

Therapeutic and Adverse Effects of Lasers in Dentistry: A Systematic Review

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Abstract: Laser therapy has become one of the gold standards of treatment in routine dentistry. In the 1970s, CO2 lasers were the first lasers to be used in oral surgery on soft tissues. Subsequently, other lasers (Diode, Nd YAG, Er: YAG, Argon and Erbium) have also been used in periodontics, implantology, orthodontics and restorative dentistry, as well as for hard tissues, such as bone, enamel and dentin. The purpose of this systematic review is to analyze both the therapeutic properties and adverse effects of laser use in dentistry, related to a non-targeted choice of medical device based on clinical need as well as an inadequate learning curve. A systematic review was performed following the PRISMA guidelines using Pubmed, Scopus and Web of Science. The use of lasers requires a specific learning curve modifying the standard surgical approach. The use of lasers provides multiple therapeutic benefits but can lead to some failures in dental treatments. In restorative dentistry, it has been found that lasers can cause cracks that can lead to fractures and/or affect the composite restoration. In periodontal treatments, the use of lasers can produce thermal damage to pulp tissue. In surgical treatments, the use of a laser caused bleeding, post-operative pain and a burning sensation. The failure of tissue cooling during laser beam emission could produce the necrosis of hard and soft tissues.

Keywords: dentistry; laser; low-level laser therapy; oral surgery; peri-implant mucositis therapy; photobiomodulation; photobiostimulation; photodynamic therapy; tissue regeneration



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1. Introduction

Laser (light amplification by stimulated emission of radiation) therapy has become one of the gold standards of treatment in routine dental practice [1]. Although the birth and first applications of lasers in the medical field date back to the middle of the last century, it was not until the 1980s that the use of this therapeutic technique really became established [2]. Since the 1970s, lasers have also been used to treat oral cavity infections, a use that has become more widespread with the advent of new types of lasers and has also extended to tooth-specific therapeutic practices, such as endodontic, periodontal, orthodontic and cosmetic dentistry treatments [3]. Indeed, precisely because of its characteristics of versatility, user-friendliness and reliability, the laser can be used as an alternative to conventional surgery, even of the oral cavity [2,3]. The biostimulating properties of laser beams at the cellular level has enabled its use in all branches of dentistry.

In periodontology, the laser removes the infected gum layer and the necrotic tissue disappears, enabling the growth of new cells [3,4]. Other dental fields have also benefited from the use of laser therapy, including endodontic treatments, teeth whitening, implantology, orthodontic and soft tissue surgery in the oral cavity [5–8]. Recently lasers have been used

also for the management of labial and perioral imperfections of a vascular or pigmentary nature and for the aesthetic treatment of wrinkles, especially in the era of modern dentistry, where aesthetics have taken on a leading role (Figure 1).

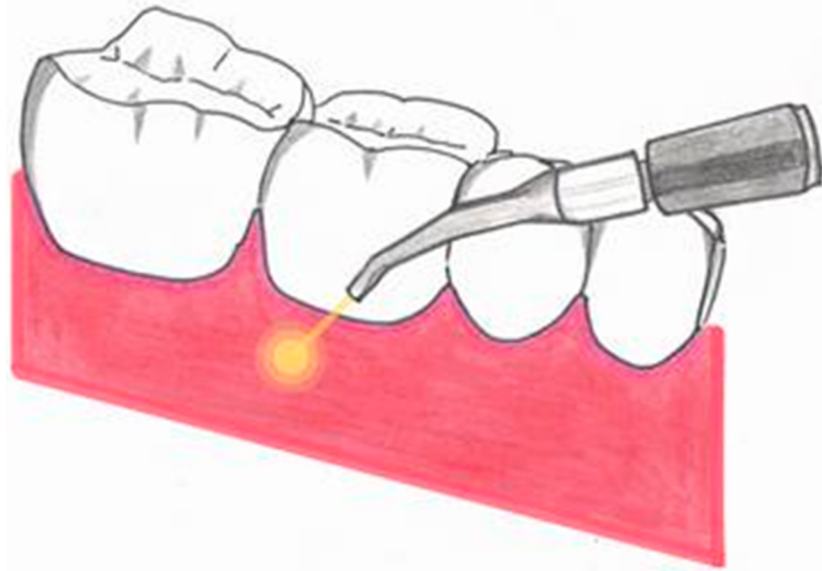


Figure 1. Use of a laser in dentistry as an accurate, non-invasive method with predictable results.

In endodontic treatments, the use of lasers ensures the sterilization of root canals after their proper cleaning [5]. In the tooth whitening, a technique using hydrogen peroxide gel, a laser is utilized to release free radicals, which in turn break down the dark pigmented molecules present on the teeth, facilitating their removal [6]. The discipline of implantology includes several phases in which laser use has proved useful: in the pre-surgery phase, where site preparation is of fundamental importance for the correct introduction of the implant and subsequent osseointegration; in the preprosthetic stage of operculectomy; and in peri-implantitis for pocket sterilization.

Each different type of laser can be categorized in a number of ways: the type of laser used, the specific chromophore used to activate the laser's effect, the tissue on which they can be used and the wavelength range of the laser (all lasers act within the infrared spectrum). In fact, lasers work with specific frequency and intensity and with a certain wavelength (λ) that determines a particular absorption and penetration coefficient, which differs according to the type of tissue to be treated. By modulating the intensity and power, it is possible to achieve a "customised" treatment with respect to the intrinsic characteristics of the patient and their oral health condition [9–12]. From a strictly practical point of view, the main types within the laser family can be divided into three large groups: solid-state lasers (Nd: YAG, Er: YAG, ErCr: YSGG), gaseous-state lasers (CO₂) and semiconductor lasers (diode lasers). Laser applications are varied: some can be used for both soft and hard tissues (Nd: YAG, Er: YAG, ErCr: YSGG), while others act only on soft tissues (CO₂ and diode lasers) [13].

Recently, a focal lens was used for the diode effects used in the low level laser therapy (LLLT) setting, which, by means of the photobiostimulation effect, allows good tissue penetration while respecting the tissues and avoiding excessive overheating and, at the same time, has a significant anti-inflammatory effect, promoting tissue healing and controlling edema and postoperative pain [14–17].

1.1. Laser Classifications

1.1.1. LLLT

Photobiomodulation (PBM), also known as low-level laser treatment (LLLT), is a photochemical and non-thermal biological interaction that, in most situations, uses red light

with a wavelength of 600–700 nm and infrared light with a wavelength of 770–1200 nm to promote healing and reduce inflammation and discomfort [18–20]. The LLLT is an alternative use of the diode laser, because it is set to low power and a diffused, defocused radius. It does not cause the overheating of tissues and penetrates deeply. The biostimulant effect is due to an increase in cellular metabolism through the stimulation of ATP production by mitochondria that absorb the emitted photons, reducing inflammation, pain and healing time [18,21].

Many oral disorders have responded quite well to the use of low-intensity lasers [22]. Combining these with antibiotics improves the condition of patients with bisphosphonate-related osteonecrosis of the jaw (BRONJ) and medication-related to the osteonecrosis of the jaw (MRONJ) by reducing clinical symptoms [23,24]. In cases of hyposalivation or xerostomia, LLLT is particularly efficient at repairing cells, and it also stimulates salivary glands to produce more secretion [25]. The use of LLLT in patients with hyposalivation results in an increase in mucin 5B, oligomeric mucus/gel-forming (MUC5B), unstimulated salivary flow and histatins, resulting in a protective action against fungal infections (e.g., *Candida albicans*). The respiratory chain of the mitochondria contains cytochrome C oxidase, which is received from the LLLT as its chromophore [14]. This effect would appear to be due to increased cellular activity, brought about via the increased ATP production of mitochondria stimulated by the photons emitted by LLLT. It also reduces pain and provides complete wound-healing in cases of recurrent aphthosis and Herpes Simplex [26,27]. Trigeminal neuralgia symptoms are also lessened by LLLT [28]. Periodontology has seen a significant increase in the application of LLLT [29,30]. However, the outcomes that motivate the use of long-term lasers seem to offer few advantages over alternative approaches [31]. The Multinational Association of Supportive Care in Cancer/International Society of Oral Oncology has approved the use of LLLT for the treatment of oral mucositis in cancer patients and adults, but LLLT has been found to reduce severe mucositis in cancer patients of all ages [32]. Moreover, the use of LLLT has promoted bone growth surrounding the implant and increased osseointegration [33,34].

The PBM's mode of action relies on the interaction of chromophores cells with laser light, particularly cytochrome C oxidase (Cox), an enzyme of the mitochondrial respiratory chain. As the final enzyme in the electron transport chain, Cox is responsible for transferring electrons from cytochrome c to molecular oxygen [35]. It appears that PBM increases the number of electrons available for reducing molecular oxygen in the Cox catalytic center. The respiratory chain's electron transport velocity alteration results in boosting the amounts of adenosine triphosphate (ATP), cyclic adenosine monophosphate (cAMP), reactive oxygen species (ROS) and nitric oxide (NO) as well as the mitochondrial membrane potential (MMP) [36,37].

The sodium and potassium pump in the cell membrane alters as the concentration of intracellular H^+ ions increase the permeability to calcium ions in the intracellular environment. The level of cyclic nucleotides that regulate the synthesis of RNA and DNA are impacted by the increased concentration of this cation [38]. In this condition, the activity of cellular receptors in the membrane increases too; as a result, endorphin production and neural cell action potential rise while bradykinin levels and the activity of C-fibers that respond to painful stimuli diminish. This entire process helps relieve symptoms of pain [39].

Inhibitory nitric oxide (NO) must be photodissociated in order for the light to be absorbed by cytochrome c-oxidase. This process is what causes the rapid increase in vasodilation and improvement in tissue oxygenation [40,41] (Figure 2).

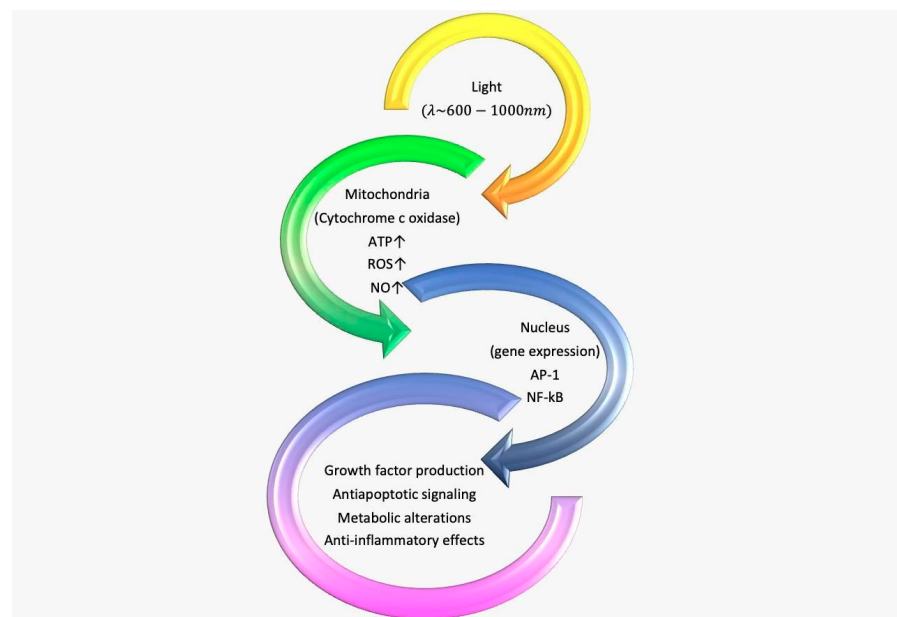


Figure 2. Summary of the mechanism of action and direct effects of low-level laser treatment (LLLT) on tissues.

Many transcription factors, including nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB), multifunctional protein (Ref-1), tumor protein (p53), group of transcription factors (ATF/CREB) and hypoxia-inducible factor 1 (HIF-1), are controlled by changes in cellular redox state [42]. Following that, various intracellular signaling pathways, including those for protein synthesis, enzyme activation, cell cycle progression and nucleic acid synthesis, are activated, as are transcriptional alterations [43]. Moreover, laser therapy causes some cell types to differentiate, which increases cell proliferation and migration as well as the production of growth factors, inflammatory mediators and cytokines [43,44] (Figure 3).

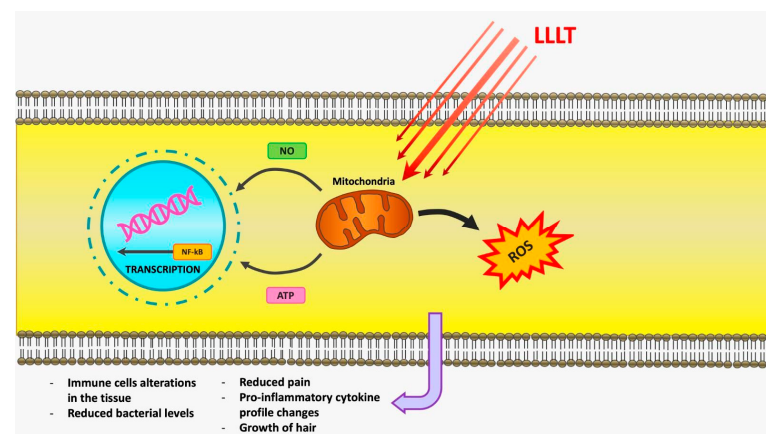


Figure 3. More in detail, graphical scheme of the direct effects of low-level laser (LLLT) stimulation on tissues.

The interaction of light with biological tissues is influenced by various factors, including wavelength, laser dose and the tissue's optical characteristics. The characteristics of the tissue include its structure, water content, density, heat capacity, thermal conductivity and capacity to either scatter, absorb or reflect the energy that is emitted [45].

The biphasic spectrum used by PBM has frequently produced favorable outcomes; nevertheless, the depth of penetration, which is caused by molecule absorption and scat-

tering, is the issue. The maximum near infrared (NIR) penetration depth occurs at about 810 nm, and as the wavelength increases, both absorption and scattering become noticeably less. At longer wavelengths, water becomes a substantial absorber, and the penetration depth decreases once more [46].

The dose, which measures the amount of energy entering the body, is equivalent to the average power (watts) applied over the course of treatment (seconds) [47]. Every time the dosage is increased, a maximum response is obtained at some value (a higher dosage has a better response); however, there is a point up to which the dose can be increased [48], and past that maximal value, the reaction declines and disappears, and it is even possible that adverse or inhibiting effects are generated via over-dosage [20]. Overdosage can paradoxically limit cell proliferation or cause apoptosis while under-dosage has a negative impact on cellular responsiveness [49]. Thirteen out of the twenty-five published RCT studies on laser tendinopathy that were the subject of a systematic review and meta-analysis failed to show any benefit. Overdosing on medication was identified as the cause [50]. Additionally, it seems that these cellular responses are tissue-specific. There are instances where it seems as though a very high dose will produce a level of ROS that is cytotoxic and will destroy the tumor [51].

The definition of protocols is still considered a problem in PBM treatment; so, is necessary for the World Association for Laser Therapy (WALT) to establish a methodology for guidelines on irradiation and the form of laser prescribed for biomodulation, as the beneficial outcomes are undeniable [52].

1.1.2. CO2 Laser

The CO2 laser, developed by Patel et al. in 1964, was first used in surgery in the early 1970s [53].

The CO2 laser emits a beam of infrared light whose main wavelength is between 9.400 and 10.600 nm, either pulsed or as a continuous wave. It has an excellent hydrophilicity that allows it to be extremely effective in the ablation of soft, water-rich tissues (e.g., frenectomy or gingival remodeling for aesthetic purposes), in the treatment of oral ulcerative lesions and to ensure proper post-surgical healing. It absorbs to a lesser extent in hydroxyapatite [14,54].

The absorption of laser light produces a photothermal effect, i.e., the coagulation, vaporization and photoablation of soft tissue. To avoid the overheating of tissue and subsequent necrosis, the CO2 laser must be set to pulsed mode (superpulse or char-free). The CO2 laser acts at a depth of 0.1 mm and does not come in contact with the tissue. It has scalpel action when focused and, by reducing bleeding, improves the view of the operating field. When in defocused mode, the CO2 laser has photoablative action and occludes small blood vessels, thus controlling small and diffuse hemorrhages [55]. Wound-healing always occurs via second intention, without complications, without the need for sutures and with a shorter healing time. It may be necessary to administer drugs for post-operative pain, mainly related to the surgical site. Compared with standard scalpel excision therapy, the use of the CO2 laser has shown delayed neovascularization and re-epithelialization but better healing with reduced contraction and the modification of the newly formed tissues [56].

Today, the limitation of using the CO2 laser in the operating field due to the size of the delivery arm has been overcome by the advent of the Photonic Band Gap Fiber Assembly (PBFA), which allows for flexible fiber CO2 delivery, making it easier for the surgeon to visualize the head and neck areas [57,58]. The PBFA system allows for variable rate gas delivery through a hollow core, allowing for cooling as well as cleaning of the site of debris and blood [57,59].

In the case of a suspected malignant lesion, excision with a scalpel is preferred because the possible charring of tissue may alter the histopathological response of the specimen [57,60]. The use of the CO2 PBFA laser requires a learning curve, both to optimize results and to avoid damage to the device [58].

1.1.3. The Nd: YAG Laser

The wavelength of the Nd: YAG laser is 1064 nm, and energy is extinguished by using long pulses that are converted to heat in the fabric. Among the many uses of these lasers in hard and soft materials, their use in endodontics should be highlighted, where they aid in the removal of pathogenic microorganisms and obstructions in the root canal by also removing the affected materials, and thanks to their anti-inflammatory and analgesic properties, scientific studies have been conducted to further understand their role in non-surgical sulcular debridement, the management of periodontal disease and the prevention of new graft attacks [61].

The Nd: YAG laser, compared to other lasers used in dentistry, has a greater ability to penetrate tissue, a low affinity for water and a high affinity for blood vessels, resulting in good hemostatic properties. To reduce the feeling of discomfort, the light is emitted onto the tissue in super-pulsed form [61].

Studies show that the combined use of the Nd: YAG and Er: YAG lasers in non-surgical periodontal therapy results in better healing due to a greater reduction in pocket depth [62–64]. The Nd: Yag laser has proven effective in peri-implantitis due to its ability to decontaminate the titanium surfaces of implants, improved healing and pocket probing depth [65–68].

1.1.4. The Er: YAG Laser

This laser type can function at two different wavelengths: Er and Cr yttrium scandium gallium garnet (YSGG) lasers at 2780 nm and Er: YAG lasers at 2940 nm [14]. Both types work with an elective affinity for hydroxyapatite, as well as hydrophilicity, which means that this laser is favored in the treatment of hard dental tissue [69]. For example, the use of the erbium laser on soft tissue allows for important advantages in routine dentistry, among which are minimized anesthesia, fewer sutures used, less post-operative sensitivity, the selective removal of diseased tissue, faster healing, less swelling and less risk of infection [70,71]. On the other hand, the use of the erbium laser on hard tissues has other advantages, including the reduced need for anesthesia for caries treatment, favoring the preservation of the healthy tooth structure, avoiding the troublesome use of a drill and facilitating the selective removal of diseased tissue [72,73]. Furthermore, treating the carious process with a Er: YAG laser in dentistry avoids the formation of micro-fractures during cavity milling, determines the decontamination and pre-treatment of the enamel-dentinal surface and avoids the generation of microcavities. This results in an improvement in ideal retention for composite resins as well as an increase in the adhesion surface, optimizing the retention effect of orthophosphoric acid to 37% [74].

The Er: YAG laser shows little tissue damage and excellent incisional capacity, making it an excellent tool in the surgical removal of lesions, such as benign oral fibroepithelial hyperplasia [75].

1.1.5. The Argon Laser

This laser works at 572 nm in pulses or in continuous wave mode. It is seen particularly in traditional therapies (the polymerization of restorative resin materials; tooth whitening and remineralization) [76–78].

1.1.6. The Diode Laser

The active component of this common dental laser is a solid-state semiconductor made of aluminum and gallium that emits an optical wavelength generally ranging from 810 to 980 nm. Both continuous and pulsed operation is possible, with optical fiber-based conductivity (diameter of 200–600) and programmable impulse durations, ranging from 0.1 milliseconds to infinity [79]. Diode lasers have displayed convincing qualities of accuracy and dependability since the beginning of their use [80]. This laser uses a mixture of peroxides, carbamide, urea and hydrogen, which is effective for reducing enamel discoloration to whiten both vital and non-vital teeth through the oxidation–reduction

(redox) process. When utilized in pulsed mode, the diode laser carried by 200 optical fibers may sterilize the apical delta and dentinal tubules to a depth of 1 mm, achieving a level of clinical sterility equivalent to a reduction in germs of 0.01 CFU per mm² [81]. Indeed, diode laser therapy facilitates and optimizes the resolution of infectious processes in the tooth apex (granuloma) and thus assists in the execution of tooth devitalization. It also stimulates osteointegration and is therefore particularly suitable for facilitating dental implants and reducing short-term postoperative complications, because its combined ablative action, along with its biostimulating effect, allows operations with a blood-free field of view and improved healing via second intention [82] (Figure 4).

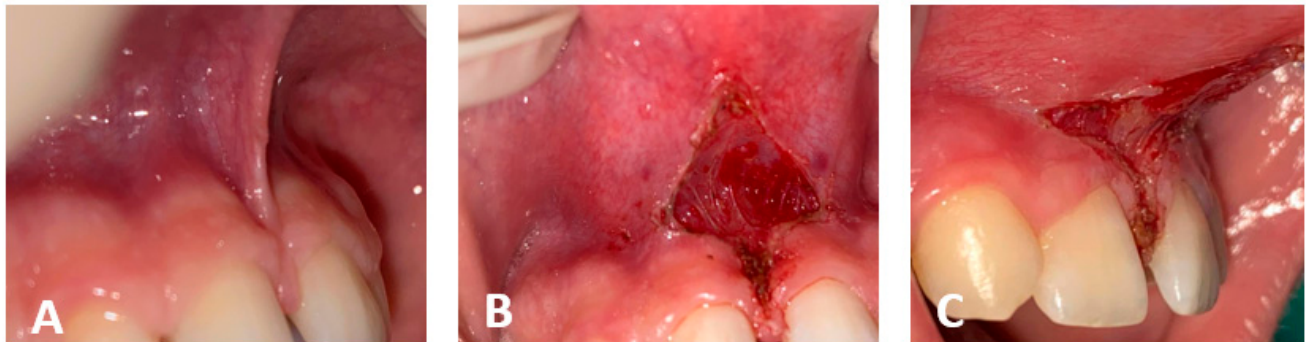


Figure 4. (A) Hypertrophic frenulum; (B) surgical approach; (C) frenectomy performed with diode laser: no bleeding, cut with defined margins, no sutures.

It also may help in the implant field by allowing a more accurate clearance of the soft tissue involved in peri-implant inflammation, also allowing the better decontamination of the implant itself. More specifically, the laser has a good effect in mucositis (the initial inflammation of the peri-implant mucosa without bone loss) [31].

In addition, diode laser technology allows the dentist to treat common and widespread clinical issues, such as oral ulcers, herpes and dentinal hypersensitivity, as well as vascular lesions, such as hemangiomas (FDIP technique: forced dehydration with induced photocoagulation), and the desensitization of dentin [32].

Moreover, individuals with pacemakers, those with coagulopathies and those receiving antiplatelet and/or anticoagulant therapy can also benefit from using the diode laser because this type of laser causes a caustic effect in its ‘surgery’ function [83].

Localized biostimulation with a diode laser increases the release of endorphins and decreases the activity of inflammation mediators to a depth of 1 cm, and it also facilitates cell replication and thus bone growth [32].

Summing up, it is obvious that lasers in dentistry have unquestionable advantages, including no or the reduced use of anesthesia required for the procedure, hemostasis, no post-operative swelling, greater compliance by the patient with less pain, shorter chair time and improved overall acceptance of the procedure, reduced healing time, no or reduced use of post-operative drugs, safer operations on cardiac and coagulopathic patients [84,85], antimicrobial effects (mainly exploited in the periodontal and surgical-implant field) and the preservation of dental hard tissue and dental pulp itself via the careful and prudent use of the laser [84].

However, the clinician must also keep in mind the possible adverse effects of using lasers, albeit with a reduced tendency, along with potential contraindications of this technique [85–91], such as the considerable cost and sometimes the long periods of use, as well as the large size of the instrument, the learning period and the safety measures necessary prior to its use. It is also important to mention that this procedure also requires the use of glasses and involves the unpleasant smell of charred flesh during laser-guided procedures [92]. It is possible to divide adverse effects into long- and short-term categories. In particular, during postoperative days, tissues may appear reddened/inflamed/swollen and nearby tissues may appear “tight”. It is probable that exudate is present in the treated

area for a brief period of time and transient tissue hyperpigmentation (or hypopigmentation) can be observed in the area, especially in dark-skinned people. Allergic reactions to anesthetics might occur, or even “fever blister” or herpes simplex dermatitis [92].

As concerns the potential long-term side effects of laser dentistry treatment, it must be said that patients could display scars (these can be reduced by carefully following the instructions for follow-up care) and the presence of soft tissue pigmentation in the treated area. There is also the possibility of infection, present in all surgical techniques, which can be reduced with appropriate postoperative care [92–94] (Figure 5).

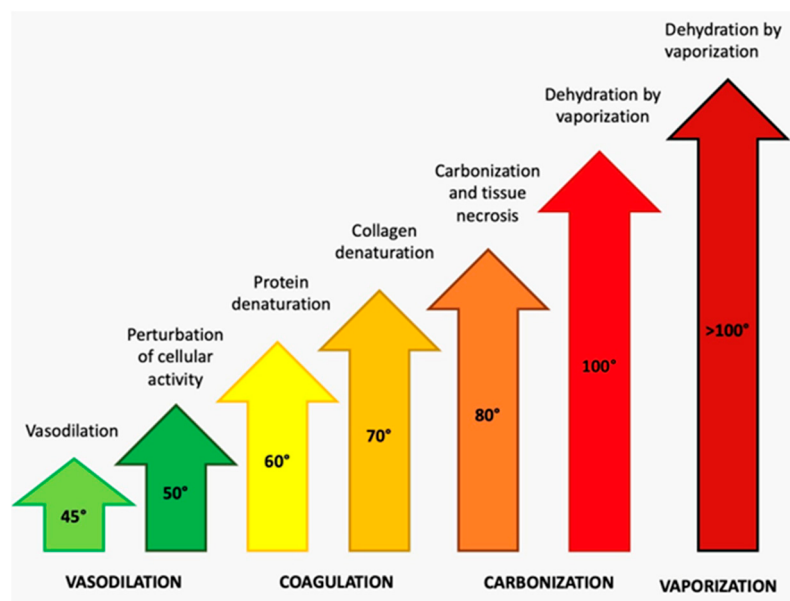


Figure 5. Illustration of the direct effects of the diode laser temperature on the treated tissue.

In this review, we analyze the potential side effects of laser therapy, review the literature on this topic to date and attempt to draw future perspectives on the possible mechanisms of improvement.

2. Materials and Methods

A systematic review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines using the PubMed, Scopus and Web of Sciences (WoS) databases with PROSPERO code 407324 [95]. The following keywords were used: “dentistry” AND “laser” AND “adverse effect” AND “therapeutic effect”. Articles from the last 10 years (2013–2023) were searched, with particular attention paid to the relationship between the use of lasers in dentistry and adverse effects or therapeutic effects. Inclusion criteria included studies on the adverse effects of various types of lasers both in vivo and in vitro and full text articles. All papers reporting no information regarding adverse and therapeutic effects of lasers, as well as literature reviews with or without meta-analysis, were excluded. Furthermore, only articles in the English language were selected, and the last search was run on 26 February 2023. Eligible articles were assessed according to the 2011 guidelines of the Oxford Centre for Evidence-Based Medicine [96]. The references of the included literature were carefully checked to identify other papers that might be pertinent.

The review was conducted using the PICOS criteria:

- Participants: children and adults were included.
- Interventions: actions of the lasers.
- Comparisons: traditional procedures in dentistry.
- Outcomes: efficacy and disadvantages of lasers in dentistry.

- Study: randomized clinical trials, retrospective and observational studies on human teeth.

Two researchers (I.T. and F.P.) independently extracted articles in accordance with the inclusion criteria, and any discrepancies were eventually settled through conversation between the two review authors.

3. Results

A total of 1671 documents were initially identified in the literature search, of which 275 were duplicates. After screening for eligibility and inclusion criteria, 16 publications were ultimately included. The study and PRISMA flowchart are summarized in Figure 6. A total of 1396 documents were screened, of which 929 were excluded. Documents available for retrieval numbered 467, and after assessment for eligibility, 451 documents were excluded. Finally, only 16 articles were suitable for inclusion. According to the Oxford Centre for Evidence-Based Medicine's 2011 standards, all of the included studies were classified as level 4 or level 5 evidence for clinical research. The included articles are summarized in detail in Table 1.

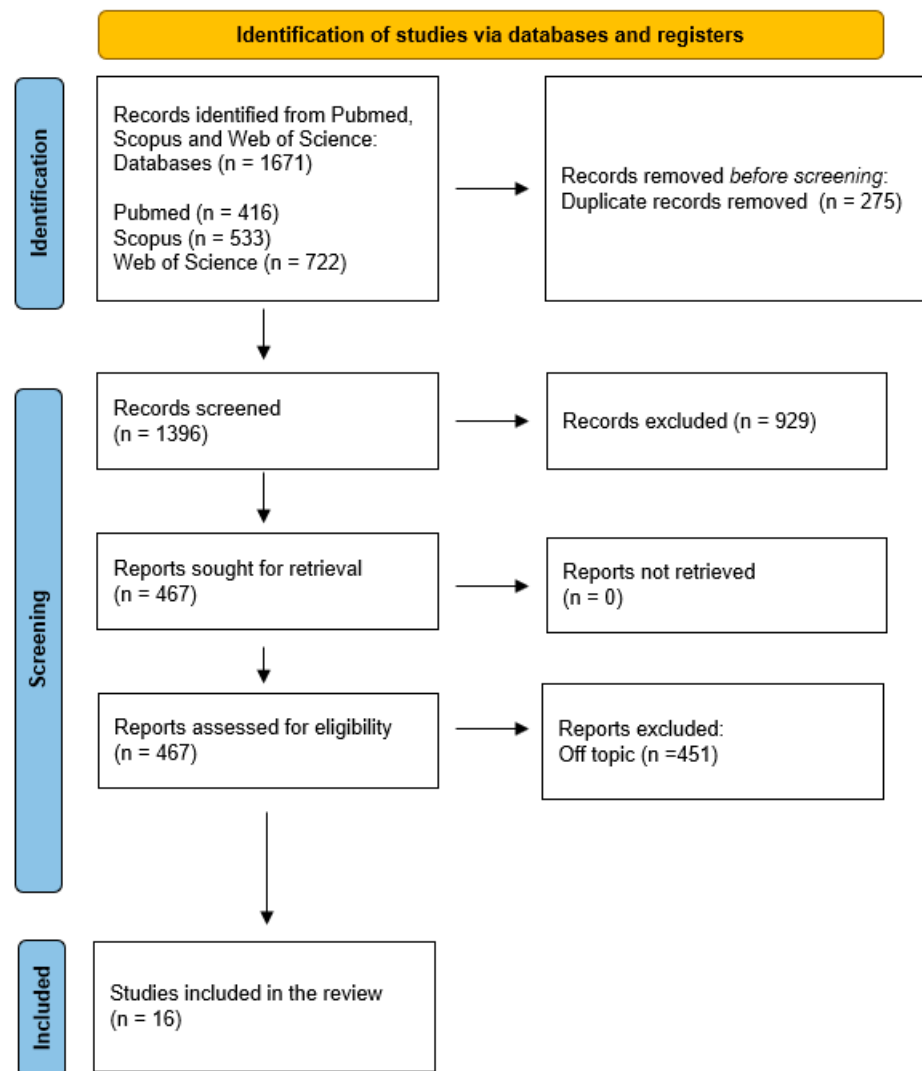


Figure 6. PRISMA flowchart with features of included articles.

Table 1. Summary of selected articles.

Authors (Year)	Type of the Study	Aim of the Study	Materials	Results
Valerie, G.A., et al., 2017 [97]	Randomized controlled clinical and histopathological trial	Compare excisional biopsies using CO ₂ and Er: YAG laser	32 Patients with f.h. in the buccal mucosa	Intraoperative bleeding 100% excisions with Er: YAG and 56% with CO ₂ laser
Saibene, A.M., et al., 2019 [98]	Study in vivo	To evaluate the outcomes of laser surgery while providing a protocol for CO ₂ laser surgery	78 patients treated with laser for benign and malignant lesions	5 patients complained of marginal pain; 3 patients had post-surgery bleeding
Hikov, T., et al., 2017 [99]	Study in vivo	To evaluate the possibility of introducing a femtosecond laser system in restorative dentistry	Patients' molars	The FELS used in this work is promising for an efficient and controlled cavity preparation
Lauritano, D., et al., 2018 [100]	Case series in a group of patients	Setting up a laser-assisted protocol for the surgical excision of malignant lesions	A specially designed medical record was used. The diode laser was used	Our findings demonstrate a statistically significant reduction in the size of the lesion
Bahammam, M.A., et al., 2018 [101]	Case report	To raise an awareness regarding the potential complications of laser gingival depigmentation	One case report	A possible treatment approach for such complications
Falkenstein, F., et al., 2014 [102]	Study in vitro	To demonstrate that laser-assisted treatment can produce thermal damage to pulp tissues	Extracted upper and lower human incisors stored in 0.9% saline solution	Middle-third portion of the root seems to be the most at-risk area for pulp damage
Franzen, R., et al., 2015 [103]	Study in vitro	To demonstrate that laser-assisted treatment can produce thermal damage to pulp tissues	30 single-rooted human teeth	Er, Cr:YSGG and a diode 2 W during irradiation show thermal rises on average of 1.68 ± 0.98 °C in the pulp chamber
Tonin, M.H., et al., 2022 [104]	Study in vitro	To show that the increasing dose of Er: YAG can produce damage of implant surface	Implants' surfaces	Modification of implant surface as adverse effect may not allow the correct formation of oxide layer that is important for wettability of implant and for the differentiation of osteoblasts
Monzavi, A., et al., 2018 [105]	Study in vitro	To investigate and compare temperature change during implant decontamination with different laser types ([Co ₂]/Nd: YAG/Er: YAG/PDT	Sixty implants were inserted into a bone block cut from a sheep's mandible	Temperature changes over 10 °C occurred at the apical point of the implants with the Co ₂ , Nd: YAG and diode laser irradiation; however, only the Co ₂ laser reached statistical significance in this regard

Table 1. *Cont.*

Authors (Year)	Type of the Study	Aim of the Study	Materials	Results
Hoedke, D., et al., 2018 [106]	Study in vitro	To show the removal of bacteria biofilm inside the root canals of extracted teeth through photodynamic therapy using phenothiazine chloride as photosensitizer and a diode laser with a wavelength 660 nm in combination with irrigants	160 extracted human single-rooted teeth	Effective method for the reduction in bacterial biofilm inside the root canals of extracted teeth
Ferreira Pires Sobral, M., et al., 2021 [107]	Longitudinal randomized and parallel clinical trial	To compare a violet light-emitting diode system and in-office dental bleaching	Sixty volunteers selected for group one bleaching with 35% hydrogen peroxide gel and for group two using bleaching using a LED	Violet light alone caused repigmentation after dental bleaching
Chung, S.E.V., et al., 2015 [108]	Study in vitro	To demonstrate that Er: YAG laser favors bacteria elimination in infected root canals together with sodium hypochlorite irrigation		The adverse reactions observed in endodontics with Er: YAG laser include the risk of thermal injury to periodontal tissues, even if it not a temperature that causes the necrosis of periodontal ligaments
Saluja, M., et al., 2016 [109]	Study in vitro	To show that Nd: YAG, CO ₂ and diode lasers can be used also for treatment of dentinal hypersensitivity through the occlusion of human dental tubules	24 extracted teeth	Risk of the expansion of dental pulp through damage
Mozaffari, H.R., et al., 2016 [110]	Study in vitro	To demonstrate that laser for dentinal hypersensitivity can also interfere with composite restoration	60 extracted teeth	The application of glutaraldehyde desensitizer and the CO ₂ laser to the surface in order to complete restoration does not increase microleakage in the enamel or dentin damage tooth surface treatment, while Er: YAG laser significantly increased microleakage at the dentin margins

Table 1. Cont.

Authors (Year)	Type of the Study	Aim of the Study	Materials	Results
Aljdaimi, A., et al., 2019 [111]	Study in vitro	To compare the impact of Er: YAG laser irradiation on enamel using an FIB	Coronal sections of sound enamel and dentine were machined to 50 µm thickness using an FIB	Microcracks in the peritubular dentine ran orthogonally to the tubules, whereas fractures in the intertubular area ran parallel to the tubules. The average depth of these fissures was around 10 µm below the surface. As a result of preferential ablation of the less mineralized intertubular dentine on the dentine surface, a tubule-associated uneven topography was created.
Kuhn-Dal Magro, A., et al., 2022 [112]	Randomized double-blind clinical trial	The effect of LLLT associated with therapeutic measures from the oral mucositis	80 subjects treated for oral mucositis with LLLT	The LLLT was effective for OM lesions

4. Discussion

In 1901, Planck introduced the concept of quantum theory, which challenged classical electromagnetic theory by proposing that energy is absorbed and emitted in discrete, indivisible units known as quanta [14]. Building on this theory, in 1913, Bohr developed a model of the atom that explained how electrons occupy well-defined orbits around the nucleus, based on the atom's energy level [15]. Later, in 1916, Einstein contributed to the field with his work on stimulated emission, laying the foundation for the concept of the emission of light quanta or photons. In 1926, G. Lewis defined the term “photons” to describe particles of light. The development of the laser began with the invention of the ammonia MASER (microwave amplification by stimulated emission of radiation) by Townes, Gordon and Zeiger in 1954. The MASER works by emitting microwaves, and it is considered the precursor to the laser. Then, in 1960, Maiman created the first functioning laser device, using a ruby rod as the active medium. This achievement opened a new era in the study of light and its properties [16].

Laser therapy has increasingly been used in various fields of dentistry, showing various advantages useful for dental practice but also accompanied by certain adverse reactions [5–7]. The use of lasers in periodontics is helpful in combination with the mechanical debridement of calculus and bacteria from tooth surfaces [8]. As an adverse reaction, laser-assisted treatment can cause thermal damage in pulp tissues. The analysis of the thermal effect of irradiation with a 940 nm diode laser of 1.0 and 1.5 W in a continuous wave mode on tooth surfaces in an in vitro study shows how the middle-third portion of the root seems to be the most at risk area for pulp damage [102].

The bactericidal power of laser is beneficial also for peri-implantitis. The laser dose is fundamental: even if the removal of bacteria increases with the increase in Er: YAG dose, the increasing dose can cause damage to the implant surface [104]. In regard to the types of lasers, the Er: YAG laser and photodynamic therapy are useful in implant decontamination, while more precaution is required in the application of the Nd: YAG, diode and, especially, CO₂ lasers regarding temperature elevation [105]. However, the Er: YAG laser irradiation on a sandblasted and acid-etched (SLA) titanium disk can modify the oxide layer, causing roughness on implant surface. In fact, laser treatment reduces the roughness of implant surface in order to prevent bacteria adhesion. On the other hand,

as an adverse effect, the modification of the implant surface may not allow the correct formation of oxide layer, which is important for the wettability of the implant and for the differentiation of osteoblasts [104].

Regarding endodontic therapy, laser therapy has also proven effective for the purposes of root canal treatments. In fact, when it is necessary to devitalize a tooth, removing the pulp, vessels and nerves and eliminating pain, the laser can be an effective aid in the procedure. For devitalization to be effective, all cavities and tissues must, in fact, be thoroughly disinfected and all root canal lumens cleansed. The laser allows for the deep cleaning of these areas, favoring the successful outcome of devitalization [106]. When comparing the effectiveness of the violet light-emitting diode system to in-office dental bleaching, it is important to consider that bleaching with violet light alone may result in unwanted discoloration as an adverse effect [107].

The Nd: YAG, CO₂ and diode lasers can also be used for the treatment of dentinal hypersensitivity through the occlusion of dental tubules. However, in an *in vitro* study about the sealing of dentinal tubules, 1.6 and 2 W lasers at a power of 1.6 or 2 on 24 extracted teeth revealed the risk of the expansion of damaged dental pulp [109]. An *in vitro* study highlighted that the use of laser for dentinal hypersensitivity can also interfere with composite restoration. In particular, the Er: YAG laser significantly increased the microleakage at the dentin margins [109]. Various types of lasers have distinct clinical implications, and when it comes to composite restoration, pre-treatment with glutaraldehyde-desensitizer and CO₂ laser irradiation does not lead to any improvement of the enamel and dentin margins [110]. Another study compares the effect of Er: YAG laser irradiation on dentine and enamel. The coronal sections of the healthy surfaces of enamel and dentine machined to a 50 µm thickness using a FEI-Helios Plasma (FIB) were analyzed using the Zeiss Xradia 810 Ultra. Er: YAG laser irradiation causes cracks in the inter-tubular region. Cracks run orthogonally to the dentinal tubules and deepen to approximately 10 µm below the surface. Consequently, the use of lasers can determine failure in the field of restorative dentistry because cracks can lead to the fracture and infiltration of the margin [111].

In surgery, a laser can be used for the excision of potentially malignant oral lesions and for the excision of the tumors of soft tissues. In oral and maxillofacial surgical procedures, lasers guarantee the accurate cutting of soft tissues with good hemostasis [80]. In this case, a lack of post-operative swelling, bleeding and pain was reported. Therefore, for the excision of vascular lesions, the laser provides many advantages thanks to good coagulation properties. For the treatment of lesions occurring in conjunction with encephalotrigeminal angiomas or Sturge-Weber syndrome, the clinical utilization of lasers is useful [70]. In oral pathology, the use of lasers with different wavelengths can also be helpful for the treatment of mucositis [112]. In the study carried out by Romeo, U., et al. in the evaluation of the effectiveness of using diode lasers as a protocol to excise leukoplakia, a light burning sensation was experienced as an adverse effect [113]. In a study in which the CO₂ laser was used to remove benign and malignant lesions, three patients experienced post-surgery bleeding [101,108]. Only minor side effects were described, such as thermal damage or a light burning sensation [100,114]. In electronic research on the impact of lasers on orodental tissues, several adverse effects on the tooth surface and subcutaneous and submucosal tissues, as well as other adverse reactions, are described. The side effects of lasers include pulping damage and subcutaneous and submucosal laser effects; in fact, the inappropriate use of dental lasers with air cooling spray can cause subcutaneous and mediastinal cervicofacial emphysema. Furthermore, the use of lasers could lead to cellular necrosis in the periodontal ligament, mainly due to the thermal effect. In fact, laser-treated teeth showed ankylosis, cement lysis and significant bone remodeling. In addition, laser smoke byproducts are considered potentially toxic chemicals. These compounds have harmful health effects, including the irritation of the eyes, nose and respiratory tract; damage to the liver and kidneys; carcinogenic cellular abnormalities; headache; dizziness; drowsiness; stomach pain; vomiting and nausea; and accelerated breathing [115]. Lasers are used also in restorative dentistry to control the correct removal of enamel and

dentine in cavity preparation [99]. A lower pain sensation is reported when lasers are used in orthodontics to treat soft tissues and for improving gingival margins present in finishing [17]. A possible treatment of an adverse reaction to a laser is described in a case report about the potential complications of laser gingival depigmentation [101].

Valerie, G.A., et al. discussed the clinical and histological effects of 32 excisional biopsies of the fibrous hyperplasia of the buccal mucosa conducted with CO₂ and Er: YAG lasers, as analyzed in this study. The area of thermal damage in the Er: YAG laser specimens was much smaller than in histological evaluations. Clinical results revealed that the operative time did not change but bleeding and the need for electrocautery significantly increased with the use of the Er: YAG laser. No link was found between the laser technology used and the experience of postoperative pain on a VAS scale completed by patients during a 15-day period. The Er: YAG laser and electrocautery were used in 94% of cases (versus 50% for the CO₂ laser), but this had no effect on the duration of surgery. The CO₂ laser is known for its ability to reduce bleeding and improve visibility during surgery by closing small blood vessels. Clinical features, such as operative time, pain and analgesic use, appear to be modest and comparable with both laser procedures. Tissue integrity is better maintained after Er: YAG laser excisions than after CO₂ laser excisions due to the reduced thermal impact, with the advantage of a smaller area of damage in histological examination [97].

In the research by Saibene, A.M., et al., there were only four patients who experienced postoperative bleeding, of whom only two required cautery with bipolar forceps and one needed resorbable sutures. There were no adverse drug responses or injuries caused by laser activity. In addition, the CO₂ laser appears to be a painless procedure, as most patients reported a low level of pain, with a mean of 2.5 on the VAS scale after 24 h and a standard deviation of 1.78; a value of 2 after 48 h and a standard deviation of 1.33; and a value of 0 at 7 days after surgery. Two patients reported transient numbness around the surgical region, which disappeared in two and five days, respectively [98]. In contrast, the study by Hikov, T., et al. aimed to evaluate the feasibility of introducing a state-of-the-art commercial femtosecond laser system into restorative dentistry, maintaining the well-known advantages of lasers for caries removal while overcoming disadvantages such as thermal damage to the irradiated substrate [99].

By varying the irradiation parameters (pulsed laser intensity, scanning speed and pulse repetition rate), no cracks were detected in the enamel or dentin after laser ablation with the optimal settings, and the craters had precise and well-defined sides and vertical edges. The craters in both materials were evenly processed, and no side effects, such as discoloration, melting or charring, were found as a result of laser contact with the dental tissue. This indicates that there was no overheating and that the dental nerves in the pulpal cavity of a real tooth were not damaged, which is an additional benefit of the absence of collateral damage. This method seems to have the potential to promote a minimally invasive laser-assisted approach in restorative dentistry, if appropriate laser settings are used [99].

The diode laser is not recommended as the main laser for soft tissue surgery, but its adaptability led us to select it for study. The diode laser is a semiconductor laser and exists in different wavelengths: from 980 nm, which has greater cutting ability and fibers that do not need to be activated, to 810 nm, which has greater biostimulatory ability. This laser thus has a dual functionality. The protocol adopted in this investigation sought to exploit both cutting and biostimulatory capabilities; the latter, in particular, was always used after the surgical phase and for controlling orthodontic tooth movement. This helped to reduce surgical pain and edema, as well as to achieve better and faster healing without scarring or recurrent functional outcomes [56].

Current Trends and Future Directions

Similar to all other medical specialties, dentistry is constantly evolving in order to improve patient comfort and efficiency. Patients who require dental care often describe their time in the chair as a nightmare. The dentist has a duty to review protocols and

constantly strive to stay up to date in order to guarantee, if not enhance, the quality of both the services provided and, most importantly, the patient's perspective on the entire dental system. In the coming years, we will most likely discuss individualized dentistry, various devices, and custom-built treatments that are as minimally invasive and painful as possible [116].

5. Conclusions

Lasers can be considered a very useful tool in all fields of dentistry. Technological evolution may lead to a preference for the use of lasers over conventional surgical and therapeutic techniques in the near future. The adverse effects of lasers can be superimposed on a common clinical outcome with conventional therapeutic techniques. Therapeutic effects differ depending on the operating protocol, the wavelengths used on different target tissues and the individual patient response. Laser therapy has a positive effect on the emotions of even the most fearful patient. The use of all types of lasers requires an appropriate learning curve in order to both optimize positive therapeutic effects and avoid adverse ones.

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Abbreviations

ATF/CREB	Group of transcription factors
ATP	Adenosine triphosphate
BRONJ	Bisphosphonate-related osteonecrosis of the jaw
cAMP	Cyclic adenosine monophosphate
CO ₂	Carbone Dioxide
Cox	Cytochrome C oxidase
DNA	Deoxyribonucleic acid
Er: YAG	Erbium-doped yttrium aluminum garnet laser
FDIP	Forced Dehydration with Induced Photocoagulation
FIB	FEI-Helios Plasma
HIF-1	Hypoxia-inducible factor 1
LASER	Light Amplification by Stimulated Emission of Radiation
LED	Light-emitting diode
LLLT	Low-level laser treatment
MMP	Mitochondrial membrane potential
MRONJ	Medication related osteonecrosis of the jaw
Nd: YAG	Neodymium yttrium aluminum garnet

NF- κ B	Nuclear factor kappa-light-chain-enhancer of activated B cells
NIR	Near infrared
NO	Nitric oxide
p53	Tumor protein
PBM	Photobiomodulation
MUC5B	Oligomeric mucus/gel-forming
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
Redox	Oxidation–reduction process
Ref-1	Multifunctional protein
RNA	Ribonucleic acid
ROS	Reactive oxygen species
WALT	World Association for Laser Therapy
YSGG	Yttrium scandium gallium garnet

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