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Review

Laser Application for Periodontal Surgical Therapy: A Literature Review

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Abstract: Objectives: The aim of this article is to examine the effectiveness and capabilities of laser use in periodontal surgical therapy by analyzing the existing literature that focuses on laser use alone or as a supplement to the already existing periodontal surgical techniques, comparing it to conventional periodontal surgical therapy, with the intent to reach a better understanding of the efficiency and therapeutic potential of lasers in periodontal surgery. Methods: An electronic search of the PubMed, Embase, and Cochrane databases was performed between October 2023 and December 2023 to identify all of the articles published in the last 15 years and investigate information about the application of Diode, Erbium:yttrium–aluminum–garnet (Er:YAG), Carbon Dioxide (CO_2), and Neodymium yttrium–aluminum–garnet (Nd:YAG) lasers to surgical periodontal therapy in human trials. Results: The database search yielded 18 studies. All of the databases showed a clinical improvement in pocket depth (PD), clinical attachment level (CAL), gingival recession (GR), and bleeding on probing (BOP) in both the test and control groups, with results from five articles showing statistically better PD reduction in the laser group compared to the control group. CAL gain was statistically higher in the laser group in six articles, while one study indicated better PD and CAL results in the control group. Improved GR reduction with a laser was noted in two articles, while one article reported a negative influence from a laser in GR. BOP was significantly better with laser in one study, while the remaining two studies reported the same results as the control group. Conclusions: Laser application in resective surgery exhibits additional benefits to the already established techniques, while in regenerative surgery, more investigation is needed. Diode laser use in periodontal surgery is already widespread and shows clinical efficacy, while low-level laser therapy (LLLT) has an exceptional potential for a variety of applications, promoting better wound healing and less post-surgical complications. However, more trials and studies are needed to further examine the maximum efficiency of each laser type in periodontal surgical therapy.

Keywords: laser; periodontal surgical therapy; periodontitis; resective surgery; regenerative surgery; diode laser; Er:YAG laser; Er,Cr:YSGG laser; Nd:YAG laser; CO_2 laser

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1. Introduction

Periodontitis is an oral disease which is widespread and characterized by irreversible damage in deeper tissues, like the alveolar bone, periodontal ligament, and cementum [1]. Typically, a dysbiotic state is initially induced by different bacteria, mainly *Aggregatibacter actinomycetemcomitans (A. actinomycetemcomitans)*, *Porphyromonas gingivalis (P. gingivalis)*, *Treponema denticola*, and *Tannerella forsythia (T. forsythia)*, which accumulate due to poor oral hygiene. The presence of these bacteria and their lipopolysaccharides (LPS) leads to an immune response, which, in the long term, is responsible for the destruction of the periodontal tissues. Polymorphonuclear neutrophils (PMNs) and monocytes migrate in the gingival sulcus, which, along with the gingival epithelium, secrete cytokines such as interleukin IL-1β, IL-6, and tumor necrosis factor α (TNF-α). Local capillaries become more permeable, and leukocytes start to concentrate on the area of infection. Prostaglandin produced by macrophages, along with IL-1β, promote PMNs and monocytes to further bind to endothelial cells, progressing the existing inflammation and activating, along with IL-6 and TNF-α, osteoclasts for alveolar bone reabsorption. At the same time, capillary serum is released due to stimulation from histamine and complement, which increases vascular permeability, becomes filled with antibodies, complement, and other molecules, and fills the gingival sulcus. This leads to an increased volume of gingival crevicular fluid and the surrounding gingival tissues [2]. All of these bioactive substances lead to changes which provoke the important loss of periodontal attachment and apical movement of the junctional epithelium [3]. An infected periodontal pocket is thus formed, which is lined by gingival epithelia. In cases where treatment is not accomplished, support of the tooth by the periodontal tissues becomes inevitably nonexistent, and the tooth is lost [4].

Establishing a case of periodontitis is achieved by specific clinical measurements like pocket depth, bleeding on probing, clinical attachment loss, radiographic bone loss, and presence of dental calculus or plaque on the areas where the disease is suspected [5]. Based on the findings of these measurements and a collection of other risk factors and indicators, a classification system has been established. It distinguishes between the stages of the periodontal disease and the grades of its rate of progression. Staging is dependent on severity, complexity, and the extent of the disease, as well as grading the future risk and potential health impacts of periodontitis by considering specific primary criteria and risk factors, like smoking and diabetes. Periodontitis can be Stage I—initial, with loss of clinical attachment level (CAL) between 1 and 2 mm, Stage II—moderate (CAL loss = 3–4 mm), Stage III—severe, with potential for additional tooth loss (CAL loss $\geq$ 5 mm), and Stage IV—advanced, with extensive tooth loss and potential for loss of dentition (CAL loss $\geq$ 5 mm and complex rehabilitation), and its grades of progression are divided into Grade A—slow rate of progression, Grade B—moderate rate of progression, and Grade C—rapid rate of progression [6].

Treatment is focused on reducing the total load of pathogenic microorganisms in the periodontal tissues and halting further tissue destruction. In gingivitis cases, treatment is limited to supragingival plaque and calculus removal, as well as the maintenance of basic oral hygiene [7]. In the case of periodontitis, depending on the severity and complexity of the case, treatment can be either nonsurgical or surgical, with the latter being applied in the later stages of the disease [8]. In nonsurgical treatment cases, the removal of the biofilm and plaque, both supra- and subgingival, with either the hand or using ultrasound instruments, often using local and/or systemic antibiotics and antiseptics, is the norm, with the aim of promoting periodontal attachment [7]. Periodontal surgical techniques have been developed and refined to address specific conditions, usually pockets with probing depths larger than 5 mm. The various techniques that can be applied are usually divided into resective and regenerative, and can be applied each on their own or together, depending on the situation [8].

The primary objective of periodontal surgery traditionally has been the elimination of the periodontal pocket through resective surgery's various techniques [8]. The modified Widman flap method [9] and gingivectomy aim to eliminate infected soft hard tissues and modify their architecture [10]. Osteoplasty is employed for the management of shallow bone defects, dense interproximal bone areas, and early-stage furcation issues, while avoiding the removal of supportive bone. Ostectomy, on the other hand, is applied for the treatment of shallow-to-moderate intrabony and hemiseptal defects, with depths ranging between 1 and 4 mm. This technique is also effective in rectifying irregularities in bone contours [11]. An apically repositioned flap [12] is another type of flap which is widely used in combination with osseous surgery and is proven to promote periodontal clinical attachment [13].

Periodontal regeneration primarily targets deep intrabony defects and furcation involvement in molars and upper first premolars, where the maintenance of oral hygiene can be difficult. Localized gingival recessions and root exposures may also be suitable for regenerative techniques due to sensitivity or esthetic concerns [14]. The means by which this is accomplished can involve a guided tissue regeneration (GTR) membrane, a bone graft (GBR) [15], or an enamel matrix derivative (EMD) [16]. Research indicates that GTR membranes offer improve pocket depth, clinical attachment, and bone formation compared to open flap debridement alone [17], while GBR alone is found to have inconclusive results from insufficient data [18]. Studies have shown that EMD affects various aspects of PDL cells, such as proliferation, attachment, and matrix production [19,20]. Research reveals that, under EMD influence, both human PDL cells and gingival fibroblasts exhibit the increased release of transforming growth factor beta 1 (TGF-β1) compared to control groups [21–23]. Another study [24] found, in vitro, that the addition of EMD to a medium containing both PDL cells and gingival fibroblasts significantly enhances the wound fill rates of PDL cells.

Over the past ten years, the integration of laser (Light Amplification by Stimulated Emission of Radiation) technology into periodontology and oral surgery has become a significant topic of discussion [25]. This interest is due to the various advantages that lasers are reported to offer, like lower invasiveness, reduced healing time, and potentially better clinical outcomes [26]. However, the effectiveness of these methods can vary depending on the type of laser used and the specific clinical application [27].

High-power lasers, which operate above 500 mW [28], are increasingly utilized in periodontal treatments for their precision in removing inflamed or dead tissues. Additionally, the application of low-power lasers, which operate below 500 mW [28], known as low-level light/laser therapy, has shown promising results [29]. They also pair effectively with external dyes for advanced microbial decontamination in a process known as antimicrobial photodynamic therapy or photoactivated disinfection [30].

Use of lasers in periodontal nonsurgical therapy mainly includes their use in the removal of plaque and calculus alone or in combination with conventional scaling and root planning (SRP) in deep pockets [31], and has been proven in the literature to be effective both when in combination with SRP [32] and when used alone, although not as much as SRP [33]. Although the treatment capabilities of aPDT are often met with conflicting results in the literature, possibly due to confusion regarding the irradiation or other clinical parameters [27], its antibacterial effects [34] and clinical benefits in reducing probing depth and promoting clinical attachment level gain have been established when used as an adjunctive to SRP [35,36].

In surgical periodontal therapy, the philosophy behind laser use is based on their ability to offer faster healing, along with enhanced coagulation, carbonization, and, therefore, hemostasis and pocket sterilization through their photoablation, vaporization, photodisruption, and photobiomodulation, actions which are not provided by conventional open flap debridement [37].

Lasers can ablate diseased tissues and vaporize soft tissues in periodontal pockets. This enhances tissue removal and decontamination during the surgical phase, reducing the bacterial load substantially. Furthermore, ablation can be used for root surface debridement by aiding the removal of calculus and infected cementum [38], while the photobiomodulation effect stimulates the surrounding healthy tissues for the promotion of faster wound healing and better tissue regeneration after periodontal surgery [25], all without generating heat, making it a less invasive but still effective therapeutic option [30], providing high precision [39].

The aim of this publication is to review the therapeutic capabilities and effectiveness of laser use in periodontal surgery. During the previous decade, several studies have been conducted regarding the use of lasers in periodontal nonsurgical therapy and have proven their advantageous clinical results both when used for mechanical debridement [32] and in the form of PDTs when used as an adjunctive to conventional SRP [35]. However, in recent years, their usefulness for surgical purposes not only alongside various resective and regenerative periodontal techniques, but also compared to them, has yet to be fully explored and thoroughly explained, as the already existing reviews of the literature provide limited data [37,40]. This leads to the need for the further exploration of the published literature from recent years, which is the main goal of this review. One hypothesis is that studies will show that the adjunctive use of lasers will promote better clinical results in periodontal surgery, with wound healing, the antimicrobial effects, and pain reduction being significantly improved. Another hypothesis is that the existing literature will struggle to provide conclusive data regarding the enhancement of varying biomaterials and graft types of periodontology in conjunction with lasers.

2. Literature Review

The previously published literature studies regarding the use of lasers in periodontal surgery are discussed below.

A meta-analysis [37] examined the use of diode, Er:YAG, Nd:YAG, and CO_2 lasers in periodontal surgical therapy alone or as an adjunctive both to flap surgery and Guided Tissue Regeneration and/or enamel matrix derivatives. The review focuses on probing depth (PD) as a primary outcome and clinical attachment level and gingival recession (GR) as secondary outcomes. In total, eight studies were included, and, by analyzing their results, it was concluded that there was no significant PD result variation regardless of whether a laser was applied or not in flap surgery and GTR with EMD. However, it was shown that EMD-alone-treated areas had better PD reduction when used without a laser. CAL gain was the same for both treatment with and without a laser in flap surgery and GTP plus EMD, but, as in the primary outcome, EMD alone showed better results than when in combination with a laser. The authors did not analyze potential results behind this correlation. Gingival recession was found to be the same in both groups in all treatment types. The review concluded that laser use in periodontal surgery failed to show additional advantages when used as an adjunctive to the already established resective and regenerative techniques, which was partially attributed to the low number of studies included and high heterogeneity of their in-between results.

A study [41] examined the use of lasers in both nonsurgical and surgical therapies of periodontitis. Several studies which compared laser-assisted new attachment procedure (LANAP) to normal SRP and modified Widman flap surgery are mentioned and led to the result of no significant improvements in pocket depth and bleeding on probing over modified Widman flap surgery. Regarding conventional SRP, LANAP showed a mean pocket depth improvement of 0.56 mm for pockets of 36 mm and 0.24 mm for pockets of >6 mm and a CAL gain of 0.60 mm for 3–6 mm pockets and 1.00 mm for pockets of >6 mm. Bleeding on probing, as an index, is mentioned only in one study found, with the differences mentioned being regarded as insignificant. The author concludes that all of the differences in indices found are not regarded as significant and that there are, however, limitations in the number and type of analyses of the studies included. Er:YAG is examined as an adjunctive to access flap surgery plus scaling and root planning, with the indices of probing depth reduction, CAL gain, and bleeding on probing reduction favoring the use of lasers, but the differences between the test and control groups being regarded as insignificant. CO_2 laser results from other studies also show superior results when using this laser in periodontal surgery. The author concludes that, although laser use, in general, as an adjunctive to flap surgery with SRP with or without EMD, does not produce noteworthy enough results, the existing literature is limited and the published data can be conflicting and produce confusion, thus expressing the need of further research.

Another meta-analysis [42] focused on the effects lasers have in periodontal mucogingival surgery. A total of seven studies were included after screening. Complete root coverage (CRC) and root esthetic score (RES) were used as primary criteria, while probing depth, clinical attachment level, gingival recession depth (GRD), gingival recession width (GRW), and width of keratinized tissue (WKT) were selected as the secondary criteria. The review showed that CRC and RES showed no significant differences from the articles involved, both in 6-month and 1-year follow-ups. PD and CAL in the 6-month follow-up showed no differences as well, but, interestingly, however, showed statistically significant differences after a 1-year follow-up. GRD and GRW showed similar effects in both groups in both follow-ups. WKT results had high heterogeneity, but showed a significant improvement in the laser group after a 6-month follow-up. The authors concluded that the laser is beneficial regarding PD, CAL, and WKT, but exhibited no noteworthy effect on the primary criteria of the study.

3. Materials and Methods

3.1. Focused Questions and Process

The main question of this review is the following:

Are there therapeutic advantages when lasers are used alone or in combination with other periodontal surgical approaches compared to when they are not?

A secondary question to be addressed is the following:

(1) If using lasers as an adjunctive has been proven to be effective, is there any type of surgical technique that shows more promising results than the rest?

The factors which will decide the selection process are the patient, intervention, comparison, and outcome (PICO) [43], as follows:

P: Dentate patients with periodontitis, regardless of stage and grade of the disease, with or without bleeding, with or without reported suppuration, and with or without gingival recessions, regardless of mobility grade, furcation involvement, or grade.

I: Laser (diode, Er:YAG, Er,Cr:YSGG, Nd:YAG, CO_2, approved by the Food and Drug Administration) appliance in periodontal therapy, regardless of the presence or absence, in any stage of the treatment, of resective and regenerative approaches and debridement using hand or ultrasonic instruments.

C: Periodontal resective or regenerative treatment which uses techniques and materials other than lasers, either alone or with laser therapy.

O: Positive results, a lack of them, or a negative influence in the outcomes of probing depth reduction, clinical attachment level gain, bleeding on probing (BOP) reduction, gingival recession reduction, or pain assessment of the surgical procedures.

3.2. Eligibility Criteria

The following are the inclusion criteria that must be met for the selection of articles:

Case studies can be both randomized or not randomized, prospective or retrospective, and cohort or case–control series which investigate, in adult humans, the application of lasers in periodontal surgical therapy over the last fifteen years.

Special attention and analysis was given regarding the inclusion or exclusion of studies where the patients included had systemic diseases which hinder healing and regeneration like diabetes, a smoking/tobacco chewing habit, taking antibiotics within 6 months, undergoing orthodontic treatment with or without traumatic occlusion, etc.; these are factors which can hinder proper diagnostic and therapeutic results. Whenever they are included, they will be mentioned.

Exclusion criteria of the selection process are as follows:

(i) Preclinical trials in animals;
(ii) Systematic reviews and literature reviews of the same topic;
(iii) Trials with underage patients;
(iv) Trials with pregnant or lactating women;
(v) Articles with laser application only in periodontal nonsurgical therapy;
(vi) Studies where the patient number was less than 8;
(vii) Articles published before 2008;
(viii) Articles where no or insufficient information for any of the clinical parameter values (PD, CAL, BOP, GR, or pain assessment) was provided.

3.3. Screening Process

The search for articles was conducted in three databases (PubMed, Embase, and Cochrane). Articles had to be in English and published from January 2008 to December 2023. In PubMed, publications had to include a combination of both MeSH terms and various keywords in their title or abstract. The search sequence was the following: (laser *[MeSH Terms] OR diode laser* OR Er:YAG laser * OR erbium YAG laser * OR CO_2 laser * OR carbon dioxide laser * OR Nd:YAG laser * OR Er,Cr:YSGG laser * OR neodymium doped yttrium aluminum garnet laser *) AND (periodontal[Other Term] OR periodontal flap[Other Term] OR periodontal surgery OR periodontal surgical therapy OR periodontal debridement) AND (bone loss OR bone gain OR CAL gain OR periodontal atrophy OR resective OR regenerative) AND English[filter] AND humans[filter] AND (2008:2023[pdat]). The key words used for the search for Embase were: laser * AND ('periodontal surgery' OR "bone loss" OR (periodontal AND disease) OR (periodontal AND treatment)) AND human, while for the Cochrane library were: laser AND ("periodontal surgery" OR "periodontal therapy" OR "periodontal disease") AND ("bone loss" OR "bone gain" OR "surgical flap" OR "open flap" OR regenerative OR resective).

The following figure (Figure 1) illustrates the flow chart of the screening process whereas Table 1 displays the studies selected after screening.

Table 1. Studies selected after screening. MWF = modified Widman flap, OFD = open flap debridement, EMD = enamel matrix derivative, CAF = coronally advanced flap, CTG = connective tissue graft, SCTG = subepithelial connective tissue graft, GTR = guided tissue regeneration, FGG = free gingival graft, ND = no data.

Reference	Type of Laser	Test Group Technique	Control Group Technique	Number of Patients	Laser Parameters	Last Follow Up
[44]	Diode	Laser + MWF	MWF alone	25	810 nm, 1 W, 4 J/cm^2	9 months
[45]	Diode	Laser + OFD	OFD alone	28	ND wavelength, 1.5 W	6 months
[46]	CO_2	CO_2 + CAF	MWF alone	25	ND	15 years

Table 1. *Cont.*

Reference	Type of Laser	Test Group Technique	Control Group Technique	Number of Patients	Laser Parameters	Last Follow Up
[47]	Nd:YAG	Laser + SCTG	SCTG alone	17	1064 nm, 1 W, 10 Hz	6 months
[48]	Er:YAG	Laser + SCTG	SCTG alone	12	2940 nm 2 Hz, 60 mJ/pulse	6 months
[49]	Nd:YAG	Laser + EMD	EDTA + EMD	21	1064 nm 1 W, 10 Hz, 100 mJ, 141.54 J/cm^2	12 months
[50]	Nd:YAG	Laser + GTR	GTR alone	13	1064 nm, 100 mW, 100 mJ, 4 J/cm^2	6 months
[51,52]	Diode	Laser + CTG	CTG alone	40	660 nm	6 months + 2 years
[53]	Diode	Laser + OFD	OFD alone	30	980 nm, 2.5 W, 50 J/cm^2	3 months
[54]	Diode	Laser + Kirkland flap	Kirkland flap alone	20	970 nm, 7 W, 50 J/cm^2	6 months
[55]	Diode	Laser + OFD	OFD alone	15	980 nm, 2 W	6 months
[56]	Diode	Laser + EMD	EMD alone	22	588 nm, 4 J/cm^2	12 months
[57]	Er,Cr:YSGG	Laser + OFD	OFD alone	8	2780 nm, 25–50 Hz, 2–3.5 W	3 months
[58]	Diode	Laser + MWF	MWF alone	13	810 nm, 1 W, 4 J/cm^2	1 week
[59]	Diode	Laser + OFD	OFD alone	15	980 nm, 2.5 W	6 months
[60]	Er:YAG	Laser + FGG	Scalpel + FGG	20	3 W, 300 mJ, 10 Hz, 1000 µs for FGG and 1.20 W, 120 mJ, 10 Hz, 100 µs for root biomodification	3 months
[61]	Diode	laser + SRP	OFD alone	25	810 nm, 0.8 W	6 months

The primary focus of these results is pocket depth and clinical attachment level, while gingival recession, bleeding on probing, and pain assessment are also analyzed as secondary indices.

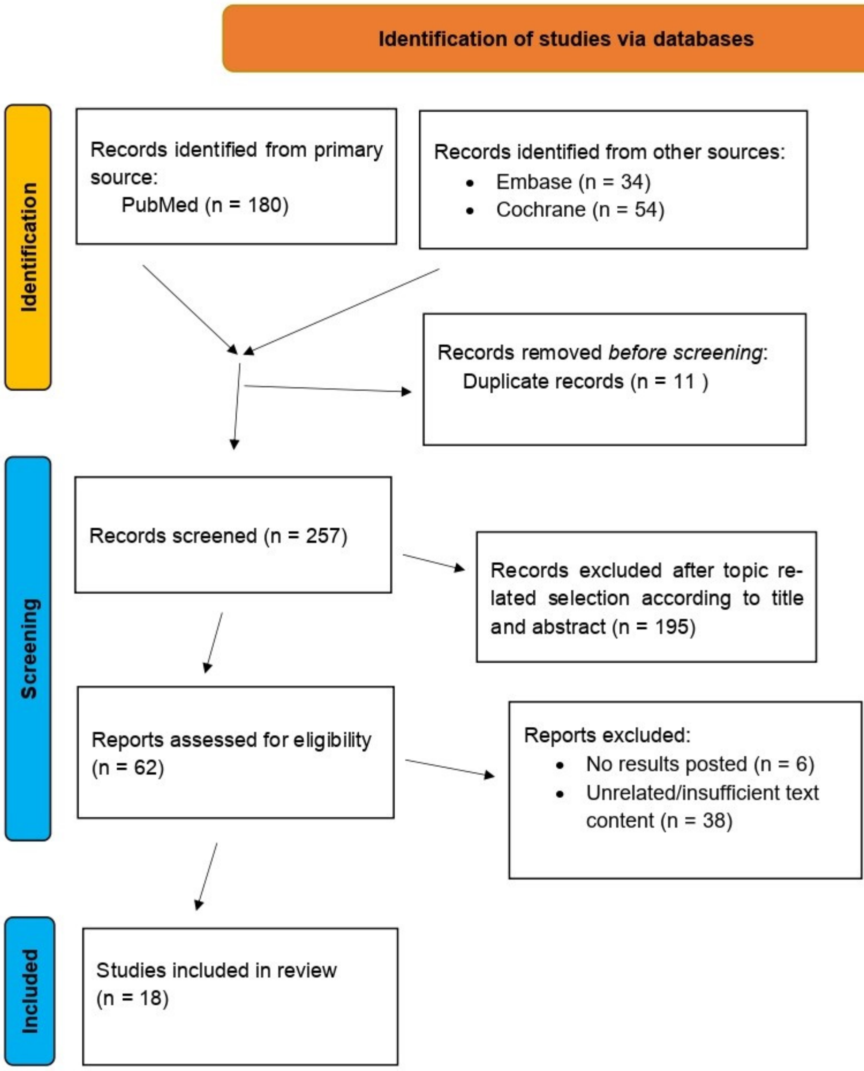

Figure 1. Flow chart of screening process.

4. Results

4.1. Study Selection

The initial search provided 268 articles across all platforms, 11 of which were removed as duplicates. Out of the 257 articles remaining, 195 of them were manually removed because of unrelated topic and context in their title and abstract parts. This led to 62 final articles, which were assessed according to the established eligibility criteria: 6 of them were removed because of posting no results, and 38 of them had unrelated or insufficient data and results. Finally, 18 articles were selected for analysis.

4.2. Pocket Depth Reduction

The results present a nuanced perspective on the effectiveness of laser integration in periodontal procedures. In five of these studies [44,46,50,54,55], both periodontal surgery with a laser alone or as an adjunctive (test group) and periodontal surgery without laser application (control group) showed a high improvement in pocket depth reduction. It was also observed that there was a significant difference in positive results in favor of the test group in comparison with the control group, suggesting that the adjunctive use of a laser can enhance the outcomes of periodontal surgery.

In another group of studies [45,47,48,56,57,59], however, it was found that, although both the test and control groups had a positive effect on PD reduction, their differences in results were insignificant. In addition, the same conclusion was found in one study [61], where, in the test group, a laser curettage with closed approach was applied, while in the control group, open flap debridement without laser was performed.

Interestingly, one study [49] showed superior results in the control group, where EMD application was performed without the adjunctive use of a laser.

4.3. Clinical Attachment Level

Regarding clinical attachment level gain, a variety of different results was again noticed.

In more detail, the results of both the test and control groups in all studies showed a noticeable improvement in CAL gain. A group of studies [44,46,50,54,55] indicated, from their results, that there was a significant improvement in CAL gain between the test (laser as an adjunctive) and control groups, in favor of the test group. Another study [61], which observed the closed approach laser debridement versus open flap debridement, also noted a significant improvement in the test group.

Several other studies [45,47,48,56,57,59] suggested, however, that although both groups had a significant improvement in CAL gain, their in-between difference in results was of no significance.

Lastly, as with pocket depth reduction, the same study [49] indicated that the group in which laser was not applied had a statistically significant better outcome in CAL gain than the group where it was used as an adjunctive.

Table 2 shows the study results regarding pocket depth reduction and clinical attachment level gain.

Table 2. Study results regarding pocket depth reduction and clinical attachment level gain for test and control groups before and after periodontal therapy.

Reference	Initial	PD (mm)	Final	PD (mm)	Initial	CAL (mm)	Final	CAL (mm)
	Test Group	Control Group	Test Group	Control Group	Test Group	Control Group	Test Group	Control Group
[44]	8.20 ± 6.2	7.40 ± 1.41	2.93 ± 0.80	3.67 ± 0.72	6.00 ± 0.85	6.13 ± 0.74	1.87 ± 0.64	0.93 ± 0.80
[45]	6.71 ± 0.72	6.93 ± 1.26	3.32 ± 0.94	2.86 ± 0.77	6.86 ± 2.65	7.64 ± 2.73	4.64 ± 2.40	4.79 ± 1.67
[46]	ND	ND	ND	ND	ND	ND	ND	ND
[47]	1.38 ± 0.51	1.46 ± 0.63	1.50 ± 0.50	1.50 ± 0.50	4.67 ± 1.33	4.88 ± 1.12	3.75 ± 1.16	2.33 ± 1.25
[48]	1.46 ± 0.43	1.58 ± 0.49	1.46 ± 0.66	1.63 ± 0.68	4.54 ± 0.90	4.67 ± 0.94	2.04 ± 0.59	2.08 ± 0.49
[49]	7.3 ± 0.6	7.3 ± 0.7	3.3 ± 0.4	3 ± 0.4	9.5 ± 0.7	9.3 ± 0.8	6.9 ± 0.7	6.4 ± 0.5
[50]	6.01 ± 0.47	5.95 ± 0.43	2.63 ± 0.29	2.93 ± 1.98	7.35 ± 0.48	7.43 ± 0.60	4.46 ± 0.57	5.18 ± 0.46
[51,52]	ND	ND	ND	ND	ND	ND	ND	ND
[53]	6.03 ± 1.22	5.80 ± 1.19	2.97 ± 0.72	3.00 ± 0.95	11.07 ± 1.57	11.5 ± 1.97	9.70 ± 1.62	9.80 ± 1.77
[54]	6.45 ± 0.84	6.13 ± 0.80	1.72 ± 0.39	3.01 ± 0.47	6.74 ± 0.93	6.50 ± 0.94	2.05 ± 0.52	3.35 ± 0.72
[55]	7.40 ± 1.76	7.00 ± 1.51	4.40 ± 0.91	5.20 ± 0.67	9.53 ± 1.72	9.26 ± 1.53	6.53 ± 0.83	7.46 ± 0.83
[56]	5.9–6.8	5.9–6.7	1.2–2.3	1.3–3.3	6.8–7.5	6.5–7.5	2.4–3.7	2.8–4.7
[57]	5.17 ± 0.19	5.51 ± 0.72	3.19 ± 0.41	3.37 ± 0.35	1.32 ± 0.16	1.12 ± 0.20	0.80 ± 0.16	0.76 ± 0.14
[58]	ND	ND	ND	ND	ND	ND	ND	ND
[59]	2.94 ± 0.67	2.98 ± 0.80	1.41 ± 0.54	1.53 ± 0.49	7.57 ± 1.38	7.00 ± 1.05	4.73 ± 1.37	4.97 ± 0.89
[60]	ND	ND	ND	ND	ND	ND	ND	ND
[61]	5.82 ± 1.16	5.80 ± 0.99	4.19 ± 1.12	4.24 ± 1.14	ND	ND	ND	ND

4.4. Gingival Recession

Regarding reductions in gingival recession, it was noted by two studies [50,56] that the addition of a laser promoted GR reduction, with better results with a laser than without.

Other studies [45,48,49] indicated that both the test and control groups showed a reduction effect in GR, but there was insignificance between their results. In another study [57], a statistically significant improvement in GR reduction was observed for the laser group in 1-month and 3-month follow-ups, but similar results as the control group were observed at later follow-ups.

One study [47] suggested that laser application negatively affected the recessions' clinical outcomes.

4.5. Bleeding on Probing

A significant reduction in BOP was shown in one study [54], where it was noted that the test group yielded better results than the control group, while two other studies [49,61] indicated that BOP was the same in both groups, whether a laser was introduced into the therapy or not.

4.6. Pain Assessment

Three studies [53,55,56] used the visual analog scale (VAS) for assessing pain caused by the periodontal surgical procedure in the test (laser) and control (without laser) groups.

The results found by Gokhale et al. (2012) for VAS intraoperative pain were 1.90 ± 0.96 and 1.93 ± 0.91 for the test and control groups, respectively, and 1.83 ± 1.23 and 1.80 ± 0.85 1 week after the operation. It was concluded that there was no significant difference in pain provoked between the two groups.

In the study by Kolamala et al. (2022), VAS was found to be 4.93 ± 1.22 and 6.47 ± 1.06 for the test and control groups, respectively, immediately after the surgical procedure, 4.60 ± 1.12 and 5.93 ± 1.16 the next day, and 1.80 ± 1.01 and 2.87 ± 1.51 after a 1 week follow-up. It was concluded that pain discomfort was higher in the control groups in all three points of time. In a similar manner, the results from Ozcelik et al. (2008) indicate that pain was more intense in the control group on the first and second days postoperatively. Finally, Sanz-Moliner et al. (2013) used the pain scale assessment (PS) and found the values to be 2.4 ± 1.9 for the test sites and 3.6 ± 2.7 for the control sites.

Table 3 shows the study results regarding gingival recession reduction, bleeding on probing, and pain assessment.

Table 3. Study results regarding gingival recession reduction, percentage of bleeding on probing, and pain assessments for test and control groups before and after periodontal therapy.

Reference	Initial GR (mm)		Final GR (mm)		Initial BOP (%)		Final BOP (%)		Pain Perception
	Test Group	Control Group	Test Group	Control Group	Test Group	Control Group	Test Group	Control Group	
[44]	ND	ND	ND	ND	ND	ND	ND	ND	ND
[45]	1.14 ± 1.29	1.29 ± 1.13	2.00 ± 1.51	1.93 ± 1.32	ND	ND	ND	ND	ND
[46]	ND	ND	ND	ND	ND	ND	ND	ND	ND
[47]	3.29 ± 1.18	3.42 ± 1.04	2.25 ± 1.23	0.83 ± 1.34	ND	ND	ND	ND	ND
[48]	3.08 ± 0.57	3.00 ± 0.71	0.58 ± 1.02	0.46 ± 0.75	ND	ND	ND	ND	ND
[49]	2.2 ± 0.5	2 ± 0.4	3.6 ± 0.5	3.4 ± 0.3	100	100	9.52	4.76	ND
[50]	1.33 ± 0.42	1.48 ± 0.55	1.82 ± 0.52	2.24 ± 0.43	ND	ND	ND	ND	ND
[51,52]	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 3. *Cont.*

Reference	Initial	GR (mm)	Final	GR (mm)	Initial	BOP (%)	Final	BOP (%)	Pain Perception
	Test Group	Control Group	Test Group	Control Group	Test Group	Control Group	Test Group	Control Group	
[53]	ND	ND	ND	ND	ND	ND	ND	ND	Insignificant in both groups
[54]	ND	ND	ND	ND	89.46 ± 12.45	85.62 ± 14.31	16.51 ± 5.98	37.05 ± 7.45	ND
[55]	ND	ND	ND	ND	ND	ND	ND	ND	Significantly lower in test group
[56]	1.1–2.4	1.8–3.0	1.1–2.8	2.4–3.8	ND	ND	ND	ND	Significantly lower in test group
[57]	0.06 ± 0.25	0.12 ± 0.34	0.96 ± 0.63	1.36 ± 0.64	ND	ND	ND	ND	ND
[58]	ND	ND	ND	ND	ND	ND	ND	ND	Significantly lower in test group
[59]	ND	ND	ND	ND	ND	ND	ND	ND	ND
[60]	ND	ND	ND	ND	ND	ND	ND	ND	ND
[61]	ND	ND	ND	ND	100	100	35	29	ND

5. Discussion

The most essential aim of periodontal therapy is the elimination of the infection by destroying or suppressing the causing pathogens found on the tooth surface or in the surrounding the tissues of periodontium through various techniques which promote an anti-infective effect [62]. Nonsurgical periodontal therapy is often met with difficulties regarding complete disinfection in cases where the periodontal pockets and bony defects are deep [63]. In these cases, a surgical approach is selected, as it enables high levels of visual contact and access to the operative area and, thus, better control of it.

In this review, the implementation of lasers in the operative surgery of periodontal therapy is the main topic. The results of all of the articles that were included are varied and, thus, a further explanation of them will be made, along with possible factors that distinguish them.

5.1. Regarding Patient Count

An important factor that needs to be addressed is the number of patients included in the studies of this review. Gunsolley et al. (1998) states that periodontal regeneration clinical trials can often produce results that offer small differences between the groups of patients that are involved, a fact that creates the need for larger and more expansive sample sizes, estimated in the range of 64–127 subjects, numbers significantly higher than the ones found in any of the studies cited in this review [64]. For comparison, only one third out of the total 18 studies had 25 or more patients included in their trials, while another 4 [48,50,57,58] had a patient count smaller than 15 subjects. This deficiency in trial subjects could potentially create a substantial loss in critical statistical data and, thus, our understanding of lasers' effectiveness in periodontal surgical therapy.

5.2. Resective Surgery

An essential distinction that must be mentioned between the different articles that were included in this literature review is the type of surgical technique that was used.

Out of the total 18 articles, 9 of them [44–46,53–55,57–59] used a type of flap elevation with surgical debridement of the targeted periodontal pathogenic areas for the control group and a laser as an adjunctive for the test group. The majority of the abovementioned articles [44,46,53–55,58,59] stated that the addition of a laser led to more beneficial clinical outcomes compared to the conventional surgical techniques that were applied on the control groups. The remaining two [45,57] articles reported that the therapeutic results from adjunctive laser use were similar to the cases where it was not applied, suggesting that it could be used as a safe alternative of the same effects. Regarding flap type, two studies [44,58] used the modified Widman flap technique, five studies [45,53,55,57,59] used generally open flap debridement, one study [46] used the coronally advanced flap technique, and another [54] used the Kirkland type of flap.

According to the data that were reported, it could be stated that lasers do indeed tend to enhance therapeutic capabilities and clinical outcomes when they are used as an adjunctive tool for periodontal debridement in resective periodontal surgery compared to conventional flap surgery alone, regardless of the flap type that they are combined with.

Special mention should be made for a study [61] where, again, flap elevation and surgical debridement of the periodontal pathogenic pockets was made for one patient group, but, in a separate group, a diode laser (810 nm, 0.8 W) was used for closed curettage without elevating any flap. There were also other groups of patients involve—for example, a group received only SRP—but since periodontal surgery is the main topic of this review, analyses will be performed on the initial two groups mentioned. This is a type of research that is not often met in the literature, since the usual practice is the comparison between laser adjunctive application in non-surgical periodontal therapy and conventional SRP or between laser adjunctive application in periodontal surgery and conventional surgical techniques. Interestingly, the results show that PD improvement was the same in both groups, while CAL gain and esthetics were significantly better in the group which received non-surgical laser debridement. It is worth mentioning, however, that smoker patients were included in the study, and, although this was controlled for, it could run the risk of promoting unforeseen results. Either way, the results from this type of study could potentially change the way laser research is established, and further research could prove to be valuable.

Nevertheless, it cannot be emphasized enough that surgical periodontal therapy is performed only after non-surgical therapy. Sufficient time must always be allowed for tissue healing and re-evaluation. This ensures that the patient's response to initial therapy has been adequately assessed. Significant clinical improvements in probing pocket depth and clinical attachment levels typically occur within the first 1–2 months after subgingival instrumentation, with additional benefits observed up to 3 months [65]. These findings underscore the critical role of re-evaluation timing in determining the necessity and potential success of surgical interventions [65].

5.3. Regenerative Surgery

Regarding regenerative surgery, the main process of periodontal regeneration relies on the successful repopulation of the wound area near the root surface with periodontal ligament (PDL) cells [66]. Since multiple articles [50–52,56,58] that are included in this review used low-level laser therapy (LLLT) as the main study target of laser use in periodontal surgery, it is important to clarify the impact of LLL energy on PDL cells.

The response of PDL fibroblasts to low-level laser energy has been demonstrated in multiple studies [67,68]. For instance, one study [69] observed that laser treatment inhibits the plasminogen activator (PA) plasmin system, potentially reducing collagen degradation around the PDL. Furthermore, other studies have shown that LLL light emitted at 809 nm encourages the proliferation of PDL fibroblasts and the production of basic fibroblast growth factor (bFGF) [68,70]. LLLT has also been noted for its post-operative benefits, including reduced pain and swelling [71], and is well-regarded for its analgesic effects, as it has been shown to selectively inhibit various nociceptive signals from peripheral nerves [72,73]. It is suggested that all major LLLT wavelengths can achieve successful analgesia following oral surgery [74], meaning that this type of therapy can enhance already recognize the positive effects of GTR and EMD on reducing post-operative complications and improving patient quality of life [75,76]. Additionally, studies by [77,78] indicate that LLLT application can diminish periodontal gingival inflammation, possibly explaining the observed reduction in swelling. The primary safety concern with LLLT is potential eye damage, particularly when using invisible collimated beams, and although no such incidents have been reported, it is recommended that both the dentist and patient wear appropriate protective glasses.

Dogan et al. [50] observed the use of GTR in combination with and without a laser for the treatment of periodontitis patients. In more detail, the periodontal bone defects were filled with equine bone grafts and covered by collagen-resorbable equine membranes, and, whenever the laser was applied, it was an Nd:YAG laser (1064 nm, 100 mW, 100 mJ, 4 J/cm^2), which was used in the form of low-level laser therapy. A second study [56] used enamel-matrix-derivative material to cover deep bony defects, and, in the test group, a diode laser (588 nm, 4 J/cm^2) was used again in the form of LLLT as an adjunctive. Both studies [50,56] showed that the use of a laser, in the form of LLLT, enhanced the therapeutic effects of the regenerative method that was applied. Interestingly, however, when a laser, Nd:YAG (1064 nm, 1 W, 10 Hz, 100 mJ, 141.54 J/cm^2, without a coolant, noncontact mode), was used for root conditioning, and when EMD was then introduced in the bone defects, it showed no statistically significant differences than the control group, where ethylenediaminetetraacetic acid (EDTA) was used for root conditioning along with EMD [47]. As the number of studies is limited and the patient count is low, further research is needed to further examine the outcomes from GTR and EMD with lasers. For now, it could be said that, according to the studies mentioned, LLLT has advantages which can be added to existing periodontal regenerative techniques to elevate clinical outcomes.

5.4. Regenerative Plastic Surgery

A group of studies, including [47,48,51,52,60], observed the efficacy of lasers in soft tissue grafts. Plastic periodontal surgery includes the use of autogenic grafts, whether they are soft tissue grafts intended to cover exposed root surfaces or bone grafts to provide support, and aims at the correction and re-establishment of the anatomically correct morphology and architecture of the periodontal tissues. The indications for the initiation of this type of surgery can be hypersensitivity, esthetic issues, susceptibility to root caries, or a combination of these factors, but can also be included in the treatment planning along with regenerative surgery in the treatment of periodontitis [79]. Soft tissue grafts can be divided into free gingival grafts (FGG) and connective tissue grafts (CTG), with the subepithelial connective tissue graft (SCTG) being regarded as the golden standard for gingival recessions [80]. This latter type of graft shows, in histologic analyses, a distinct collagen-rich connective tissue close to the epithelium [81]. Studies have reported that SCTG can promote better blood supply, improved thickening, and better esthetics [80,82], and thus improve the possibility for better root coverage outcomes by promoting a stabilized environment and reducing the chance for complications through the transformation of the gingival biotype [83], with one study reporting lesser late post-operative complications compared to de-epithelialized FGG [84].

Dilsiz, Aydin, and Canakci et al. (2010) compared SCTG efficacy with adjunctive use of an Nd:YAG laser (1 W, 10 Hz, 60 s, 1064 nm, without coolant, non-contact mode) for root biomodification of the intended recipient site and with SCTG without a laser for the treatment of gingival recessions. It was concluded that laser use negatively impacted the root coverage with SCTG, with average root coverage being 33% and 77% and complete root coverage being 18% and 65% for test and control groups, respectively, in the last follow-up. Recession width and recession depth also favored the control group results. Interestingly, the same author published the same type of study [48], but an Er:YAG laser (2 Hz, 60 mJ/pulse, 40 s, 2094 nm, air coolant, non-contact) was used for root biomodification in the test group's patients before receiving SCTG. In this case, no statistically significant differences in the results were found. The reason suggested by the author regarding the negative effect of the laser in the first publication is that Nd:YAG specifically can alter the biocompatibility of the root surface by inhibition of its cell proliferation and thus lower the levels of fibroblast attachment and changes in the dentin biomolecules' structure. This is backed by another publication which observed the fibroblast attachment with a laser in vitro and reached the same outcome [85].

LLLT has also been found to promote better root coverage of CTGs in the short term of several months, as a publication [51] used a diode laser (660 nm) as LLLT with the intend of enhancing the plastic periodontal therapy. The last follow-up was 6 months after surgery, and it was observed that the mean percentage of root coverage was 91.9% and 89.48%, respectively, after 6 months, with complete root coverage also favoring the test group. It was concluded that LLLT could offer additional benefits to CTG surgeries. However, 90% of the patients of this study, specifically 36 of the initial 40, were recalled for examination in another study [52] 2 years after the publication of the initial article. Mean percentage was found to be 93.43% for the test group and 92.32% for the control group, while complete root coverage was 79% for the test group and 76% for the control group. Both groups maintained a good quality of esthetics. It was thus suggested that LLLT offered potentially no benefits associated with CTG. Unfortunately, there are no detailed data given regarding the parameters of diode use. It could be suggested that clinical benefits exist for CTG when LLLT is applied, since, in initial follow-ups, the coverage of recessions was significantly better, which implies faster tissue regeneration and wound healing. After the maximum coverage potential of the test group was reached, it was halted to the same level that the control group reached at a later point in time, thus reading the same clinical results of root coverage in a time span of 2.5 years after the initial surgery.

Certainly, there are hindrances in the study of this field, since the placement of soft tissue grafts requires knowledge of techniques of high skill levels, and cases where patients wish to undertake surgery for gingival recession coverage can be limited. Further research would certainly shed more light on the efficacy of lasers in soft tissue plastic periodontal surgery. FGG, for example, was studied by only one author, where the graft was used for root conditioning in combination with an Er:YAG laser and was compared to conventional scalpel use [60]. It was found that they both had the same clinical results. However, it is, again, one study that cannot be compared to other recent FGG laser studies of the same type, since the literature is limited and, therefore, further analysis is prevented.

5.5. Additional Beneficial Effects

Lesser pain after laser use in periodontal surgery compared to conventional periodontal surgery was reported by a number of studies [55,56,58], while insignificant differences between pain levels in the two groups was reported by [53]. This improvement in pain management could be attributed to a laser's capability to prevent pain signaling reaching the brain and thus reducing its perception by the central nervous system and the brain [86]. Chow et al. (2011), for example, observed that lasers caused neural impairment of the nociceptive Aδ and C fibers. In addition, stimulants like endorphins and enkephalins are increasingly secreted. These substances are known to act as pain relievers and reduce the nerve's perceptive abilities [86].

The index of the pain scale [58], as well as the VAS used in the other studies [53,55,56] that are included in this review, are highly dependent on patients' experiences and perceptions. A patient's psychological state and expectations can potentially play an important role for each separate individual. Worth mentioning are the reports regarding pain assessment by [58]. In this study, the patients acted as both the control and test group. In order to limit as much as possible the subjective aspect of pain perception by each individual, the patients were kept intentionally uninformed of which operative sites were going to be treated with and without a laser, something that the author describes as removing the potential "placebo effect of laser". The results mentioned were statistically significant in favor of the laser sites. However, it was also reported that pain experience was also significantly better and lower in the second surgical procedure, regardless of whether it was for the control or test group sites. The idea that the sequence of surgical procedures can alter the results of how each technique performs is something worth taking into consideration and could affect the way we perceive existing research. None of the remaining publications that studied pain discomfort mentioned whether the test or group sites were treated first and whether patients were informed regarding which sites and at what time they will be treated with laser, leaving room for further discussion and investigations into how patients can perceive post-operative pain when it is already experienced and expected. It is also reported [58] that patients received significantly lower amounts of pain medication for the discomfort caused by test sites compared to control sites, indicating not only less pain, but potentially lesser duration and intensity, which led to a decreased need for receiving medication. Significantly lower levels of edema were also noted in the test sites compared to the control sites, and, according to the author, the results were not altered by the fact that some patients were smokers. The same improvement in reduced edema was also reported by [56].

It is worth noting that three publications [44,50,55] studied the effects of lasers on bleeding of the gingiva, but did not use the BOP index and so were not included in the Results section. Reference [50] used the sulcus bleeding index (SBI), while [55] used the modified sulcus bleeding index (mSBI), and both found a better clinical outcome for the group in which a laser was applied. Reference [44] applied the papillary bleeding index (PBI), and although a better clinical efficacy of lasers was found in 6-month follow ups, in the final 9-month follow ups, there was no statistically significant difference in results between both groups, indicating better healing capabilities in the first 6 months, as was also reported by [51].

Three studies [53,54,59] observed the antimicrobial effects of lasers when applied in periodontal surgery. All of these studies used diode lasers and reached the conclusion that the number of anaerobes was much more significantly reduced in the cases where lasers were applied. Diode lasers have been reported to be more effectively absorbed and penetrate the targeted hemoglobin-rich sites, where the main periopathogenic bacteria are found, less [87]. Two studies [53,59] used a colony-forming unit (CFU) as the measuring index, while [54] measured the levels of *P. gingivalis*, *T. denticola*, and *T. forsythia* in the two groups and found the results from the laser group to be superior to the control group. Protohemin and protoporphyrin IX pigments are included in *P. gingivalis* and can be ablated using a diode laser, since they are biomolecules that are photosensitive to a diode's operative wavelength, resulting in the eradication of the whole bacteria. The high decrease in *T. denticola* levels is caused by the ability of lasers to neutralize key virulence factors in the bacteria, such as lipopolysaccharides and proteases [88]. This effect of lasers was highlighted in an in vitro study by Ando et al. (1996), demonstrating that laser irradiation created growth-inhibitory zones around bacterial colonies and reduced the survival rates of bacteria in irradiated colonies compared to those that were not irradiated. Similarly, a significant decrease in *T. forsythia* levels in the test group may result from the penetration of diode laser energy up to a few millimeters into deeper tissues, effectively targeting tissue-invasive periopathogens. This process involves breaking down molecular and chemical bonds which leads to the vaporization of water and the consequent lysis of bacterial cell walls, ultimately causing cell death [89].

5.6. Limitations

A significant limitation is that the authors did not analyze the risk of bias in the included studies. Furthermore, we included all of the relevant studies, regardless of the heterogeneity of the results and the smallness of the sample size.

6. Conclusions

The literature shows that lasers offer additional advantages in their many forms of application in resective periodontal surgery, while regenerative surgery seems to gain advantages from lasers whenever they are applied in the form of LLLT. It has been established that LLLT has been proven to promote more effective wound healing and reduce discomfort. Data regarding the connection between lasers and soft tissue grafts remain limited, and no outcome can be formulated. Diode lasers are the most widespread type of laser, and they exhibit very effective results in periodontal surgery. Er:YAG and Er,Cr:YSGG also have a promising potential for additional benefits compared to conventional surgical techniques, especially in the processing of bone and hard dental tissues; however, more research is needed. The same could also be said for the use of Nd:YAG and CO_2 lasers. Pain during and after surgery is significantly reduced when lasers are applied, while the antimicrobial effect of lasers on periopathogenic microorganisms shows very exciting prospects. As the sample size of this review is relatively small and the heterogeneity among studies is often met, additional research and trials are crucial in order to deepen our understanding of the full potential of laser efficacy in periodontal surgery treatment.

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