limited thermal damage. However, their higher cost and more complex operation may restrict routine use compared with diode systems [49]. CO₂ lasers demonstrate very high absorption by water-containing tissues and provide excellent soft tissue vaporization and cutting



capability. Nevertheless, their larger equipment size and specialized delivery requirements reduce their portability and routine clinical accessibility compared with diode lasers [50].

VII. Advantages, Limitations, and Safety Considerations

Diode lasers provide several advantages that have contributed to their widespread adoption in modern dentistry. Their compact size, portability, relatively affordable cost, and compatibility with flexible optical fibers make them practical tools for general dental clinics and specialized practices. A major clinical advantage of diode lasers is their ability to perform soft tissue procedures with simultaneous coagulation. This characteristic improves surgical visibility, minimizes bleeding, and may contribute to reduced postoperative discomfort. Furthermore, their antimicrobial properties provide additional benefits in periodontal and endodontic applications. Another important advantage of diode lasers is their compatibility with minimally invasive dentistry concepts. By allowing controlled and selective energy delivery, diode lasers can reduce unnecessary tissue trauma and support improved patient acceptance.

Despite these advantages, diode lasers have several limitations. Their most important limitation is their inability to efficiently ablate mineralized dental tissues. Therefore, they cannot replace erbium lasers in procedures requiring enamel, dentin, or bone removal. Thermal safety remains a critical factor during diode laser application. Excessive energy delivery may cause carbonization, tissue necrosis, delayed healing, and damage to adjacent structures. Proper clinician training, appropriate parameter selection, and adherence to laser safety principles are essential for minimizing risks. Laser safety protocols include the use of wavelength-specific protective eyewear, controlled clinical environments, prevention of accidental exposure, and appropriate education of dental personnel. International recommendations such as ANSI Z136.1 provide guidelines for safe laser operation in healthcare settings [51].

VIII. Future Perspectives and Emerging Technologies

The future development of diode laser technology in dentistry is expected to be influenced by advances in biomedical engineering, artificial intelligence, digital dentistry, and nanotechnology. Although diode lasers have already achieved widespread clinical acceptance, emerging technologies may further improve their accuracy, safety, and therapeutic efficiency. One of the most promising future directions is the development of intelligent laser systems equipped with real-time monitoring and automatic feedback control. Currently, most dental diode laser devices require clinicians to manually select parameters such as power output, exposure duration, and emission mode based on clinical experience and manufacturer recommendations. Future systems incorporating optical sensors and artificial intelligence algorithms may continuously analyze tissue responses and automatically adjust laser parameters according to biological conditions, improving treatment reproducibility and reducing operator-dependent variability [52].

Artificial intelligence has the potential to significantly influence laser-assisted dentistry by enabling data-driven clinical decision-making. Machine learning algorithms can analyze large datasets containing patient characteristics, treatment parameters, tissue responses, and clinical outcomes. These systems may assist clinicians in selecting optimized wavelengths, energy levels, and treatment protocols according to individual patient conditions [53]. The integration of diode lasers with digital dentistry platforms represents another important area of future development. Technologies such as three-dimensional imaging, intraoral scanning, computer-assisted treatment planning, and robotic guidance systems may



allow more accurate localization and delivery of laser energy. Such integration may support personalized treatment strategies and improve clinical predictability.

Nanotechnology-based approaches may further expand diode laser applications, particularly in antimicrobial photodynamic therapy. Nanoparticles can function as advanced photosensitizers, increasing reactive oxygen species production and enhancing microbial destruction while reducing the required laser energy. These strategies may provide more selective antimicrobial effects with minimal damage to surrounding tissues [54]. Future endodontic applications may involve improved optical fiber designs capable of delivering laser energy more uniformly throughout complex root canal systems. Combining diode lasers with advanced irrigation techniques, regenerative materials, and bioactive compounds may provide new strategies for improving root canal disinfection and tissue healing.

In periodontal and regenerative dentistry, diode lasers may become integrated with tissue engineering approaches involving stem cells, growth factors, and biomaterials. Since photobiomodulation can influence cellular behavior, future applications may include periodontal regeneration, bone healing enhancement, and improved implant therapy outcomes. Despite these promising developments, several challenges remain before advanced diode laser technologies can be widely incorporated into routine dental practice. These challenges include the requirement for standardized clinical protocols, long-term clinical validation, improved understanding of dose-response relationships, and development of internationally accepted treatment guidelines.

IX. Research Gaps and Limitations of Current Evidence

Although diode lasers have demonstrated considerable potential in dentistry, several limitations remain within the current scientific evidence. One of the most important challenges is the absence of standardized treatment protocols. Variations in wavelength selection, power settings, emission mode, irradiation time, fiber movement technique, and clinical indications have resulted in significant heterogeneity among published studies. This variability makes comparison between investigations difficult and limits the ability to establish universal clinical recommendations. Future research should provide detailed descriptions of laser parameters and standardized outcome measurements to improve reproducibility and clinical translation. Another limitation is the relatively limited number of large-scale randomized controlled clinical trials evaluating long-term outcomes of diode laser-assisted treatments. Many existing studies involve small patient populations, short follow-up periods, or laboratory-based models. Although promising short-term effects have been reported, additional evidence is required to determine the long-term clinical significance of these findings.

In periodontal therapy, diode lasers demonstrate antimicrobial effects and may improve some clinical parameters when used as adjunctive treatments. However, their additional benefit compared with conventional scaling and root planing remains debated. Current evidence supports the use of diode lasers as complementary tools rather than replacements for established periodontal treatment methods. In endodontics, laboratory studies frequently demonstrate significant microbial reduction after diode laser irradiation. However, translating these findings into improved clinical success remains challenging because of variations in root canal anatomy, infection complexity, and treatment protocols. Photobiomodulation represents another field requiring further investigation. Although mitochondrial activation and cellular stimulation mechanisms have been widely described, the optimal therapeutic parameters remain uncertain. Establishing reliable dose-response models will be necessary to improve clinical consistency.



Economic factors also influence the adoption of diode laser technology. Although diode lasers are generally more affordable than several alternative laser systems, equipment costs, maintenance requirements, and clinician training may still represent barriers, particularly in smaller dental practices. Future studies should focus on multicenter clinical trials, standardized reporting methods, long-term outcome assessment, and integration of molecular and clinical measurements. Such efforts will strengthen the evidence base and support wider implementation of diode lasers in evidence-based dentistry.

X. Conclusion

Diode lasers have become an important component of contemporary dentistry because of their versatility, portability, efficiency, and ability to interact selectively with biological tissues. Their applications have expanded considerably, particularly in soft tissue surgery, periodontal therapy, endodontics, antimicrobial procedures, esthetic dentistry, and photobiomodulation. The main clinical advantages of diode lasers include precise soft tissue management, excellent hemostasis, reduced bleeding, microbial reduction, and potential enhancement of tissue healing. These properties support their role as valuable adjunctive technologies in minimally invasive dental procedures. However, diode lasers should not be considered substitutes for conventional dental treatments. Their effectiveness depends on appropriate case selection, correct adjustment of treatment parameters, clinician expertise, and adherence to safety principles. Limitations related to hard tissue applications, thermal effects, and variability among clinical protocols remain important considerations. Compared with other dental laser systems, diode lasers provide unique practical advantages due to their compact design, fiber-based delivery, and cost-effectiveness. Nevertheless, selection of an appropriate laser system should always be based on the biological characteristics of the target tissue and the specific clinical objective. Future advances involving artificial intelligence, digital dentistry, nanotechnology, and intelligent feedback-controlled systems may significantly improve the precision and therapeutic capabilities of diode lasers. Continued clinical research, standardized protocols, and evidence-based guidelines will be essential for maximizing the role of diode lasers in personalized, minimally invasive dental care.

References

- [1] D. J. Coluzzi, “**Fundamentals of dental lasers: Science and instruments,**” *Dental Clinics of North America*, vol. 48, no. 4, pp. 751–770, 2004.
- [2] M. Aoki, H. Sasaki, K. Watanabe, and H. Ishikawa, “**Lasers in dentistry: A review,**” *International Dental Journal*, vol. 50, no. 4, pp. 233–238, 2000.
- [3] R. A. Convissar, ***Principles and Practice of Laser Dentistry***, 2nd ed. St. Louis, MO, USA: Elsevier, 2016.
- [4] A. A. Parker, “**The use of diode lasers in dentistry: Clinical applications and advantages,**” *Journal of Laser Dentistry*, vol. 18, no. 2, pp. 75–82, 2010.
- [5] D. J. Coluzzi, “**An overview of laser wavelengths used in dentistry,**” *Dental Clinics of North America*, vol. 44, no. 4, pp. 753–765, 2000.
- [6] P. Rechmann, J. Fried, and E. D. H. Le, “**Dental laser applications: Current status and future developments,**” *Dental Materials Journal*, vol. 31, no. 2, pp. 123–130, 2012.



24th International Conference on Innovation and Research in Engineering Sciences

GEORGIAN INTERNATIONAL ACADEMY OF SCIENCES AND STUDIES

18 September 2026 -TBILISI GEORGIA

www.icires.ir

info@icires.ir

- [7] M. S. S. Hossain, Y. Nakamura, and Y. Kimura, “A study on thermal effects of laser irradiation in dental tissues,” *Lasers in Medical Science*, vol. 15, pp. 123–129, 2000.
- [8] T. Karu, “Photobiology of low-power laser effects,” *Health Physics*, vol. 56, no. 5, pp. 691–704, 1989.
- [9] G. P. Agrawal, *Fiber-Optic Communication Systems*, 4th ed. Hoboken, NJ, USA: Wiley, 2010.
- [10] M. Bornstein, “Clinical applications of diode lasers in dentistry,” *Journal of Clinical Laser Medicine & Surgery*, vol. 21, no. 2, pp. 89–96, 2003.
- [11] S. Jacques, “Optical properties of biological tissues: A review,” *Physics in Medicine and Biology*, vol. 58, no. 11, pp. R37–R61, 2013.
- [12] J. E. Rossmann and R. A. Cobb, “Lasers in periodontal therapy,” *Periodontology 2000*, vol. 34, pp. 107–126, 2004.
- [13] M. D. Walsh, “The current status of laser applications in dentistry,” *Australian Dental Journal*, vol. 48, no. 3, pp. 146–155, 2003.
- [14] J. M. Parker, “Laser parameters and biological effects in oral tissues,” *Lasers in Surgery and Medicine*, vol. 36, pp. 211–218, 2005.
- [15] T. Karu, “Mitochondrial mechanisms of photobiomodulation,” *Photomedicine and Laser Surgery*, vol. 27, no. 4, pp. 579–587, 2009.
- [16] M. R. Hamblin, “Mechanisms and applications of the anti-inflammatory effects of photobiomodulation,” *AIMS Biophysics*, vol. 4, no. 3, pp. 337–361, 2017.
- [17] M. Wainwright, “Photodynamic antimicrobial chemotherapy,” *Journal of Antimicrobial Chemotherapy*, vol. 42, pp. 13–28, 1998.
- [18] A. M. Romanos, “Laser applications in oral surgery,” *Oral and Maxillofacial Surgery Clinics of North America*, vol. 16, pp. 1–15, 2004.
- [19] R. A. Convissar and D. J. Goldstein, “Laser dentistry: Current status and future applications,” *Dental Clinics of North America*, vol. 48, no. 4, pp. 779–792, 2004.
- [20] M. A. Gutknecht, “Laser applications in dentistry: Clinical considerations,” *Lasers in Medical Science*, vol. 17, pp. 193–198, 2002.
- [21] D. J. Coluzzi, “Laser-assisted soft tissue procedures in dentistry,” *Dentistry Today*, vol. 26, pp. 84–89, 2007.
- [22] M. Ozbayrak, H. Dumlu, and M. Ercalik-Yalcinkaya, “Treatment of gingival melanin pigmentation with diode laser,” *Journal of Clinical Periodontology*, vol. 34, pp. 138–143, 2007.
- [23] J. Lindhe and N. P. Lang, *Clinical Periodontology and Implant Dentistry*, 6th ed. Oxford, U.K.: Wiley-Blackwell, 2015.
- [24] A. Moritz et al., “Treatment of periodontal pockets with a diode laser,” *Lasers in Surgery and Medicine*, vol. 22, pp. 302–311, 1998.



- [25] M. Kreisler et al., “Effect of diode laser irradiation on periodontal pathogens,” *Lasers in Surgery and Medicine*, vol. 30, pp. 203–210, 2002.
- [26] A. Schwarz et al., “Laser application in periodontal therapy: A review,” *Journal of Clinical Periodontology*, vol. 30, pp. 45–52, 2003.
- [27] A. B. Sigusch et al., “Antimicrobial photodynamic therapy in periodontal treatment,” *Journal of Periodontology*, vol. 79, pp. 133–140, 2008.
- [28] A. S. Slot and F. A. Van der Weijden, “The effect of adjunctive laser therapy in periodontal treatment,” *Journal of Clinical Periodontology*, vol. 42, pp. 119–129, 2015.
- [29] P. N. Nair, “On the causes of persistent apical periodontitis,” *International Endodontic Journal*, vol. 39, pp. 249–281, 2006.
- [30] E. Gutknecht et al., “Laser applications in endodontics,” *Lasers in Medical Science*, vol. 16, pp. 1–8, 2001.
- [31] M. Moritz et al., “Bacterial reduction in root canals using diode lasers,” *Journal of Clinical Laser Medicine & Surgery*, vol. 19, pp. 231–236, 2001.
- [32] A. Meire et al., “Evaluation of laser-induced temperature changes during endodontic procedures,” *International Endodontic Journal*, vol. 42, pp. 789–796, 2009.
- [33] F. Bago et al., “Antimicrobial photodynamic therapy in endodontics,” *Lasers in Medical Science*, vol. 28, pp. 459–466, 2013.
- [34] S. Mohammadi, “Laser applications in endodontics: A review,” *International Dental Journal*, vol. 59, pp. 1–9, 2009.
- [35] R. Joiner, “The bleaching of teeth: A review of the literature,” *Journal of Dentistry*, vol. 34, pp. 412–419, 2006.
- [36] C. G. Kossatz et al., “Light-activated bleaching systems and their clinical effects,” *Clinical Oral Investigations*, vol. 17, pp. 1329–1337, 2013.
- [37] L. Hein et al., “Laser activation of dental bleaching agents,” *Lasers in Medical Science*, vol. 24, pp. 1–6, 2009.
- [38] M. Maran et al., “Effectiveness of light sources for dental bleaching,” *Journal of Dentistry*, vol. 46, pp. 1–10, 2016.
- [39] M. S. Baik et al., “Thermal effects of laser-assisted tooth bleaching,” *Dental Materials*, vol. 25, pp. 129–134, 2009.
- [40] M. R. Hamblin and T. N. Demidova, “Mechanisms of low level light therapy,” *Proceedings of SPIE*, vol. 6140, pp. 1–12, 2006.
- [41] T. Karu, “Cellular mechanisms of low-power laser therapy,” *IEEE Journal of Quantum Electronics*, vol. 23, no. 10, pp. 1703–1717, 1987.



[42] L. A. Mester et al., “Effect of laser stimulation on wound healing,” *Radiobiologia Radiotherapia*, vol. 27, pp. 233–236, 1986.

[43] R. A. Bjordal et al., “Low-level laser therapy in pain management,” *Photomedicine and Laser Surgery*, vol. 25, pp. 107–117, 2007.

[44] C. de Almeida et al., “Photobiomodulation therapy in dentistry: Clinical applications,” *Lasers in Medical Science*, vol. 34, pp. 1–12, 2019.

[45] A. J. Nicolau et al., “Photobiomodulation and implant osseointegration,” *Clinical Implant Dentistry and Related Research*, vol. 19, pp. 1–9, 2017.

[46] M. Cruz et al., “Effects of low-level laser therapy during orthodontic movement,” *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 151, pp. 1–10, 2017.

[47] M. R. Hamblin, “The biphasic dose response in photobiomodulation,” *Photomedicine and Laser Surgery*, vol. 32, pp. 1–5, 2014.

[48] A. Romanos and R. Nentwig, “Diode laser applications in periodontal therapy,” *Journal of Clinical Periodontology*, vol. 31, pp. 453–457, 2004.

[49] P. Rechmann et al., “Er:YAG laser applications in dentistry,” *Lasers in Medical Science*, vol. 31, pp. 1–15, 2016.

[50] D. J. Coluzzi, “CO₂ lasers in dentistry,” *Dental Clinics of North America*, vol. 44, pp. 831–840, 2000.

[51] American National Standards Institute, *ANSI Z136.1: Safe Use of Lasers*, Laser Institute of America, Orlando, FL, USA, 2014.

[52] A. Topolsky et al., “Artificial intelligence and intelligent systems in medical laser applications,” *Lasers in Medical Science*, vol. 36, pp. 1–10, 2021.

[53] Y. LeCun, Y. Bengio, and G. Hinton, “Deep learning,” *Nature*, vol. 521, pp. 436–444, 2015.

[54] M. R. Hamblin, “Nanotechnology approaches for antimicrobial photodynamic therapy,” *Photochemical & Photobiological Sciences*, vol. 15, pp. 1–12, 2016.