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Review Article

Bioengineering: An Alternative Technological Innovation for the Use of Dental Laser

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Abstract: The word "laser" is an acronym for Light Amplification by Stimulated Emission of Radiation. These words define the unique qualities of lasers, whose application in the dental field focuses on dental therapy, aesthetic dentistry, prosthetics, and oral and periodontal surgery. Through this literature review, the application of lasers in dental clinical practice and its relevant parameters will be evaluated from a bioengineering perspective. Bioengineering can serve as a transdisciplinary bridge between engineering and dentistry, which is refined in the use of lasers to enhance the oral health of patients.

Keywords: Dental laser, Multidisciplinary dentistry, Bioengineering, Personalized dentistry.

INTRODUCTION

Transdisciplinary activities are of greater complexity than multidisciplinary ones because they demand an integration of the theory or scientific and technological elements from various disciplines. This integration requires a methodology agreed upon by researchers from different fields. The significant successes in science have necessitated notable multi and transdisciplinary efforts (Paoli, 2018). Transdisciplinary groups have played a crucial role in advancing scientific research, becoming particularly evident since the 20th century.

While the possibilities of laser application in dentistry are often very promising, there is a notable lack of interest among dental professionals in the clinical and applied phases. This is likely due to a lack of training in its use but also because of the unavailability of appropriate laser equipment. In this regard, a fertile field opens up from the perspective of bioengineering to support dentists in the application and even innovation of dental procedures based on laser use. This would positively impact more effective and safer treatments for the patient.

Principles of Laser Physics

In laser-assisted procedures, the laser's energy is absorbed by the chromophore, a histological biomolecule with a specific chemical structure that allows it to absorb certain peaks of specific wavelengths of light. For example, hemoglobin absorbs visible light, melanin absorbs ultraviolet and visible light, and water absorbs ultraviolet and mid to far-infrared light. In all cases, absorptions are converted into photothermal energy. There are different types of chromophores that vary depending on the tissue, the wavelength of the laser light, and the tissue's chemical composition. The emitted radiation can be transmitted, scattered, reflected, or absorbed. However, laser actions also depend on the properties of the tissue being treated. A specific wavelength may be well absorbed in one tissue but transmitted and scattered in another. Nevertheless, laser absorption and effects exhibit a particular selectivity in chromophores, linked to a specific action time; otherwise, thermal effects would spread to neighboring tissues (Convissar, 2012).

Light is a form of electromagnetic energy that exhibits both particle-like and wave-like behavior at a constant speed. The basic unit of this radiant energy is

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called photon. Light waves are characterized by amplitude and wavelength. Amplitude represents the intensity in the wave, correlating with brightness. The unit of energy is the joule (J), and a useful quantity for dentistry is a millijoule (mj). Wavelength (λ) is the distance between the crests or valleys of a wave. This parameter is crucial for how laser light is delivered to the surgical area and how it interacts with the tissue. Wavelength is measured in meters (m), and dental lasers typically have wavelengths in the order of micrometers (µm).

The frequency of light is generally measured in hertz (Hz); 1 Hz is equal to one oscillation per second. Frequency is inversely proportional to the wavelength: the shorter the wavelength, the higher the frequency, and vice versa. Moreover, hertz is also used to describe the number of laser energy pulses emitted per second.

The light and colors perceived by our eyes are usually diffuse and unfocused. Laser light, on the other hand, is monochromatic because it generates a beam of a single color. It can be invisible if its wavelength is outside the visible range of the electromagnetic spectrum. In other words, laser light is coherent, meaning it is in phase with the same frequency and amplitude. This results in the production of a specific form of focused electromagnetic energy.

Laser beams emitted by some instruments are collimated over a considerable distance, but beams transmitted through optical fibers (e.g., in Nd:YAG and diode lasers) often slightly diverge at the fiber's end. All laser beams can be precisely focused, allowing them to be used to achieve specific treatment goals in oral pathology. In terms of power, two watts of laser light can be easily used for the precise removal of a fibroma while providing adequate hemoestasis at the surgical site without altering the surrounding tissue (Convissar, 2012).

Background of Lasers in Biomedical Applications

In 1960, the American Theodore Harold Maiman became the first person to develop the ruby laser and use it as a method for cutting both hard and soft biological tissues. Shortly after Maiman's invention of the laser, researchers identified its potential use as a valuable instrument in medicine. It was observed that this laser could vaporize caries, but the high energy density caused irreversible necrotic changes in pulp tissues. Years later, the erbium (Er) laser was developed with a wavelength of 2940 nm, which improved clinical requirements for cavity preparation without detrimental effects on the pulp. This laser has high absorption in both water and hemoglobin. The wavelength is optimized to achieve performance that results in optimal tissue ablation, long-lasting coagulation, and improved appearance. The initial investigations of lasers on intraoral soft tissues were conducted using a ruby laser. Subsequently, the development of the CO2 laser and its ability to cause soft tissue ablation with minimal bleeding led to studies in oral surgery. Additionally, other research groups continued studying soft tissues using an Nd:YAG laser and the photopolymerization of dental composites with an argon laser. There is also ongoing research into the potential use of Nd:YAG lasers (Neodymium-doped Yttrium Aluminum Garnet) in the welding of prosthetic devices and gold alloys, as well as the application of various lasers in specific endodontic procedures.

An extensive review of published scientific research and clinical reports on the use of lasers in dentistry references experimental uses dating back to 1964, progressing to numerous clinical applications by the year 2000. Otolaryngologists, oral surgeons, and periodontists were among the first professionals to use intraoral medical lasers to perform a range of surgical applications on soft tissues. On May 3th, 1990, in the United States, the first laser designed specifically for general dentistry was introduced: the Nd:YAG dLase 300 laser, developed by the Myers and Myers laboratory. This event marked the beginning of the clinical use of lasers by dentists, thanks to the pioneering work of León Goldman, an early adopter in laser surgery. It is important to note that Goldman reported on the biomedical aspects of lasers as early as 1963, publishing findings on the laser's effect on dental caries, teeth, and other tissues as part of his pioneering research on the potential applications of lasers in dentistry (Alexander *et al.,* 2019).

Dental Lasers and Methodological Fundamentals

Lasers can be classified based on their active medium, wavelength, emission form, or other criteria, but perhaps the most common way to classify them is by considering the power required for their clinical application. Each laser has unique characteristics that differentiate it. In some cases, the same treatment can be performed with more than one type of laser, although one of them may offer better features for a particular treatment. In general, it is common to refer to two groups of lasers: low-power lasers and high-power lasers (España, 2022) (Table 1).

Table 1: Groups of low and high-power lasers

Laser type	Specific laser
Low-power lasers are primarily used for their bio-stimulating, analgesic, and anti-inflammatory effects.	-As,Ga (Gallium Arsenide). -As,Ga,Al (Gallium Aluminum Arsenide). -He,Ne (Helium-Neon).
High-power lasers correspond to those that produce visible physical effects and are	-Diode (Combination of Gallium, Arsenium and other elements such as Aluminum or Indium).

Laser type	Specific laser
used as substitutes for cold scalpels or conventional rotary instruments.	-Nd:YAG (Garnet of Itrium and Aluminum, contaminated by Neodymium). -Nd:YAP (Itrium Aluminum Peruschite, contaminated with trivalent Neodymium ions). -Er,Cr:YSGG (Rhombodecahedron crystal garnet, which is composed of Itrium, Scandium and Gallium contaminated with Erbium and Chromium). -Er:YAG (Itrium-Aluminum-Garnet crystal contaminated with Erbium metal molecules). -CO2 (Helium, Nitrogen, Hydrogen and CO2).

The wavelength of the laser will remain constant for the selected laser; therefore, based on the chromophores considered most important, we will find a wavelength that is more absorbed (España, 2022) (Figure 1).

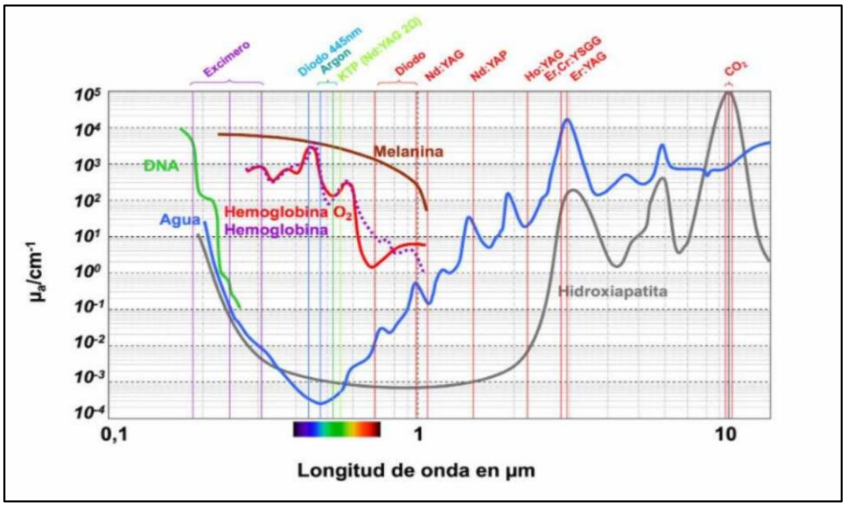

Figure 1: Graph of light absorption according to wavelength in different chromophores

In laser therapy on oral tissues, it is necessary to understand, in the first place, the effects when the laser interacts with them. Depending on the temperature reached by the tissue, two major groups of lasers must be distinguished: the hard and the soft lasers. The soft or soft lasers (LLLT for low-level laser therapy) do not produce an increase in temperature and generate direct effects on healing and cellular regeneration. They are called bio-stimulating effects. The basis of LLLT therapy is that its activity on tissues is not due to thermal effects but to the interaction of the electromagnetic waves of this radiation with cells. Energy is absorbed where the concentration of fluids is higher. Therefore, there will be greater absorption in inflamed and edematous tissues, stimulating numerous biological reactions related to the wound healing process (Angeles *et al.*, 2020), (Rodriguez Y *et al.*, 2023), and (Camargo, 2023) (Table 2).

Table 2: Main types of Lasers used in Dentistry

Laser type	Wavelength (nm)	Waveform	Applications
Diode	810 a 1064	Continuous or pulsed.	Surgical interventions on soft tissues that do not involve excessive bleeding.
Neodymium, YAG or Nd:YAG	1064	Pulsed.	Incision and ablation of soft tissues, vaporization of incipient caries, hemostasis, periodontal decontamination, endodontic decontamination.
CO_2	10600	Continuous superpulsed.	"Incision and ablation of soft tissues. Gingival de-epithelialization during periodontal regenerative procedures.
Erbium, Er:YAG	2940	Pulsed.	Incision and ablation of soft tissues, treatment of dentin hypersensitivity, removal of caries, ablation of hard tissues, periodontal and endodontic decontamination.
Erbium, Er,Cr:YSGG	2780	Pulsed.	Incision and ablation of soft tissues, treatment of dentin hypersensitivity, removal of caries, ablation of hard tissues, periodontal decontamination, endodontic decontamination.

Dental Lasers

Before addressing the different aspects of the use of high-power lasers in various dental treatments, it is important to remember that there are very strict safety standards in handling such lasers that must be known and implemented. The lasers we will be referring to emit light that is not visible to the human eye, with wavelengths in the infrared spectrum. The interaction of these wavelengths with tissues produces a significant photothermal effect. Thus, the principle of use for all of them is based on this photothermal effect. However, since they are different wavelengths, they will not always be absorbed in the same way, producing a wide range of effects related to their absorption. Depending on the temperature reached by the target tissue, different effects can occur, ranging from transient hyperthermia to its carbonization (España, 2022), (Runki S *et al.*, 2023) (Table 3).

Table 3: Tissue effect

Tissue effect	Temperature
Tissue hyperthermia.	107-113°F
Desiccation, protein denaturation and coagulation.	>149°F
Tissue coagulation and fusion.	158-194°F
Vaporization.	>212°F
Carbonization.	>392°F

Photothermal interaction is characterized by a localized temperature increase induced by laser action, a distinctive feature of surgical lasers. Thus, the main photothermal interactions are tissue incision/excision, ablation/vaporization, and hemostasis/coagulation (Convissar, 2012). The light energy contacts the tissue for a specific period, producing a thermal interaction. Depending on the temperature reached, the effect varies: when the temperature is between 98.6 and 122°F, bacterial inactivation occurs, which is very useful in periodontal and endodontic processes. Several studies have been reported supporting the effectiveness of laser therapy as a high-level decontaminant in periodontal and endodontic tissues. When the temperature is between 140 and 158°F, coagulation and denaturation of proteins are observed. Thus, when the temperature rises to 212°F, water vaporization occurs in a phenomenon called ablation.

Several studies demonstrate a greater healing capacity and better postoperative effects when comparing laser therapies versus other therapies. They simultaneously show analgesic, anti-inflammatory, healing, and hemostatic effects that are not observed with other techniques. When the thermal process exceeds 392°F, a phenomenon called carbonization occurs, where charcoal develops as the final product, acting as a heat sink, causing trauma to adjacent tissues. (Mocanu R *et al.*, 2021).

Indications and Contraindications for the Use of Different Types of Lasers

Most dental treatments in which some type of laser can be used are evaluated from the perspective of stomatologists. This evaluation may be subjective and, therefore, only serves as a guide, as also demonstrated by the scientific evidence published in the literature on the successful use of different types of lasers in the treatment of excision of a variety of benign tumors in the oral cavity.

Below are two tables that summarize the indications and contraindications for the use of different lasers in various treatments (Table 4). Some treatments for hard dental tissues related to dental therapy, such as cavity preparation, composite removal, endodontics, etc., are included. Different procedures and pathologies in the field of Oral Surgery are presented (España, 2022) (Table 5).

Table 4: Treatments in dental therapeutics

Odontological applications	Laser				
	Diode	Nd:YAG	Er,Cr:YSGG	Er:YAG	CO_2
Cavity preparation.	0	1	4	4	0
Composite removal.	0	0	4	4	0
Enamel etching.	0	1	4	4	2
Sealing pits and fissures.	1	2	4	4	1
Dentin hypersensitivity.	1	2	4	4	2
Aesthetic veneers.	0	0	4	4	0
Dental whitening.	4	4	0	0	1
Crown preparation.	0	0	3	3	0
Endodontics.	4	4	2	2	1
Endpoints: 0= Contraindicated. 1= Can be used. 2= Indicated. 3= Fairly indicated. 4= Strongly indicated.					

Table 5: Treatments and pathologies in the field of oral surgery

Odontological applications	Laser				
	Diode	Nd:YAG	Er, Cr:YSGG	Er:YAG	CO_2
Upper labial frenulum.	2	1	3	3	4
Frenillo labial inferior.	2	1	3	3	4
Lingual frenulum.	2	1	3	3	4
Viral-origin papilloma.	1	1	0	0	4
Non-viral origin papilloma.	2	2	3	3	4
Diapneusias.	2	1	4	4	4
Mucoceles.	2	1	3	3	4
Fibrous hyperplasias.	2	1	3	3	4
Telangiectatic epulis.	3	2	3	3	4
Fibrous epulis.	2	1	3	3	4
Epulis gravidarum.	3	2	3	3	4
Giant cell peripheral granuloma.	2	1	3	3	4
Pyogenic granuloma.	2	1	3	3	4
Cracked epulis.	2	1	3	3	4
Gingivectomies.	1	0	2	2	2
Elimination of granulation tissue.	1	1	3	3	4
Crown lengthening.	1	0	3	3	3
Vestibuloplasty with graft.	0	0	3	4	0
Vestibuloplasty by 2nd intention.	1	1	3	3	4
Elimination of flanges and braces.	2	1	3	3	4
Exostosis and mandibular torus or pelatine.	0	0	4	4	0
Periodontics: Removal of calculus.	0	0	3	3	0
Periodontics: Decontamination of pockets.	4	4	3	3	2
Periapical surgery: Apical curettage.	1	1	3	3	3
Endpoints: 0= Contraindicated. 1= Can be used. 2= Indicated. 3= Fairly indicated. 4= Strongly indicated					

CONCLUSION

Although the clinical use of dental laser is becoming more commonplace, it is essential for the clinician to be familiar with the technique, usage parameters, and the intervention and manipulation of oral tissues. Bioengineering, as a branch of engineering, integrates its concepts and methodological foundations, establishing a transdisciplinary bridge with dental sciences in the clinical use of dental laser to improve the oral health of the patient.

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