Diode lasers: The optical tool in dentistry (Review)

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Abstract. The present review aimed to provide a summary of the clinical applications, mechanisms of action and benefits of diode lasers in dentistry. It highlights their expanding role in soft tissue surgical procedures, biostimulation and antimicrobial therapies, while addressing their limitations, including cost, safety concerns and restricted use in hard tissues. A detailed analysis of existing literature was performed to evaluate the utility of diode lasers in dental procedures, such as crown lengthening, gingival depigmentation, frenectomy, the exposure of unerupted teeth, root canal disinfection, periodontal pocket therapy, photodynamic therapy and tooth whitening. Comparative studies between diode lasers and conventional techniques were reviewed to assess outcomes, mechanisms of tissue interaction and safety considerations. Relevant data were obtained from a comprehensive search of peer-reviewed journals from the Scopus, PubMed and other scientific databases. Diode lasers provide significant advantages over traditional methods, including precise soft tissue incisions, reduced bleeding, faster healing and minimal postoperative discomfort. Procedures, such as gingival depigmentation, frenectomy and crown lengthening achieve superior outcomes and aesthetics with diode lasers. They were also effective in bacterial decontamination and photodynamic therapy, reducing the need for antibiotics. Despite these benefits, limitations such as high costs, the potential for thermal damage and the necessity for specialized training were identified. In summary, diode lasers are versatile, minimally invasive tools offering superior results in soft tissue surgery and antimicrobial therapy. Their incorporation into dental practices enhances treatment outcomes; however, appropriate training and safety measures remain essential.

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1. Introduction

Light amplification by stimulated emission of radiation (termed laser), introduced in the 1960s by Maiman has been a breakthrough in the field of dentistry (1). Lasers can broadly be classified, on the type of tissue adaptability into hard-tissue lasers, such as neodymium-doped yttrium aluminum garnet (Nd:YAG), Er:YAG and carbon-dioxide, and soft-tissue lasers, such as diode lasers (2). While hard-tissue lasers are more versatile as regards their application, they are more costly and run a risk of causing thermal injury to the pulp (3).

The diode laser, running on the principle of a semi-conductor is compact, affordable and versatile in its application for soft tissue procedures and biostimulation. Its application has been tried and tested over a number of years in the field of dentistry and more specifically, in periodontology (3). It has multiple settings for various wavelength applications. Lower wavelengths (630-810 nm) are appropriate for use in techniques, such as antibacterial photodynamic therapy, while higher wavelengths (940-980 nm) are used for bacterial decontamination, soft tissue curettage in periodontal pockets and photobiomodulation (PBM) therapy.

2. Mechanisms of action of lasers

Lasers produce a single, coherent and monochromatic light through stimulated emission in a medium excited by an external energy source. Mirrors reflect and amplify photons, with a partially reflecting mirror, at an angle, narrowing the light to a focused beam prepared to emerge (4).

The wavelength is primarily determined by the composition of its active medium, namely gas, crystal or a solid semiconductor. Out of the four possible interactions which can occur, that include reflection, transmission, scattering and absorption, the latter is the most ideal for its application (5). Once absorbed, the temperature rises, producing photochemical effects. Protein denaturation occurs at temperatures ranging from 60 to 100˚C. Beyond this range, water ablation or vaporization occurs. In the event that the temperature exceeds 200˚C, all water content is lost and dehydration results in burning (Fig. 1).

Diode lasers. Diode lasers are packed into a conveniently sized and portable device, allowing for an easier application across different procedures in the field of dentistry. A diode laser is primarily a solid semiconductor comprised of aluminium, gallium, arsenide and indium. This is used to convert the input electrical energy to produce light of varying wavelengths. These are further readily absorbed by chromophores, such as melanin and hemoglobin present in the soft tissue, allowing for ideal application. The use of diode lasers in hard tissue, however, is not practically applicable, as they exhibit poor absorption by hydroxyapatite, predominantly observed in enamel. The flexible fiber optic fiber aids in delivering treatment rays to the desired area (6). The treatment plan determines the use of either continuous or pulsed modes and that of contact and non-contact applications.

Over the years, ample research has been performed to further investigate diode lasers, and various advantages have been suggested. Compared to more conventional techniques, such as the use of scalpels, diode lasers provide higher precision, a more bloodless field, and thus, improved visualization, and the placement of suture is obsolete. Diode lasers also provide an excellent post-operative recovery period with minimal bleeding, swelling and pain (7).

However, the use of diode lasers is not without disadvantages. The equipment is costly, and is thus not accessible to all dental clinics. Their use is also associated a risk of morbidities, such as damage to the eye in the case that appropriate protection is not used; thus, specialized training is required for the use of diode lasers (8). Below, the use of diode lasers in dentistry is discussed.

Crown lengthening. Diode lasers can be applied to various procedures, such as in case of inadequate crown length prior to crown placement, for the restoration of subgingival caries or fracture exposure and for the correction of gummy smile (9). However due to a lack of hard-tissue applications, it cannot only be used in cases where there is a wide band of keratinized tissue and optimal space between the alveolar crest and cementoenamel junction. The use of diode lasers is proposed to be a more safe and effective alternative to the traditional scalpel, as these lasers minimize bleeding and improve post-operative pain according, to the visual analogue score (10).

Gingival depigmentation. In the case of severely pigmented gingiva, a surgical periodontal procedure may be used to reduce or remove the zones of hyperpigmentation with the aid of a scalpel, high-speed handpiece, cryosurgery or electrosurgery (11). Diode lasers have been proven to be a single-step alternative. They eliminate the need for a periodontal dressing, as their use is associated with a more rapid healing process, with reduced pain and discomfort (12). A higher esthetic appearance is expected when using the diode laser for gingival depigmentation compared to the CO_2 laser. The application of the diode laser at pulsed mode may be recommended for gingival depigmentation, as its use is associated with improved esthetic outcomes and requires a smaller amount of time to achieve results (13). The increasing esthetic demands of individuals require the removal of hyperpigmented gingival areas to create a confident and appealing smile, which can be easily attained using a laser. As regards clinical significance, the use of a laser is an effective tool which requires a smaller amount of time to obtain results. The use of lasers is also associated with lower levels of pain and discomfort, as well as a more rapid healing process, and delayed repigmentation compared with the use of scalpels or electrosurgery for gingival depigmentation (14).

Exposure of unerupted and partially erupted teeth. Lasers are also used for soft tissue removal over unexposed or partially erupted teeth, for the placement of orthodontic brackets or the removal of an operculum. They have an added advantage over surgery in sealing small blood vessels and lymphatic vessels. There is also minimal tissue shrinkage in laser procedures, and thus, less scarring. The need for suturing is also eliminated in the majority of cases, as healing occurs by secondary intention (15).

Removal of tissue overgrowth. Fibrous hyperplasia is often observed due to chronically ill-fitting dentures. To resume the use of dentures, overgrowth removal is necessary (16). Diode lasers exhibit positive results along with suitable homeostasis and less post-operative pain. They can also be utilized to obtain biopsy specimens (17).

Frenectomies. A high labial frenum can cause severe discomfort and pain, in which case its removal may be indicated (18). For a relatively painless, bloodless procedure with reduced post-surgical complications, diode lasers can be used. The use of diode lasers is also particularly useful in ankyloglossia. In these cases, a thick band of frenal attachment is observed from the floor of the mouth until the tip of the tongue. The excision of this band of tissue is essential for free tongue movement (19).

Implant dentistry. Implant dentistry has been revolutionized over the past few years. It has been striving to replace more redundant techniques (20). In such a field, diode lasers have been proven to be an immense success. They are particularly useful in the second-stage of implant surgeries, as they provide an efficient, safe, bloodless and painless procedure (21). Diode lasers have also been proven to be useful for the removal of peri-implant soft tissue and the decontamination of failing implants. Various studies have been conducted in this field of study that prove that diode laser-assisted implant exposure eliminates the need for local anesthesia (22).

However, the duration of surgery, healing time, post-operative pain and overall success of the implant exhibit similar results to those of scalpel surgery. Following treatment for peri-implantitis with lasers, there is also a lack of re-osseointegration observed with the use of lasers. There is also a concern raised regarding the overheating of the implant surface, followed by melting which can be a crucial drawback (23).

Wound healing. Biostimulation is another term for low-level laser therapy (LLLT). Research indicates that a small amount of laser energy (2 J/cm^2) encourages the growth of fibroblasts,

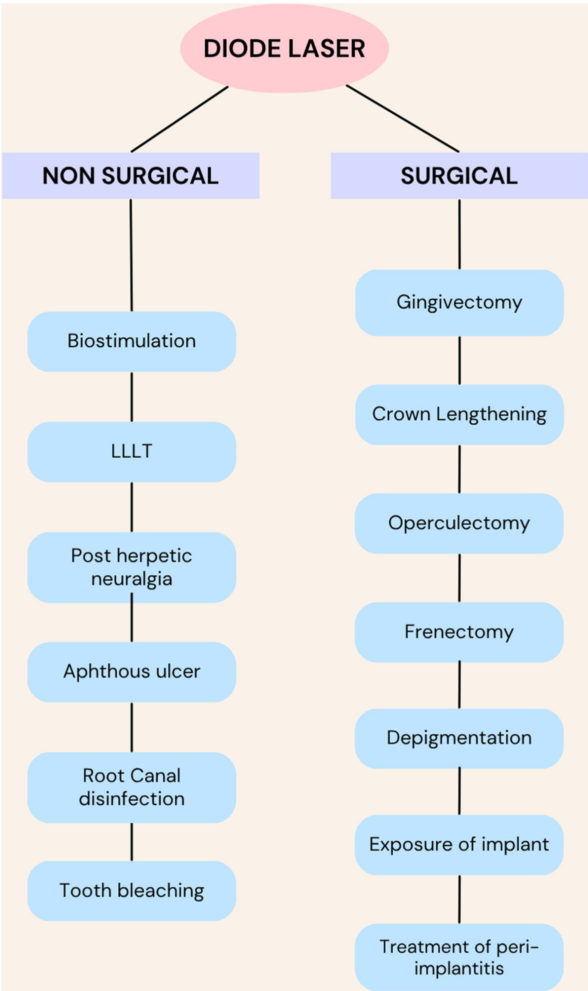

Figure 1. Diagrammatic representation of the mechanisms of action of lasers in dental applications. The figure illustrates how laser energy is produced, transmitted, and interacts with biological tissues including reflection, transmission, scattering, and absorption. These interactions lead to clinical effects such as protein denaturation, ablation and coagulation. LLLT, low-level laser therapy.

whereas larger doses (16 J/cm^2) inhibit their proliferation (24). The rise in fibroblast growth and movement leads to greater strength in healed wounds. Research indicates that within the initial 72 h following radiation exposure, biostimulation through LLLT leads to the increased proliferation and maturation of human osteoblast-like cells. In fact, a synergistic effect of laser use in combination with ozonized substances has been demonstrated (25).

Photoactivated disinfection (PAD). Low-level laser energy from a diode lasers functions as a photo-activator of oxygen releasing dyes, such as Methylene blue. This has been shown to cause membrane and DNA damage to microorganisms when activated (26).

As stated in the literature, PAD has been found to be particularly effective in killing bacteria, including sub-gingival plaque in deep periodontal pockets, which are generally known to be resistant to anti-microbial agents. It has also been demonstrated to kill Gram-positive bacteria (including methicillin-resistant *Staphylococcus aureus*), Gram-negative bacteria, fungi and viruses. It is also now being used in the disinfection of peri-mucositis and peri-implantitis (26).

Post-herpetic neuralgia and aphthous ulcers. Post-herpetic neuralgia is a chronic painful condition that occurs as a complication of herpes zoster virus (27). It is generally observed due to the reactivation of a varicella zoster virus found dormant in a nerve cell near the spinal cord. This virus is commonly known to cause chickenpox. Upon reactivation, it manifests as a painful rash along the specific dermatome innervated by the spinal nerve (27).

The condition is commonly known to be painful along with hyperesthesia or even allodynia. LLLT has been demonstrated to reduce this pain and enhance the healing process in these conditions. In particular, in the case of recurrent herpes simplex labialis lesions, photostimulation during the prodomal stage has been shown to arrest the acceleration and progression of the healing process and to reduce recurrence (28).

Root canal disinfection. Traditionally, root canal preparation is performed with mechanical instrumentation using files and irrigants. *In vitro* studies (29-31) have suggested the use of laser irradiation following this to increase the disinfection of deep radicular dentin. It has also been associated with effective sealing of dentinal tubules, eliminating *Escherichia coli* and *Enterococcus faecalis*. This has also been suggested to increase the efficacy of endodontic treatments (29-31).

Removal of periodontal pocket lining. In the case of a periodontal pocket, scaling and root planing are the primary steps for treatment. This helps remove the inflamed gingival tissue and infected material present in the pocket. Following this, the optical fiber of a diode laser can be introduced into the pocket in ascending and descending movements, while maintaining it parallel to the main access of the tooth root (32). It is rotated around the perimeter of each involved tooth. This helps to remove the pocket lining, leading to a reduction of the periodontal pocket (33).

In their study, Assaf *et al* (34) used a diode laser in conjunction with ultrasonic scaling for the treatment of gingivitis. The results of their study revealed a significantly lower incidence of bacteremia in the group treated with diode and ultrasonic therapy (36%) compared with the group treated only with ultrasonic therapy (68%) (34). In addition, it has been suggested that in order to prevent bacteremia, particularly in immuno-compromised patients, diode lasers should be used. For example, Kamma *et al* (35) confirmed that the total bacterial load in pockets was reduced without the use of any systemic antibiotic therapy.

Tooth whitening. Laser lights enhance the efficacy of hydrogen peroxide in the bleaching agent to a greater extent than light-emitting-diodes (LEDs) (36). Teeth bleached with LEDs exhibit a significant decrease in color intensity and appear gray, while those treated with laser exhibit improved color intensity and less grayness (37). Furthermore, increased brightness and decreased sensitivity can be attained using lasers to activate hydrogen peroxide (38).

3. Laser-assisted pediatric dentistry

Lasers have emerged as a valuable tool in pediatric dentistry due to their minimally invasive nature, reduced need for anesthesia and improved patient comfort. Diode lasers are commonly used for soft tissue procedures, such as frenectomy, pulpotomy and gingivoplasty. In children, lasers provide advantages, such as reduced bleeding, a more rapid healing process and lower anxiety levels compared to conventional techniques. Moreover, their bactericidal properties enhance infection control in procedures involving the pulp or soft tissues. However, careful parameter selection is essential to avoid thermal damage, particularly in immature or developing tissues (39).

PBM and anesthesia. PBM has gained increasing attention due to its efficacy in pain reduction in various fields of dentistry. However, available studies on the effects of PBM on injection pain in children are minimal. A previous study examined the efficacy of PBM with three different application parameters (doses) and topical anesthesia in reducing injection pain and compared these results with the placebo PBM and topical anesthesia in children during supraperiosteal anesthesia administration; however, no differences were found between the groups (P=0.109 and P=0.317). In addition, in that study, the injection pain in children did not differ compared to the placebo and PBM applied at a power of 0.3 W for 20, 30 and 40 sec (40).

4. Laser-tissue interactions and related complications

Laser-tissue interactions in periodontal therapy are governed by factors, such as wavelength, power density, pulse duration and tissue characteristics. While lasers provide numerous advantages, including precise cutting, hemostasis and minimal postoperative discomfort, overexposure to laser energy can lead to significant soft tissue complications. Excessive thermal energy can cause coagulative necrosis, carbonization, or deep tissue burns, leading to delayed wound healing and scarring. Moreover, prolonged or improperly focused exposure can result in destruction of adjacent healthy tissue, compromising the structural and functional integrity of the periodontium. Overheating may also impair microcirculation and fibroblast viability, essential for optimal regeneration. In some cases, laser-induced edema, pain, or ulceration has been reported due to excessive tissue ablation or inadequate cooling. Therefore, strict adherence to recommended laser parameters and technique is critical to avoid iatrogenic injury and ensure therapeutic efficacy (41).

5. Advances in diode lasers

A dual-wavelength diode laser in dentistry has been introduced that combines two distinct wavelengths, typically 450 and 808 nm, in order to provide a versatile approach to soft-tissue procedures. This approach has certain advantages compared to single-wavelength lasers, as it utilizes the unique properties of each wavelength to achieve optimal coagulation, ablation and healing (42).

A flexible optical fiber, typically in the form of a handpiece, transmits the laser beams to the target area. The laser can be used in both continuous and pulsed modes (pulse duration ranging from 0.1 msec to infinity, with programmable frequencies up to 10,000-20,000 Hz). The laser beam is delivered through optical fibers with diameters ranging from 200 to 600 μm. The clinical approach and treatment methods determine the selection between continuous and pulsed modes, contact or non-contact tissue application, and the specific type of tip recommended by the manufacturer. A number of diode lasers allow for the adjustment of parameters, such as power and frequency to minimize tissue damage and enhance precision. The use of dual-wavelength lasers for surgical purposes can lead to improved hemostatic cutting. In the majority of cases, healing occurs by secondary intention with minimal scar formation, eliminating the need for sutures. Additionally, there is a significant reduction in post-operative pain and inflammation, attributed to cellular biomodulation resulting from residual energy transmission to the tissues during the cutting action. By using both wavelengths, dual-wavelength lasers can achieve a balance between coagulation and ablation, potentially minimizing collateral damage and promoting more rapid healing (42).

6. Conclusion and future perspectives

Diode laser technology and its various applications in dentistry date back to several decades; however, it has been in the past 10 years that diode lasers have gained a greater prominence owing to the immense technical development achieved and the materialization of affordable equipment for the dentist. All these advancements have allowed for the current use of lasers in numerous procedures to improve the performance of conventional therapies; however, this is not sufficient. The use of different diode laser therapies should be consolidated with further research. In recent years, progress has been made in this regard, as it has gained increasing prominence as an adjuvant therapy; however, although there are several notable *in vitro* and clinical studies available on the use of lasers (as aforementioned), further research is warranted to address laser therapy from a different perspective (43).

There is a possibility to match laser technology with other recently introduced technology, such as smartphone applications and artificial intelligence. It is desirable that future studies evaluate long-term results to confirm the effectiveness and use of diode lasers. Furthermore, studies involving larger samples are warranted. The importance of lasers should be explained by dental practitioners to make patients aware of their existence and benefits. The ethical and legal implications of the use of lasers should also be carefully considered. It would also of interest to combine lasers with recently introduced artificial intelligence software, which is an interesting and current research topic (44,45).

In conclusion, the utilization of diode lasers in oral soft tissue surgery is due to their simple application, improved coagulation, elimination of suturing, reduced swelling and pain, and their ability to address physiological gingival pigmentation for aesthetic purposes. Diode lasers are a preferred option for their swift action, enhanced de-epithelialization, lack of bleeding and superior healing. Over the past 40 years, diode lasers have been increasingly utilized in various dental procedures, such as biostimulation for wounds, activating teeth whitening gel, photodynamic disinfection and enhancing root canal disinfection. Due to its affordable price and convenient size, this optical scalpel is becoming increasingly popular among dentists in dental clinics and hospitals.

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Authors' contributions

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Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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