Chapter

Introduction to Diode Laser Therapies in Dentistry

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Abstract

Actually, there are different types of lasers that can be used in dentistry, being the diode laser one of the most popular. The therapies in which diode laser is used are photothermic therapy, which is subdivided into low- and high-intensity photothermal therapy and photodynamic therapy. Photothermic therapy is based on an increase in local temperature, allowing the incision, excision, ablation, and vaporisation of the tissues, as well as haemostasis and coagulation of lesions. It also produces bacterial decontamination through thermal photo disinfection. Low-intensity photothermic therapy also achieves an analgesic, anti-inflammatory, and healing effect. On the other hand, photodynamic therapy facilitates bacterial decontamination through activated photodisinfection in combination with a photoactive substance. These therapies can be used in a separate way or combined, obtaining different results depending on the tissue in which they are applied and according to the technical specifications used. Therefore, the diode laser, thanks to its versatility, applicability, and good clinical results in specialities such as endodontics, periodontics, surgery, or implantology, should be considered as an implement of transversal application in contemporary dentistry.

Keywords: dentistry, diode laser, photothermal therapy, photodynamic therapy, cellular biostimulation

1. Introduction

The application of laser in medicine is one of the most used and developed treatments in recent years. It was first introduced to the health field in dermatology in 1960 [1]. Laser technology is developing very rapidly, allowing for the diversification of lasers in the field of dentistry. The word LASER as it is commonly known today, comes from the initials of its acronym: "Light Amplification by Stimulated Emission of Radiation". The laser is an electro-optic device that, when stimulated, emits a beam of monochromatic light with high-intensity energy [2].

Dermatology was the first medical speciality to introduce laser therapy in 1995. That is when the clinical uses and limitations were presented. The main function with which it was presented was selective photothermolysis in common vascular and pigmented conditions of the skin and mucous membranes, including infants and children. The results were effective and quickly evaluated, being incorporated into the daily practice of the moment [1].

Lasers were introduced into the field of clinical dentistry with the hope of overcoming some of the drawbacks posed by conventional dental procedure methods [3]. Among the first studies such as that of Maiman et al. in 1960 [4] about the first operative laser, already introduced the use of the laser itself in the world of dentistry. The first laser studies on dental tissues, such as the one carried out by Stern and Sognnaes in 1965, already reported significant clinical effects on tooth structure *in vivo* and *in vitro* with the ruby laser. In these articles, the absence of heat harmful to oral tissues or sensitive dental pulp has already been demonstrated [5].

Nowadays, dental lasers are widely used in the dental field around the world, allowing patients to be provided with high-quality treatments in minimally invasive dentistry [6, 7].

1.1 Mechanism of action

A laser is a device that produces coherent electromagnetic radiation. Therefore, light amplification by stimulated emission of radiation, known as LASER for short, is an electro-optic device that produces a narrow and highly energised monochromatic beam of radiation of a specific wavelength. Depending on the wavelength of the laser and where it is applied, different optical phenomena may occur [8].

It is light, so it has the basic properties of optics, such as transmission, absorption, reflection, and refraction. The absorption by the tissues of the incident light energy on the irradiated tissues will be the one that releases their energy [2]. The emitting units of laser energy allow for the variation of some parameters related to the amount of energy released per unit of time, or what is the same, the power. The handpieces that will facilitate the transport of energy to the target tissue are usually provided with optics that will allow us, depending on the distance of application, to concentrate or distribute the laser energy on a smaller or larger application surface [9]. Thus, when we apply a certain amount of energy per unit of time, we obtain a higher power density on a small surface than when we apply it to a larger surface. Power density will determine different effects on the same tissue [10].

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2. Laser in dentistry

2.1 Types of lasers most used in dentistry

Lasers in dentistry are diverse and, as mentioned above, will be specific according to the target tissue to be treated. That is why they will be divided into specialities to talk about the most used in each of the areas. Specifically in oral implantology and periodontology, they are the CO_2 laser, the diode laser, the Nd: YAG laser and the Er: YAG laser. These have, in this area, as main utility, debridement treatments, subgingival curettage (in scaling and root planing), and periodontal surgeries such as open flap, which are complementary to mechanical debridement. Other surgical procedures found with these lasers are bone recontouring, and implant maintenance, in prophylaxis of mucositis or peri-implantitis [12, 13]. Nd:YAG lasers have the advantage of being used whether or not they come into contact with the medium to be treated. Er: YAG lasers are mostly used in the decontamination of implant surfaces without causing any detrimental effect on the surrounding bone. In those treatments on teeth, it has been shown that CO**2** lasers are safe for use on hydroxyapatite, the main dental component [14, 15].

2.1.1 CO_2 laser

The CO_2 laser belongs to the group of high-power lasers. Its medium is the gaseous state, and it has a wavelength of around 9600–10,600 nm. Its waveform is described as continuous superpulsed. Due to its characteristics, it is absorbed by soft tissues, producing temperature increases of around 1700°C in the target tissue. As an advantage, it presents less heating in the adjacent tissues with respect to other less surface-absorbed lasers [9, 16].

The main use of the CO_2 laser in dentistry is focused on the specialities of oral implantology and periodontics, as well as the diode laser, the Nd:YAG laser and the Er: YAG laser. Specifically for tissue cuts such as incision, soft tissue ablation, and gingival de-epithelialisation in periodontal regenerative procedures. In addition, in the treatment of dental implants for disinfection, bone recontouring, and the maintenance of implants, in the prophylaxis of mucositis or peri-implantitis [17].

2.1.2 Nd:YAG laser

The neodymium:yttrium-aluminium-garnet (Nd:YAG) laser belongs to the group of high-power lasers. Its medium is the solid state, and it has a wavelength of around 1064 nm. Its waveform is pulsed. As a disadvantage, studies point out that both the Nd:YAG laser and the diode laser present a risk of thermal accumulation in adjacent tissues, since they are not well absorbed by soft tissues. That is why they should not exceed 65°C to avoid necrosis of the same [9].

The use of the Nd:YAG laser in dentistry is focused on the specialities of oral implantology and periodontology, as well as the diode laser, the CO_2 laser and the Er: YAG laser. It is also used in dental therapy, specifically for tissue cuts such as incision, soft tissue ablation, haemostasis, periodontal decontamination, and in dental therapy for vaporisation of incipient caries, treatment of dentin hypersensitivity, and root canal decontamination in endodontics [9, 18].

2.1.3 Er: YAG laser

The Erbium, yttrium-aluminium-garnet (Er: YAG) laser's waveform is described as continuous pulsed. Its medium is the solid state, and it has a wavelength of around 2940 nm [10].

Among the main uses are tissue cuts such as incision, soft tissue ablation, haemostasis, periodontal decontamination, and in dental therapy for vaporisation of incipient caries, treatment of dentin hypersensitivity and root canal decontamination in endodontics. The biomechanical preparation of the root canal is carried out in a conventional way, but there are publications in which Er, Cr:YSGG or Er: YAG lasers are used for this purpose. Both the Er: YAG laser and the Er, Cr:YSGG laser have shown high disinfection in exposed dentin, where it is common to find smears with the presence of bacteria, that is, caries [8].

2.1.4 Diode laser

The diode laser corresponds like the previous ones, to high-power lasers. This type of laser is not visible, and the transmission is by fibre optics and infrared, continuous wave. It shows variations in its wavelength presentation, from 810 to 980 nm. Hence, it is versatile in its forms [19]. Depending on their power, diode lasers can be classified into two large groups. Low-power diode lasers are also called soft lasers due to their low energy. They emit in the region of the near-infrared or red spectrum (632.8, 670 and 830 nm wavelength), with an average power of 1–100 mW. Its main clinical applications are based on its biostimulatory effect and its analgesic-anti-inflammatory effect. The other type of diode laser is High Power. Lasers with powers between 1 and 15 W or higher and with a wavelength between 810 and 980 nm. In accordance with international classifications regarding the safety measures to be taken into account when using these devices, the European Union (ISO) and the United States (ANSI) regulations consider the diode laser a type IV laser [8, 9].

2.2 Laser therapies

In addition to the physical foundations of laser operation, the response of the tissues to laser light must also be taken into account. The oral cavity is a very complex application area for laser therapy [16]. This is due to the fact that it has highly differentiated and specialised areas. Hard and mineralised tissues such as teeth or bone tissue, as well as soft tissues. All these structures have different optical characteristics and will not respond in the same way to the same laser or the same wavelength [20].

Treatment guidelines, and therefore therapies, depend on the laser used and the thermal effects to be achieved on the target tissue. In order to advance in the understanding of laser therapy in oral tissues, it is necessary to understand, first, the main photobiological effects. These are the effects that the laser beam produces when it is absorbed by the oral tissues. The main photobiological effects are photothermal and photochemical effects [21]. The most widely used diode laser therapies are based on these two principles.

3. Photothermal diode laser therapy

Photothermic therapy was the first to be studied; lasers produce a thermal effect on tissues, which translates into very precise cuts, vaporisation, and coagulation of small blood vessels [16]. This therapy is based on the conversion of light energy into thermal energy, increasing the temperature in the tissues and producing injuries that will depend on the degrees reached [8, 20].

Photothermic therapy can be divided into two distinct varieties. High- and low-intensity photothermal therapy [22]. Although both employ the same principle of thermal energy, high-intensity therapy derives its benefits from increasing the temperature produced by the laser beam in the tissues, while low-intensity therapy focuses more on cellular biostimulation instead of temperature (**Table 1**).

Diode laser therapy		Mechanism of action	Biological effect
Photothermal laser therapy	High-intensity photothermal therapy	Thermal energy	Bemostatic cut Coagulation Bactericidal and bacteriostatic
	Low-intensity photothermal therapy	Photon-cell interaction	Cell biostimulation Analgesic Anti-inflammatory
Photodynamic therapy	Photochemical therapy	Photochemical reaction	Bactericidal and bacteriostatic

Table 1.
Summary of diode laser therapies.

3.1 High-intensity diode photothermal therapy

3.1.1 Mechanism of action

In order to perform high-intensity photothermal therapy, it is necessary to have a diode laser capable of emitting a wavelength between 810 and 980 nm and with powers between 1 and 15 W. The photothermal interaction is characterised by an increase in local temperature induced by the action of the laser [6, 7]. Thus, the main photothermal interactions are tissue incision/excision, ablation/vaporisation, and haemostasis/coagulation. The light energy contacts the tissue for a certain time (exposure time) and produces a thermal interaction [5–7, 18].

Depending on the temperature reached, the effect will vary. Bacterial inactivation occurs when the temperature reaches 37–50°C [21]. When the temperature rises to 60–70°C, protein coagulation and denaturation are observed [6, 7, 13]. If the temperature is 100°C, the histological water vaporisation occurs in a phenomenon called vaporysis, a process that results in tissue ablation [21]. In the event that the thermal process exceeds 200°C, an effect called carbonisation occurs, where the carbon develops as the final product of thermolysis and acts by dissipating heat, causing potential trauma to the adjacent tissues [16, 18].

3.1.2 Main indications

The first speciality in dentistry to implement the use of diode laser photothermal therapy was surgery, and today, it continues to be one of its main indications for use [8, 9]. When the use of the diode laser was implemented in this speciality there was already experience in the use of the CO_2 laser; however, a less aggressive laser with soft tissues was necessary and one that was safe to use close to the teeth since the diode laser is less absorbed by the water of the mineralised tissue. The main advantage of the diode laser in surgery is its great haemostatic cutting effect, which makes it ideal when excision is intended, limiting bleeding [23]. However, the diode laser can be used to perform all types of soft tissue surgeries such as the removal of benign lesions. Especially indicated for soft tissue injuries near the teeth. In most cases, the lesions heal by the second intention, so there is no need for a suture [24]. We can successfully use the diode laser in the treatment of excision of a wide variety of benign tumours of the oral cavity, such as papillomas, ranulas, mucoceles, fibromas, focal epithelial hyperplasia of the oral cavity, recurrent aphthae, epulis, melanic spots, etc.

Therefore, the main advantages of diode laser in surgery are less postoperative swelling, improvement in tissue healing and reduction in scar formation [11, 23].

Another speciality in which diode laser photothermal therapy is widely used is periodontics. The main benefit sought with the application of lasers in periodontics is bacterial decontamination [25]. It is a great help in areas of difficult access where the benefit of conventional treatments is more limited, such as furcations or deep pockets [26]. One of the most used lasers in periodontics is Er: YAG, with its bactericidal effects against periodontopathogenic bacteria [27]; it also eliminates bacterial endotoxins and the temperature reached by the cement was kept within clinically safe limits for dental pulp [26, 27]. However, the root morphology obtained after instrumentation with the Er: YAG laser has been the subject of study, since it has been reported that the root surfaces treated with this laser show an irregular, chalky appearance with isolated craters, which could favour bacterial recolonisation [28]. The current lines of research are focused on the use of the diode laser since its bactericidal efficacy has been well documented [29]. Mainly in colonies of *Actinobacillus actinomycetemcomitans*, this bacterium is associated with the most aggressive forms of periodontal disease, and diode laser can be an aid where the classic treatment of scaling and root planing is less effective [16, 26].

Photothermic therapy with diode laser in implantology has been used mainly for the treatment of peri-implant pathologies [16, 18, 26]. The term "peri-implant diseases" collectively refers to the inflammatory processes that take place in the tissues surrounding an implant [30] and follow the same principles as in the speciality of periodontics, seeking its bactericidal effect and tissue biostimulation. The evidence obtained in experimental studies in animals and humans shows that the main etiological factor involved in the development of peri-implant pathologies is the accumulation of biofilm [31, 32]. However, despite the fact that the evidence in periodontal studies demonstrated the bactericidal effectiveness of the diode laser and its safety in periodontal and dental tissues, it was necessary to investigate its interaction with the titanium structure of dental implants to allow its use in implantology [16, 18]. This interaction is observed in a study carried out by Romanos et al. In 2000, they compared *in vitro* the effects of Nd:YAG and diode lasers (980 nm) on titanium discs that simulated dental implants. Their results were that, contrary to what happened with the Nd:YAG laser, the discs subjected to the diode laser were not damaged or modified [33]. Showing, therefore, that the diode laser does not change the surface of dental implants and that it can be used in the treatment of peri-implant diseases. Several studies have reported better results in the resolution of peri-implant pathologies by adding diode laser photothermal therapy to mechanical debridement [32]. This is due to its bactericidal effect against the main periodontopathogens together with its ability to biostimulate tissue in deep layers [33]. These characteristics allow the laser to act against the main etiological factor of peri-implant pathologies in addition to favouring the response of the tissues to the treatment [24]. However, although the results are promising, more research is needed to determine if photothermal diode laser therapy can alleviate the limitations of conventional therapy in the treatment of these pathologies [32, 34]. **Figure 1** shows the 300 μ optical fibre tip of the 890 nm diode laser being used in the treatment of peri-implant mucositis.

Similar to how it occurs in periodontics and implantology, the bactericidal effect of the diode laser can also be used in the endodontic treatment of teeth [34, 35]. One of the main objectives of endodontic treatment is to leave the root canal free of microorganisms [36]. For this, different disinfection systems can be used, and the diode laser is one of them. However, caution must be taken to prevent possible thermal damage generated by the laser on the periodontium or the tooth itself. Photothermal disinfection of root canals can increase root canal dentin

Figure 1.
Fox III diode laser (a.R.C. Laser GmbH, Nürnberg, Germany) 300 μ optical fibre tip being used in the treatment of peri-implant mucositis.

temperatures, but periodontal fluid circulation has a cooling effect on the outer root surface, reducing the risk of potential thermal injury to periodontal tissue [37]. Several studies have shown that this laser can be used with up to 4.5 W of power with an exposure time of 60 seconds, achieving a correct bacterial elimination from the canal (**Table 2**) [38].

3.1.3 Contraindications

The main contraindications of diode laser photothermal therapy derive from one of its main characteristics, which is the high penetration of the thermal action in deep layers [24]. This effective penetration of the laser is what allows biostimulation of oral soft tissues; however, it can be a disadvantage on certain occasions. For example, its use in the removal of premalignant or malignant lesions is more limited due to the high penetration capacity of the laser, which will cause an area of cellular biostimulation in deep tissue layers [9, 11]. This could lead to a recurrence of the lesion if it were not completely excised with wide margins of safety. For the treatment of these lesions, the use of the CO_2 laser is more indicated [10].

Another element to take into account, especially in surgery, is that its haemostatic effect is much lower compared to the CO_2 laser, so it will only be useful for excision of superficial lesions, and it will not be recommended for excision of angiomatous lesions or for surgical interventions in which profuse bleeding is expected [23].

The diode laser is also not indicated for taking biopsies [10]. Because the use of laser with a marked thermal effect can alter the structure of the margins of the lesion and make the anatomopathological analysis of the sample difficult, in these cases, it is more advisable to use a cold scalpel [24].

Oral Surgery	Periodontics	Implantology	Endodontics
• Remove benign oral lesions • Haemostatic cut	• Coadjuvant treatment of periodontal disease	• Coadjuvant treatment of peri-implant pathologies	• Root canal desinfection

Table 2.
Main indications in dentistry for high inesity photothermal therapy.

Regarding the use of diode laser in the treatment of periodontal diseases and peri-implant pathologies, although it can be used as an adjunctive treatment in the management of these pathologies, it should never be used as an alternative to mechanical debridement [20, 26]. Conventional nonsurgical treatment based on mechanical debridement continues to be, as occurs in periodontics, the gold standard treatment [32, 39]. This is due to the fact that the bactericidal action of the laser is not capable of showing its efficacy without prior destructuring of the biofilm [26, 40]. Laser therapy therefore constitutes an aid to mechanical decontamination through thermal decontamination [40]. In a very similar way, it has also been shown that the use of the diode laser cannot replace the chemical disinfection obtained in endodontics with products such as sodium hypochlorite. In this way, it also constitutes an adjunctive treatment for the disinfection of the root canals [35].

3.2 Low-intensity photothermal therapy

3.2.1 Mechanism of action

Low-level light/laser therapy (LLLT) is the application of light (usually delivered via a low-power laser or light-emitting diode; LED) to promote tissue repair, reduce inflammation or induce analgesia [41]. The basis of low-intensity photothermal therapy is that its activity on tissues is not due to thermal effects but to the interaction of electromagnetic waves with cells [8]. This laser therapy uses the action of light and light alone to directly stimulate host cells in order to reduce inflammation, relieve pain and/or promote wound healing [41]. The therapy uses low-power lasers, also called soft lasers. These emit in the region of the infrared spectrum near red (632, 670 and 830 nm), with powers lower than 0,5 W or with lasers of higher emission power but used in defocused mode [9]. Its basic applications in health sciences are based on its tissue biostimulation effects and its anti-inflammatory analgesic action [42].

The mechanism of action of low-power laser therapy is based on cellular biostimulation. The photon-cell interaction mechanism consists of biomodulating tissue cells by supplying them with laser light, causing effects at a cellular level [43]. These effects occur due to the absorption of photons of a certain wavelength by the cellular photoreceptors, causing the transformation of the functional and metabolic activity of the cells [44]. In fact most of the effects of this biomodulation can be explained by light absorption within the mitochondria [41, 45].

The effect of photobiomodulation is based on its action on energy reserves in the adenosine triphosphate (ATP) in cells [45]. When the cell is damaged, these reserves decrease, and therefore, its metabolic activity is altered. The laser radiation acts directly on the photoreceptors of the respiratory chain, facilitating the conversion of adenosine diphosphate (ADP) to ATP [44]. Increased ATP stores facilitate the general activation of cellular metabolism. In turn, DNA is activated by ATP and protein synthesis begins, which results in the formation of structural proteins [41]. As laser radiation acts as an activator of protein synthesis and therefore of cell function, the processes of cell division and multiplication are accelerated [44]. This phenomenon could be responsible for the improvement in tissue healing when this therapy is used.

Laser energy is absorbed more easily where the concentration of fluids is greatest. Therefore, there will be a greater absorption in the inflamed and oedematous tissues, stimulating the numerous biological reactions related to the wound repair process [45]. Therefore, the biostimulatory effects of laser irradiation, such as higher cell proliferation and wound healing, may have interesting applications in current therapy approaches such as promotion of wound healing and reduction of inflammation as well as pain relief [41].

The effects of biostimulation by low-intensity laser therapy on cell metabolism are reflected at the clinical level. It has been documented that the activation and proliferation of human gingival fibroblasts, periodontal ligament cells, osteoblasts and mesenchymal stem cells, and the release of growth factors *in vitro*, were enhanced by low-level laser irradiation, according to several studies [16, 46, 47]. Reductions in inflammation have also been reported, and several *in vitro* studies indicated the reduction of proinflammatory molecules, such as prostaglandin E2, interleukins and tumour necrosis factor-alpha [48, 49]. Low-level laser therapy has been reported to promote osteogenesis, and several *in vitro* studies have shown that laser irradiation could promote bone nodule formation by inducing osteoblast proliferation and differentiation [50, 51]. This evidence has also been demonstrated in *in vivo* studies, and several histological studies indicated an increase in angiogenesis and the formation of connective tissue, also observing an increase in the formation of new bone in the site treated with laser, compared to the non-treated controls [52, 53].

3.2.2 Main indications

Dental applications for low-intensity photothermal therapy are not well documented; however, more studies are now being reported. In fact, we now have promising data for the application of this diode laser therapy in a number of dental specialities including endodontics, periodontics, orthodontics, and maxillofacial surgery, as described below [41].

In surgery, it can be used after especially complex extractions to reduce pain, oedema trismus, and inflammation. It can also be used to promote osteogenesis after tooth extraction because laser-irradiated extraction wound healing showed different characteristics from those of the normal healing process, suggesting the promotion of healing [54, 55]. In periodontics, the anti-inflammatory effect reduces the deterioration of periodontal tissues, reduces inflammation, and facilitates the hygienic phase, polished scaling and root planing or periodontal surgical treatments [56, 57]. In implant therapy, low-level laser therapy applied after conventional techniques shows promise for increased and faster osseointegration of implants following irradiation [16]. This therapy can also be useful in the treatment of peri-implant pathologies, since if it is used as an adjunct to conventional therapy [58], it could favour the reduction of inflammation and contribute to osteogenesis and tissue regeneration [41]. This treatment is shown in **Figure 2**.

Another important application of low-intensity photothermal therapy is in orthodontics. The essence of orthodontics is based on causing dental or orthopaedic movements by applying controlled forces. The use of laser has been studied to accelerate tooth movement by favouring bone remodelling due to its biostimulation effect, which allows orthodontic treatments to be performed in less time [59]. In addition, its anti-inflammatory and analgesic effect has proven to be effective, not only reducing treatment time but also reducing the pain and inflammation inherent to these types of treatment [60].

In oral pathology, this therapy is used for the stimulation of the physiological response of tissues. Its use in the treatment of various injuries has been described [46]. In the case of herpes simplex, soft lasers produce a similar effect to acyclovir, and it has been shown that if 2 J/cm^2 is applied in the prodromal phase, the blisters are likely to

Figure 2.
Fox III 890 nm diode laser (a.R.C. Laser GmbH, Nürnberg, Germany) diffusor optical fibre tip being used in the treatment of peri-implant mucositis.

disappear in 2–3 days with little discomfort, instead of 8 to 14 days. Low-intensity laser therapy also appears to reduce the frequency of recurrence and the rate of relapse. The main advantages of herpes simplex laser treatment appear to be the absence of side effects and drug interactions, which are especially useful for older and immunocompromised patients [61]. It has also been documented in the management of herpes zoster, trigeminal neuralgia, and recurrent aphthous stomatitis [41, 62]. The diode laser acts as an analgesic relieving pain, and in some cases, such as canker sores, it also shortens the healing time [41]. Another important application in oral medicine is its use in oral mucositis, since these ulcerative-type oral lesions produced by radiotherapy or chemotherapy can compromise the quality of life and nutrition of patients. Diode lasers, in conjunction with low-intensity laser therapy, have been shown to reduce the severity of oral mucositis and can be used prophylactically before radiation. Once produced, the lesions provide an analgesic effect and accelerate healing (**Table 3**) [63].

3.2.3 Contraindications

The main contraindication of this therapy is its use in malignant or premalignant oral lesions. This is because cells with dysplasia have a higher metabolic activity and are much more sensitive to biostimulation from laser light. Irradiating these lesions with low-power lasers could worsen the degree of dysplasia and stimulate tumour growth [41]. Another limitation of this laser therapy is that, as occurred in high-intensity laser therapy, in some cases, it must be used as adjuvant therapy, and its use as replacement therapy is more

Oral Surgery	Periodontics	Implantology	Oral Pathology
• Third molar extraction • Paraesthesia alveolar nerve • Reduced pain, reduced swelling, improved trismus	• Coadjuvant treatment of periodontal disease • Reduced inflammation Improved healing	• Coadjuvant treatment of peri-implant pathologies • Osseointegration of dental implants • Reduced pain	• Herpes simplex • Herpes Zoster • Trigeminal neuralgia • Recurrent aphthous stomatitis • Oral mucositis • Temporomandibular disorders

Table 3.
Main indications in dentistry for low-intensity photothermal therapy.

limited, for example, in the treatment of periodontal disease or peri-implant pathologies [24]. However, even if it does not replace conventional therapies, it could have a coadjuvant effect that makes a difference in terms of pain management and inflammation.

4. Photodynamic or photochemical therapy

4.1 Mechanism of action

Photodynamic therapy is based on a non-thermal photochemical mechanism. This treatment aims to achieve the same bactericidal effects as high-intensity photothermal therapy but uses laser emission powers comparable to low-intensity photothermal therapy [40]. This is achieved thanks to the interaction of the laser light with the photosensitising pigment, and it is important to emphasise that temperature does not intervene in this interaction, only the absorption of the wavelength of the emitting laser by the photosensitiser [64].

The photodynamic process is therefore based on a photochemical reaction. A photochemical reaction is one in which light initiates a chemical process [65]. A pigment, called a photosensitiser, is used, which selectively reaches the cell or microorganism to be eliminated and is irradiated with a wavelength according to the selected pigment [40]. For this process to be carried out, the photosensitiser must be administered to the target and be irradiated with the specific wavelength; then, it reacts and produces reactive oxygen species (ROS) like hydroxyl radicals [64, 66]. These will cause oxidative stress that leads to damage or destruction of the cell membranes, causing irreversible biological damage. This damage will always be selective since only the selected microorganisms will be sensitive to the photosensitiser and therefore affected by this therapy [67].

In recent years, photodynamic therapy has proven to be an effective, noninvasive and highly specialised treatment alternative in bacterial elimination [68]. However, for the successful elimination of bacteria, some elements must be taken into account. As it is an oxygen-dependent process, its usefulness will be limited in areas poor in this element. In these cases, photothermal therapy can be a more effective option for bacterial elimination [65, 66].

Another key aspect is the choice of photosensitiser and the light source. In antimicrobial photodynamic therapy, it is essential that the photosensitiser has a high affinity for pathogenic microorganisms and also a low binding affinity with the cells of the host tissues [65, 69]. Most of the photosensitisers marketed in dentistry are made from Methylene Blue, Toluidine Blue, or some of their fractions. Another common photosensitiser used in recent years is indocyanine green solution [64]. Regarding the light source and laser parameters, these must be specific to activate the photosensitiser [66]. Various light sources have been used in the literature, such as helium-neon, diode and argon lasers activated by wavelengths between 630 and 810 nm [64]. However, other combinations of photosensitisers and wavelengths appear [67]. The important thing is to emphasise that there must always be an affinity between the photosensitiser and the wavelength with which it is irradiated in order for photodynamic therapy to be effective and safe [65].

4.2 Main indications

The general indications of photodynamic therapy are clear: to eliminate bacteria, fungi, viruses, or fungi resistant to other types of treatments. It is true that the photothermic effect produced by most high-power lasers can produce high decontamination of irradiated areas, but this can involve a high risk of damage to neighbouring structures in the contaminated area [64]. Photodynamic therapy is therefore postulated as a more conservative treatment.

Some of its main indications are in the speciality of periodontics and implantology. The central role of bacteria in the development of peri-implant pathologies and periodontal disease is well known [70]. Biofilms that colonise tooth surfaces and epithelial cells lining the periodontal pocket/gingival sulcus (subgingival dental plaques) are among the most complex biofilms that exist in nature [40]. Therapies that improve the results of conventional therapies based on mechanical debridement are constantly being sought [71]. Systemic use of antibiotics in conjunction with mechanical treatment is a commonly performed treatment modality in periodontology and is regarded as a reliable method in the treatment of periodontal diseases [72]. Photodynamic therapy has been suggested as an alternative to chemical antimicrobial agents and antibiotics to eliminate subgingival species [40]. Microbiological reduction was observed *in vivo* following photodynamic therapy in the treatment of peri-implantitis in animal model [73]. Also, it has been observed in randomised controlled trials that scaling and root planing, combined with photodisinfection, leads to a reduction of pocket depths, bleeding scores and clinical attachment gain in the nonsurgical treatment of periodontitis [74, 75]. However, other similar trials did not obtain statistically significant differences in the reduction of clinical parameters applying photodynamic diode laser therapy [12, 76]. Therefore, the potential effects of antimicrobial photodynamic therapy should be studied more extensively to establish the optimal conditions during clinical application [72] since recent systematic reviews and metanalysis such as the one published by Bashir et al. have reported promising results that encourage further research [77].

This therapy can also be used in restorative dentistry. Treatment of cavitated lesions involves the surgical removal of the infected tooth structure followed by tooth restoration [40]. The antibacterial capacity of the diode laser can be used once the cavity to be filled has been made, since the exposed dentin may contain, in addition to hydroxyapatite remains, odontoblastic extensions, collagen, and other common debris of the smear layer, bacteria typical of dentin infection [78]. Therefore, photodynamic therapy could be used as a minimally invasive technique to eliminate bacteria within carious lesions [40]. Several laboratory studies have demonstrated, using toluidine blue, the susceptibility of cariogenic bacteria to photodynamic therapy [78–80]. This technique could offer the following benefits: rapid noninvasive topical *in vivo* application of the drug to the carious lesion; rapid bacterial killing after a short exposure to light; unlikely development of resistance considering the widespread generic toxicity of reactive oxygen species; and confined killing by restricting the field of irradiation and the inherently short diffusion radius of reactive oxygen species [40].

Another speciality in which bacterial elimination is a central axis is endodontics. The ultimate goal of endodontic treatment is the elimination of infection from the root canal system [72]. For root canal treatments, irrigation solutions such as sodium hypochlorite are used, constituting a powerful chemical disinfection system that is difficult to overcome [81]. However, there are some situations, such as necrotic teeth with open apices, where hypochlorite irrigation can reach beyond the apex, penetrating the tissues adjacent to the apex and producing necrosis of said tissues. It is in these cases like this that photodynamic therapy can be used without risk of complications [40, 81]. It is true that activated photo disinfection is not higher than that produced

Periodontics	Implantology	Restorative	Endodontics
• Coadjuvant treatment of periodontal disease	• Coadjuvant treatment of peri-implant pathologies	• Disinfection of cavitated lesions	• Coadjuvant to root canal irrigation • Root canal irrigation with open apex

Table 4.
Main indications in dentistry for photodynamic therapy.

by hypochlorite, but the risk involved is much lower [72]. Photodynamic therapy has been employed in recent years to target microorganisms in root canals *in vitro* [82, 83] and *in vivo* [84, 85]. These studies suggested the potential of photodynamic therapy as an adjunctive technique to eliminate residual root canal bacteria after standard endodontic chemo-mechanical debridement [40]. Thus, in endodontics, the application of diode laser photodynamic therapy in specific cases can replace the use of sodium hypochlorite to improve the bactericidal effect during the biomechanical preparation of the root canal (**Table 4**) [81].

4.3 Contraindications

For a successful bacterial photoelimination, some factors must be considered, e.g., the selection of appropriate photosensitiser, light source and parameters [64]. The microorganisms to be eliminated must be known, as well as the characteristics of the photosensitiser and the wavelength to which it responds. If the pigment does not bind to the microorganisms, it is used in excess or insufficient quantity, or it is not irradiated with the specified wavelength, the therapy will not achieve good results [81].

Photosensitisers are not universal, and although they are capable of acting on a wide variety of microorganisms, some may not be affected. Another limitation is that bacteria associate to form dynamic structures called biofilms [72]. This structure, where a great variety of bacteria coexist, prevents the photosensitiser from penetrating deeply, with which the bactericidal effect may not be complete. It has been suggested, in studies of model systems, that water channels can carry solutes into or out of the depths of a biofilm, but they do not guarantee access to the interior of the cell clusters [40, 77]. For this reason, we need to deconstruct the biofilm before using this laser therapy, as happened in photothemic therapies [77].

5. Future research lines with diode laser

Diode laser technology and its different applications in dentistry date back several decades; however, it has been in the last 10 years that it has gained a greater prominence thanks to the great technical development achieved and the materialisation of affordable equipment for the dentist. All this advancement has allowed it to be used today in many procedures to improve the performance of conventional therapies and yet this is not enough. The use of different diode laser therapies should be consolidated with more research. In recent years, progress has been made in this regard as it has gained more and more prominence as adjuvant therapy; however, although there are several important *in vitro* [29, 86, 87] and clinical studies [66, 74, 75, 88], more research is still needed to address laser therapy from a different perspective.

More research is needed to study the different diode laser therapies from a histological, immunological and microbiological point of view [77]. The contemporary notion of how oral biofilms are causing oral diseases, such as tooth decay, periodontitis, or peri-implantitis, is well summarised by the "ecological plaque hypothesis". According to this hypothesis, it is the interrelation between the bacteria and the host's response that defines health or disease [89]. Current treatment techniques involve either periodic mechanical disruption of oral microbial biofilms or maintaining therapeutic concentrations of antimicrobials in the oral cavity, both of which are fraught with limitations [40].

We know that the true potential of the diode laser lies in its bactericidal capacity, either through temperature or photosensitisation, and in its ability to stimulate the host's immune response against that aggression. Therefore, studies are needed to provide the scientific community with evidence of this potential. Microbiological studies compare the bacterial reduction between conventional therapies and the adjuvant use of diode laser, immunological studies correlate this bacterial decrease with the activation of the host's immune system, and histological studies show how areas irradiated with diode laser heal better and with less pain and inflammation than those that have not been treated with laser. In summary, more high-quality, randomised controlled trials are necessitated before recommendations for use can be made [40, 72, 77]; only when we consolidate this knowledge will we be able to understand the clinical effects of diode laser therapies.

6. Conclusions

Diode laser therapies have shown promising results in dentistry. For our discipline, its potential lies in its bactericidal and biostimulation capacity. However, due to the complex field of application that is the oral cavity, more high-quality, randomised controlled trials with good methodology are necessary to show the true efficacy of these therapies, studies that evaluate the diode laser not only from a clinical perspective but also from a microbiological and immunological point of view. With solid scientific evidence, even today under construction, in the future, clinical protocols could be achieved. Therefore, it is now the time to investigate and demonstrate clear evidence of clinical efficacy and applicability to show the true potential of diode laser therapies in destintry.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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