

Lasers in minimally invasive periodontal and peri-implant therapy

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'Pain free' and 'simple procedure' are two of the most attractive phrases to patients who are otherwise reluctant to accept any dental treatment (138). Minimally invasive dental therapy (81) could satisfy the demands of such patients. The procedures can be comfortable, although not necessarily without any pain; and be effective for disease control whilst preserving more healthy dental tissue.

Scaling and root planing is an example of a minimally invasive procedure because it is a conservative, cause-related therapy that attempts to eliminate etiologic factors from the root surface (26). Scaling and root planing can result in improved clinical outcomes such as reduced bleeding on probing and decreased periodontal pocket depth. However, some calculus occasionally remains on the 'scaled' and 'planed' root surface. Moreover, treatment outcomes may not always be successful for moderate and deep periodontal pockets (95). In those cases, and after further evaluation, surgical procedures may be performed in an attempt to eliminate the remaining etiological factors, as well as to achieve regeneration of lost periodontal tissue. Although periodontal surgery is not minimally invasive, it will produce better results if preceded by scaling and root planing (47).

Clearly, if predictable treatment could be established for moderate periodontitis without surgery or with minimally invasive flapless surgery, it would provide a significant benefit to many patients with chronic periodontal disease, as well as to dentists providing their care. Thus far, conventional mechanical therapy has not resulted in such an ideal treatment outcome, even when using power-driven devices. Moreover, antimicrobial therapy using systemic or locally delivered antibiotics has only

occasionally demonstrated some effectiveness. Recent evidence demonstrates that laser treatment has the potential to improve therapeutic outcomes and therefore be a valuable addition to conventional treatments (55). Currently, high-power-output lasers are used adjunctively with scaling and root planing or as minimally invasive surgery. Also, very-low-power-output lasers are employed for cellular stimulation and/or activation of antimicrobial agents following scaling and root planing. Both of these laser applications can be considered as minimally invasive approaches to periodontal disease treatment.

The aim of the present review was to survey the relevant literature of the clinical application of lasers as minimally invasive treatment in periodontal and implant therapy for periodontists, general practitioners and dental hygienists who are the primary providers of initial treatment of these periodontal diseases and conditions. This paper will focus on the potential therapeutic benefits of photonic energy produced by laser instruments and exclude discussions of other nonlaser optical devices, such as light-emitting diodes.

Lasers in periodontics and peri-implant therapy

Laser applications for periodontal and implant therapy have gradually expanded as a result of the increase in published basic and clinical investigations using diode, carbon dioxide (CO₂), neodymium-doped yttrium aluminium garnet (Nd:YAG), erbium-doped yttrium aluminium garnet (Er:YAG) and erbium, chromium-doped: yttrium, scandium, gallium, garnet (Er,Cr:YSGG) lasers. All of these wavelengths with moderate

power output can be used adjunctively for initial periodontal therapy, not only to debride connective tissue and epithelium within periodontal pockets, but also to inactivate bacteria that invade the periodontal tissues. In addition, erbium lasers can ablate calculus with efficiency comparable with that of hand or ultrasonic instruments, preserving the root cementum underneath the calculus (8, 11, 46, 51, 55). The delivery of laser power through a fine laser tip enables the practitioner to perform precise and small procedures with minimal damage around the treated site. Such a precise treatment modality is essential for performing minimally invasive periodontal treatments.

In contrast to the laser approaches discussed above, another treatment modality has emerged, named phototherapy, which is better known as low-level laser therapy (76). An important principle of phototherapy is that the power parameters employed are at a lower dose than those used for surgery (5, 12). Low-level laser therapy was often termed 'soft laser therapy' or 'cold laser therapy', which created some confusion. The current term, photobiomodulation, more accurately describes the intended process, that is, the reduction of inflammation along with the stimulation of cell proliferation. Another application of phototherapy is antimicrobial photodynamic therapy, which aims to destroy pathogens in the pocket with reactive oxygen species produced by the combination of a low-level visible light laser and a photosensitizer. This protocol has attracted attention as a novel, minimally invasive approach for the treatment of pockets around teeth and dental implants (130). For a proper understanding of the basic principles of the applications of lasers in minimally invasive periodontal therapy, it is essential to discuss the characteristics of each laser and their applications based on their particular wavelengths.

Characteristics of each wavelength in periodontal and peri-implant therapy

Lasers used for periodontal and peri-implant therapy can be divided into three groups.

Lasers for soft-tissue ablation only

Diode and Nd:YAG lasers

The photonic energy from diode and Nd:YAG lasers is in the near-infrared spectrum (approximately 800–1,100 nm) and is readily and selectively absorbed in

areas of inflammation by blood components and tissue pigment. Wavelengths of 800–1,100 nm are essentially transmitted through water, which explains their deep penetration into healthy soft tissue. As most subgingival calculus is dark in color, to avoid thermal damage, care should be taken to avoid prolonged contact of these types of laser on the root structure. Similarly, the same precautions must be taken around osseous tissue. On the other hand, there is minimal to no interaction of these types of laser with healthy dental hard tissue. This property of diode and Nd:YAG lasers makes them suitable for soft-tissue procedures. The laser beam is conducted through an optical fiber, which is used 'in contact' with the target tissue. ~~However, a noncontact mode may be employed when attempting any hemostasis.~~

Although diode and Nd:YAG lasers have similar interactions with hard and soft tissues, they differ in their emission mode. The Nd:YAG is a free-running pulsed laser, with very-short-duration pulses and an emission cycle (ratio of 'on' time to total treatment time) of <1% and correspondingly very high peak power per pulse (in the order of 100–1,000 W). All diode lasers can be used in a continuous-wave mode, in which there is a constant emission of laser energy. In addition, they can operate by producing pulses, although with larger emission cycles and significantly less peak power than the Nd:YAG laser. Thus, the clinician must be aware of the heat that could be produced in the target tissue by each of these types of laser.

For initial periodontal therapy, these lasers are used for inactivation of bacteria and removal of inflamed soft tissue from the periodontal pocket or from around the implant sulcus, as well as for achieving hemostasis in acutely inflamed tissue. ~~These procedures employ relatively low average power, which are usually below that used for surgery.~~

Regarding use of the Nd:YAG laser in implant therapy, two studies suggest that the free-running pulsed Nd:YAG laser is contraindicated for treatment of titanium implant surfaces because the high peak power, as well as the moderate reflection rate of this laser from titanium metal, easily causes melting of the metal surface, as reported by Romanos et al. (99) and Schwarz et al. (108). However, Gonçalves et al. (41), in an *in vitro* study, used an Nd:YAG laser in noncontact mode with a longer pulse duration and demonstrated no damage to these titanium surfaces. The difference in the results of these studies was caused by the irradiation parameters. Romanos et al. (99) employed a contact mode with a very short pulse duration of 100 microseconds and higher average

power, and Giannelli et al. (39) used a pulse duration approximately 10 times longer (1 millisecond). This latter study demonstrated the ability of low-energy Nd:YAG laser irradiation to suppress experimentally induced inflammation from contaminated implant surfaces without affecting the surface morphology of those implant fixtures. In general, an Nd:YAG laser must be used with caution, and attention must be given to the irradiation parameters and to the laser beam placement.

CO₂ laser

CO₂ lasers employ photonic energy in the far-infrared spectrum (wavelength 9,300–10,600 nm). Compared to any other dental wavelengths, they have the highest absorption in dental minerals, such as hydroxyapatite and calcium phosphate, and must be used with some care during periodontal soft-tissue procedures in order to avoid direct contact with hard tissue. The penetration depth into soft tissue is relatively shallow (approximately 0.2 mm) (77).

In an identical manner to diode lasers, CO₂ lasers can be used in a continuous wave or pulsed. Their peak powers can approach 200 W, so they are very efficient at soft-tissue removal. The laser beam is focused on the tissue without direct contact, which differs from the approach of the fiber optic system of a diode. Some accessory tips are employed to direct the energy into the periodontal pocket. CO₂ lasers have similar soft tissue applications for periodontal therapy as the diode and Nd:YAG wavelengths. These applications include bacterial reduction, debridement of diseased soft tissue in pockets and around implants, and coagulation.

Lasers for ablation of both hard and soft tissues

Erbium lasers, such as Er:YAG and Er,Cr:YSGG lasers, target water or the hydroxide ion (OH⁻) as primary targets and mineral as a secondary target, and emit in the mid-infrared range at a wavelength of 2,940 nm for Er:YAG and 2,780 nm for Er,Cr:YSGG, respectively. As they are well absorbed in water, their penetration depth can be as shallow as 5 μm (55). Erbium laser systems have free-running pulsed emission modes with peak powers similar to those of Nd:YAG lasers. They thus offer ablation with minimal thermal-related side effects. The photonic energy of both the Er:YAG and Er,Cr:YSGG lasers can be delivered in either a contact or noncontact mode. These erbium

lasers can be used for soft-tissue debridement of periodontal and peri-implant diseased tissue, bacterial reduction and calculus removal in a nonsurgical approach (106). As dental calculus has a moderate water content, erbium lasers are indicated for its removal; however, caution should be exercised not to remove excessive cementum, which has similar hydration properties (8).

Low-level lasers for biomodulation

Recent evidence has demonstrated that the photobiomodulatory effects of laser treatment, also conventionally termed low-level laser treatment, using the above-described wavelengths utilized to cut soft or hard tissue, contribute to the beneficial effects of 'surgical' laser-treatment approaches (93). For example, in an *in vitro* study, Er:YAG lasers have been shown to stimulate mouse osteoblasts and human gingival fibroblasts. At these significantly lower doses of laser energy delivery, there was enhanced proliferation and earlier structural formation compared with nonirradiated control fibroblast cultures (92). The mechanism of enhanced proliferation and accelerated wound healing with low-level laser therapy is not completely clear but can be partially explained by biostimulation (3,139). Devices specifically designed for photobiomodulation are available in diode lasers with emission wavelengths of 630–980 nm (32).

Photodynamic therapy is a technique that uses some of these low-powered diode lasers and light-emitting diode devices emitting visible and near-infrared light along with a photosensitive liquid dye. With photodynamic therapy, the terms antimicrobial photodynamic therapy or photoactivated disinfection are often used to denote the targeting of pathogenic organisms (22). The photonic energy 'excites' the dye molecules in the presence of tissue oxygen and 'highly reactive' oxygen species are produced. This cytotoxic radical can then destroy bacterial cells.

Nonsurgical periodontal therapy

Procedures in nonsurgical therapy

To avoid potential confusion of interpretation of the term 'nonsurgical periodontal therapy', it has been defined, in this paper, as: 'the therapy which includes all procedures to reduce inflammation and to alter or eliminate the microbial etiology contributing to peri-

odontal disease up to and including re-evaluation to determine if a surgical procedure must be implemented as a next step.' In essence, 'surgery' would include procedures such as gingivectomy, flap surgery (including osseous recontouring and root resection) and regenerative techniques (such as bone grafting, guided tissue regeneration and growth factor application). The nonsurgical approaches would include oral hygiene therapy, calculus removal and anti-infective measures. Specifically, the therapeutic approaches and goals for the practitioner would be biofilm disruption, scaling to remove calculus and reduction in the numbers of bacteria and other pathogens. For periodontal conditions in which immediate referral to a specialist is not indicated, this protocol is often performed in the general dentist's practice (as the primary caregiver). Within this setting, the dental hygienist may be allowed to deliver all or part of the therapy, in accordance with local, regional and/or national regulations.

Along with the establishment of an effective oral hygiene regimen for the patient, the chief component of traditional cause-related periodontal therapy has been, and continues to be, plaque and calculus removal. The necessity for removal of the hardened calculus accretions on the root surface continues to pose challenges for approaches using conventional instruments alone. Some studies indicate that, in spite of careful instrumentation, calculus deposits can remain on the root surface, particularly in less accessible areas (62, 121, 122). In addition, strictly mechanical procedures do not have a direct bactericidal effect on the residual deposits of bacteria (105), which reduces the effectiveness of these approaches for complete elimination of pathogenic bacteria.

Role of lasers in nonsurgical periodontal therapy

Commercially available dental lasers can be used for nonsurgical treatment of periodontal diseases. The common wavelengths for these different types of laser are: 810, 940, 980 and 1,064 nm for diode lasers; 1,064 nm for Nd:YAG lasers; 2,780 nm for Er,Cr:YSGG lasers; 2,940 nm for Er:YAG lasers; and 9,300 and 10,600 nm for CO₂ lasers. All of these types of laser have a thermal effect on dental soft tissue, with a resulting rise in tissue temperature. At 50°C, most nonspore-forming bacteria, including periodontopathic anaerobes, can be readily deactivated (103). Both coagulation of the inflamed sulcular epithelium and hemostasis are achieved at 60°C (8) Therefore, the various goals of nonsurgical periodontal therapy,

including reducing the number of bacteria in the biofilm and coagulation of blood, can be performed using dental lasers. In addition, the wavelengths of the two erbium lasers are appropriate for calculus removal, but the wavelengths of other lasers are not. With erbium lasers, vaporization of the interstitial water in calculus occurs at a temperature higher than 100°C by rapid accumulation of light energy within the calculus. With careful technique, including targeting the calculus and using adequate water spray, the root surface should experience on a few degrees of temperature rise. In the 2011 American Academy of Periodontology statement on lasers in the nonsurgical treatment of periodontitis (1) it was noted that erbium lasers have the potential to act as adjuncts for root debridement (scaling and root planing). In addition, this statement alerted of the possibility of root surface damage because of an operator not being able to observe the irradiation site during a nonsurgical procedure.

After a proper diagnosis, the comprehensive periodontal chart serves as the roadmap for planned nonsurgical periodontal therapy. The clinician usually treats one section of the mouth at a time. The basic protocol of nonsurgical periodontal laser therapy generally includes the following steps:

- 1 Anesthesia as needed.
- 2 Initial laser irradiation for reduction in the amount of bacteria and debridement of the diseased epithelial lining at the wavelength outputs for each type of laser (Nd:YAG, diode or erbium). This initial laser irradiation is also useful for reducing the incidence of bacteremia during pocket treatment (9, 11). Care should be taken to avoid prolonged contact of the laser, particularly Nd:YAG and diode lasers, with subgingival calculus and root surfaces. Therefore, some clinicians remove the hard accretions before laser treatment. When using erbium lasers, calculus removal is occasionally performed at the same time as initial laser irradiation.
- 3 Calculus removal with conventional instrumentation (e.g. ultrasonic scalers, air scalers and/or hand scalers) and/or erbium lasers.
- 4 Laser irradiation for bacterial reduction and decontamination of the periodontal pocket.
- 5 Laser irradiation for coagulation of the blood in the sulcular fluid at the pocket entrance.
- 6 Postoperative instructions, specifically for oral hygiene.

Figures 1 and 2 show examples of the protocol described above using diode and Nd:YAG lasers, respectively. It is important to note that the clinician must employ an average power well below that used

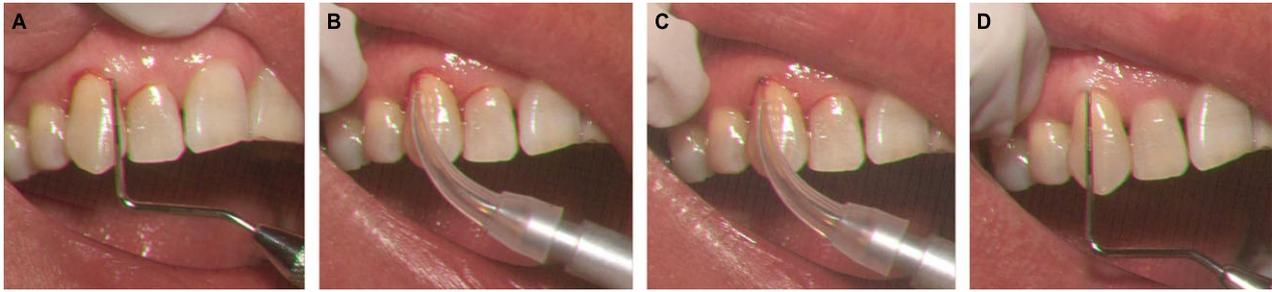


Fig. 1. Clinical application of a diode laser in nonsurgical periodontal therapy of a 45-year-old male patient. (A) Preoperative view of a shallow inflamed periodontal pocket. Pocket depth of 3 mm with bleeding on probing was observed. (B) After very minimal ultrasonic scaling, an 810-nm diode laser was used to remove the diseased epithelial lining of the pocket and for pathogen reduction. The irradiation was directed toward the soft-tissue side of the pocket in a sweeping motion, both apically and horizontally. Irradiation involved emission of 0.4 W of continuous-wave power, with a 300-lm bare fiber, for 30 s. (C)

Completion of diode laser sulcular treatment. Note that the diseased tissue removed from the pocket adheres to the laser fiber. Debris was cleaned from the fiber, and the laser was used to accomplish hemostasis, with a setting of 0.6 W of continuous-wave power, with the same fiber, 1 mm from the entrance to the sulcus, for 15 s. (D) Six-month postoperative view of periodontal health; the pocket depth is 1 mm and there is no bleeding on probing. Note the absence of tissue recession. (Case details provided by Donald Coluzzi.)

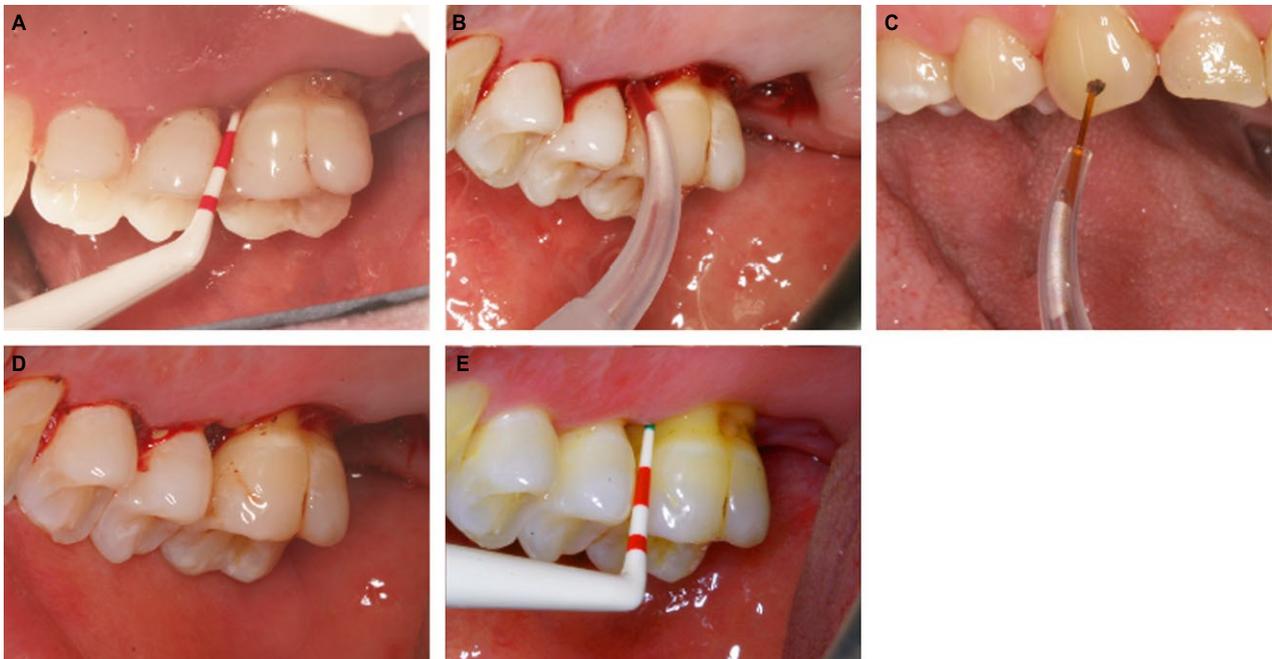


Fig. 2. Clinical application of a neodymium-doped yttrium aluminium garnet (Nd:YAG) laser in nonsurgical periodontal therapy of a 45-year-old male patient. (A) Preoperative view of the first molar, which presented with a pocket depth of 6 mm and slight bleeding on probing. Before periodontal therapy began, the upper-left second molar was extracted. (B) After hand and ultrasonic scaling, a 1064-nm free-running pulsed Nd:YAG laser was used for removal of the diseased epithelial lining of the pocket and for pathogen reduction. The irradiation was directed toward the soft-tissue side of the pocket in a sweeping

motion, both apically and horizontally. An average power of 1.8 W (30 mJ/pulse and 60 Hz) was used with a 400 lm bare fiber for 40 s. (C) The diseased tissue removed from the pocket adhered to the laser fiber. (D) After this debris was cleaned from the fiber, the laser was used to accomplish hemostasis, with an average power of 2.0 W (100 mJ/pulse and 20 Hz), using the same fiber held 1 mm from the entrance to the sulcus for 20 s. (E) View, 3 months postoperatively, of periodontal health. The pocket depth is 3 mm without bleeding on probing. (Case details provided by Mary Lynn Smith, RDH, and Donald Coluzzi.)

for surgical excision when using any of the lasers in this protocol. The intention of nonsurgical treatment is to avoid vaporizing healthy tissue. Rather, the

denatured inflammatory tissue and bacteria are targeted, which require lower power and less temperature rise in the tissues.

Currently, the concept of adjunctive laser therapy in the nonsurgical phase has given rise to a number of acronyms and terms. Clinicians will find these phrases in the various laser-operating manuals, and include:

- Phase one periodontal therapy: conventional instrumentation and laser instrumentation utilized in nonsurgical therapy.
- Laser-assisted decontamination or laser-assisted bacterial reduction.
- Laser-assisted scaling and root planing using erbium lasers.
- Laser-assisted periodontal therapy.

Clinical studies of the use of lasers in nonsurgical periodontal therapy

There are a large number of published studies and case reports that evaluate the adjunctive use of lasers for nonsurgical periodontal therapy. Over 15 years ago, the first manuscript was published and indicated how a dental laser could gain attachment (44). Since then, numerous studies and case reports using diode

(57, 65, 103), CO₂, Nd:YAG (33, 34), Er:YAG (71, 113) and Er,Cr:YSGG (61) lasers have indicated some utility in decreasing inflammation and/or pocket depths (Table 1). As noted above, altering or eliminating the periodontal biofilm is essential, and at the same time is a challenge for successful periodontal treatment (29). Lasers are thus employed chiefly as an adjunct to conventional instruments to aid in the removal of harmful substances.

Systematic literature review of lasers in nonsurgical periodontal therapy

The therapeutic benefit of laser application for periodontal nonsurgical therapy has been reviewed and statistically analyzed by several researchers, using systematic approaches, in published reports (Table 2). In 2008, Karlsson et al. (59) concluded that laser therapy as an adjunct to or a replacement (laser monotherapy) of scaling and root planing should be interpreted with caution as the first treatment option in chronic periodontitis. In contrast, Schwarz et al.

Table 1. Nonsurgical periodontal laser therapy

Author (ref.)	Laser used	Number of subjects/sites (if given)	Length of study	Summary of authors' conclusion
Kreisler et al. (65)	809 nm diode	22/492	3 months	De-epithelialization of periodontal pockets can lead to enhanced attachment and the laser can be recommended as a safe adjunct to scaling and root planing.
Kamma et al. (57)	980 nm diode	30/120	6 months	Scaling and root planing + laser showed a superior effect over scaling and root planing only or laser only in reducing probing depth and increasing attachment.
Saglam et al. (103)	940 nm diode	30/90	6 months	Scaling and root planing + adjunctive laser treatment offered significant improvements in clinical parameters compared with scaling and root planing alone.
Miyazaki et al. (79)	Nd:YAG	18/28	12 weeks	Scaling and root planing + laser showed significant improvements in clinical parameters and subgingival microflora compared with baseline.
Eltas & Orbak (33)	Nd:YAG	52/208	6 months	Scaling and root planing + laser produced significant probing depth reduction in nonsmokers; laser application may be helpful in periodontal treatment of smokers.
Schwarz et al. (113)	Er:YAG	20/660	6 months	Er:YAG monotherapy compared with scaling and root planing alone may be a suitable alternative for nonsurgical periodontal treatment.
Lopes et al. (71)	Er:YAG	21/84	1 year	Scaling and root planing + laser provided additional reduction of microorganisms.
Kelbauskiene et al. (61)	Er,Cr:YSGG	30/278	1 year	Scaling and root planing + laser appeared to be more advantageous for nonsurgical therapy.

Er:YAG, erbium-doped yttrium aluminium garnet; Er,Cr:YSGG, erbium, chromium-doped: yttrium, scandium, gallium, garnet; Nd:YAG, neodymium-doped yttrium aluminium garnet.

Table 2. Systematic review and meta-analysis of nonsurgical periodontal laser therapy

Author, year	Type of study	Searched period	Lasers applied number of studies	Main results
Schwarz et al. (107) 2008	Systematic review	1990–2007	Er:YAG; 7 Diode; 3 Nd:YAG; 1 Nd:YAP; 1	6 RCTs and 6 comparative studies. Er:YAG laser seems to possess characteristics most suitable for the nonsurgical treatment of chronic periodontitis. Meta-analysis could not be performed due to the heterogeneity.
Karlsson et al. (59) 2008	Systematic review	1996–2008	aPDT; 1 Er,Cr:YSGG; 1 Nd:YAG; 1 Nd:YAP; 1	4 RCTs. No consistent evidence supports the efficacy of laser treatment as an adjunct to non-surgical periodontal treatment in adults with chronic periodontitis.
Slot et al. (125) 2009	Systematic review and meta-analysis	–2009.1	Nd:YAG; 8	8 RCTs. No evidence to support the superiority of the pulsed Nd:YAG laser as monotherapy and an adjunct to SRP over traditional modalities in the initial treatment of patients with periodontitis.
Sgolastra et al. (120) 2014	Systematic review and meta-analysis	–2012.10	Nd:YAG adjunctive to SRP; 3	3 RCTs Nd:YAG laser therapy adjunctive to SRP potentially provide additional benefits such as significant PD reduction (MD 0.55 mm, CI [0.34, 0.76]). Significant CAL gain was not detected (MD 0.53 mm, CI [-0.53, 1.18]).
Sgolastra et al. (117) 2012	Systematic review and meta-analysis	–2011.1	Er:YAG; 5	5 RCTs; 3 monotherapies and 2 adjunctive therapies to SRP. Meta-analysis of both 6 and 12 months outcomes could not find the statistically significant difference between Er:YAG laser therapy and conventional SRP in PD reduction and CAL gain (MD -0.03 mm, CI [-0.45, 0.38] and MD +0.01 mm, CI [-0.72, 0.73], respectively).
Zhao et al. (142) 2014	Systematic review and meta-analysis	1960–2013.7	Er:YAG; 12	12 RCTs; 8 monotherapies and 5 adjunctive therapies. Meta-analysis of 3-month outcomes of 8 studies showed that Er:YAG laser resulted in similar clinical improvement in PD reduction and CAL gain to scaling and root planning (MD -0.11 mm, CI [-0.34, 0.56] and MD +0.13 mm, CI [-0.49, 0.76], respectively). Authors highlighted the significant attachment gain following the combination with Er:YAG laser therapy and SRP.
Sgolastra et al. (119) 2013	Systematic review and meta-analysis	–2012.3	Diode adjunctive to SRP; 5	5 RCTs; 5 adjunctive therapies. Meta-analysis of 6-months outcomes showed no significant difference between the adjunctive diode laser therapy and conventional SRP in PD reduction and CAL gain (MD -0.10 mm, CI [-0.31, 0.11] and MD +0.02 mm, CI [-0.39, 0.44], respectively).

Table 2. (Continued)

Author, year	Type of study	Searched period	Lasers applied number of studies	Main results
Slot et al. (124) 2014	Systematic review and meta-analysis	–2013.9	Diode adjunctive to SRP ⁹	9 RCTs; 9 adjunctive therapies. The studies selected addressed the initial phase of periodontal therapy. Combined treatment of diode laser therapy and SRP provides an effect comparable to that of SRP alone in PD reduction and CAL gain (MD -0.11 mm, CI [-0.65, 0.43] and MD +0.04 mm, CI [-0.26, 0.34], respectively).

apDT, antimicrobial photodynamic therapy; CAL, clinical attachment level; CI, 95% confidence interval; MD, mean difference; PD, probing depth; RCT, randomized controlled trial; SRP, scaling and root planing.

(107) concluded, in their 2008 systematic review, that the Er:YAG laser seems to possess characteristics most suitable for the nonsurgical treatment of chronic periodontitis, although the evidence is weak. Both of these systematic reviews indicated the necessity of further well-designed clinical studies for accumulation of scientific evidence.

Regarding laser monotherapy, namely therapy not used as an adjunct to conventional mechanical debridement, a systematic review by Slot et al. (125) in 2009, with an analysis of eight clinical studies focusing on Nd:YAG laser therapy, showed no beneficial effect of Nd:YAG laser therapy compared with conventional therapy.

Two systematic reviews and meta-analyses (117, 142) on Er:YAG laser application have been performed. A meta-analysis by Sgolastra et al. (117), in 2012, showed a statistically significant difference in pocket depth reduction and clinical attachment gain between Er:YAG laser monotherapy and conventional scaling and root planing among 170 patients in five randomized controlled trials. This meta-analysis also reported that the results should be considered with caution because of significant heterogeneity, high risk of bias and methodological shortcomings of the included studies. On the other hand, another review, by Zhao et al. (143), reported that Er:YAG laser monotherapy resulted in similar clinical improvement in pocket depth reduction and clinical attachment gain. Interestingly, this systematic approach demonstrated a significant clinical improvement with the combination of Er:YAG laser and scaling and root planing, based on the positive results of postoperative pocket depth reduction and attachment gain obtained in several studies (30, 71).

A recent meta-analysis by Sgolastra et al. (120), for a combined 204 patients from three randomized controlled trials, reported that Nd:YAG laser therapy

adjunctive to scaling and root planing potentially provides additional benefits, such as significant pocket depth reduction; however, significant clinical attachment gain was not detected. A point to be aware of in this review was that 25 articles were selected for the final screening, but a full-text assessment excluded 20 articles because of high risk of bias of the study design. Therefore, to obtain sufficient evidence of the adjunctive use of Nd:YAG laser, further well-designed clinical trials are required.

Diode laser therapy, adjunctive to scaling and root planing, was analyzed in two systematic reviews. In one meta-analysis, by Sgolastra et al. (119), 6-month outcomes showed no significant difference in pocket depth reduction and clinical attachment gain between the use of the diode laser as an adjunctive therapy and conventional scaling and root planing. Another meta-analysis, by Slot et al. (124), which focused on the initial phase of periodontal therapy, concluded that combined treatment of diode laser and scaling and root planing provides an effect comparable with that of scaling and root planing alone in pocket depth reduction and clinical attachment gain, and that the effect of the adjunctive use of diode laser was considered to be moderate for changes in pocket depth reduction and attachment gain.

Every systematic review published to date has similarly reported that further high-quality, large-scale randomized controlled trials are needed. Looking at a number of actual successful clinical cases following laser therapy, as demonstrated in the above section of this article, there is a gap between statistical evidence and actual outcomes reported by clinicians in case reports and case series. This gap may be partly attributed to the fact that the most effective modality of laser application in nonsurgical therapy for each wavelength has not yet been completely established. These include the irradiation method (power, time and man-

ner) and the concept and purpose of the laser application.

In addition, proper case selection is important. Based on the current evidence, ~~the first choice (sometimes called the gold standard) in phase one periodontal therapy is conventional scaling and root planing (25), not laser application. Lasers are not required for universal use as phase one therapy in every case of mild periodontal disease.~~ Laser application should be considered specifically for moderate-to-advanced or complicated cases of periodontitis in nonsurgical periodontal therapy, as well as for treatment of recurring, remaining or persistent periodontal pockets in supportive periodontal therapy (9). Laser therapy is well accepted by patients as a minimally invasive procedure that potentially reduces the necessity of subsequent periodontal flap surgery. However, to develop an evidence base to support the beneficial effects of laser therapy, not only are well-designed scientific studies required, but also well-defined and developed standard protocols for laser application.

Minimally invasive flapless periodontal pocket surgery

Some evidence (37, 115) has shown the benefits of adjunctive use of lasers in conventional periodontal flap surgery, although recent systematic reviews have pointed out that there is insufficient evidence for the adjunctive benefits of lasers in resective or regenerative surgical periodontal therapy (17). Apart from these adjunctive procedures with conventional open flap debridement, two wavelength-specific flapless techniques are considered as minimally invasive periodontal pocket treatment.

Laser Assisted New Attachment Procedure (LANAP[®]) using an Nd:YAG laser

LANAP was developed by two dentists in California in the 1990s who were looking for alternatives to conventional periodontal surgery, especially for periodontally hopeless teeth. Through trial and error and several evolutions and name changes, from Laser ENAP to LPT to LANAP, over many years, the definitive LANAP[®] protocol was established and patented. LANAP is a minimally invasive surgical procedure, as indicated in the systematic review of the

Academy of Periodontology Workshop by Kao et al. (58) and in a recent review by Aoki et al. (9). The steps of this LANAP protocol are outlined in Fig. 3. It is still the only laser procedure to have human histologic evidence to justify the United States Food and Drug Administration 510(k) marketing clearance (K030290) for 'cementum-mediated periodontal ligament attachment in the absence of a long junctional epithelium' (142).

Histologic support for new attachment following use of LANAP is provided by the studies of Yukna et al. (142) and Nevins et al. (86) (Table 3). Yukna et al. (142) utilized the LANAP[®] protocol in a histologic case study using six pairs of single-rooted teeth with moderate-to-advanced periodontal disease. One tooth from each pair was randomly treated using the protocol, whilst the other tooth served as a scaling and root planing-only control with no laser treatment. At 3 months all 12 teeth were removed with a single proximal area en bloc for histologic study. Clinically, the LANAP-treated areas showed more pocket depth reduction and clinical attachment gain than the nonlaser-treated areas. Histologically, each of the six LANAP-treated teeth showed new connective tissue and new cementum compared with only one of the control teeth; in addition, two LANAP-treated teeth had new alveolar bone as well as demonstrating periodontal regeneration. Nevins et al. (86) reported a histologic study using full-mouth LANAP therapy, but without any controls. Ten single- and multiple-rooted teeth from among those patients were analyzed from en bloc biopsy sections 9 months after treatment. Five teeth showed evidence of regeneration, with new periodontal ligament, new cementum and new alveolar bone, and an additional specimen showed new attachment.

LANAP protocols entail a single session of laser treatment. The Nd:YAG laser itself is used for three primary purposes: removal of pocket epithelium; killing periodontal pathogens; and achieving hemostasis. In addition (owing to the penetration of the Nd:YAG laser wavelength) photobiomodulation occurs as a positive side effect. Follow-up visits with oral hygiene review, plaque removal, occlusal adjustments and periodontal maintenance are scheduled until the re-evaluation of results at about 12 months.

At present, there are no published randomized controlled clinical trials comparing LANAP with other surgical and/or nonsurgical procedures. However, at the time of preparation of this manuscript, one such randomized controlled clinical trial has been completed and the data are being analyzed. A large number of case reports and case series are available

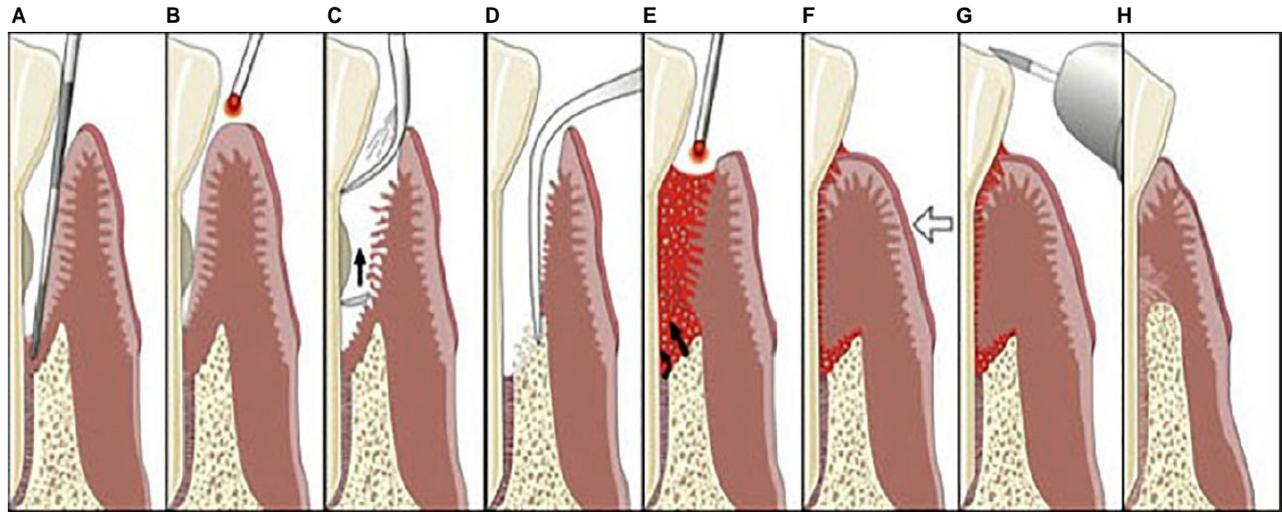


Fig. 3. Schematic illustration of the Laser Assisted New Attachment Procedure (LANAP[®]) using a neodymium-doped yttrium aluminium garnet (Nd:YAG) laser. (A) Treatment is most effective without prior scaling and root planing. Bone sounding under anesthesia was performed to identify bony defect depths. (B) Under local anesthesia sufficient for traditional scalpel surgery, an Nd:YAG laser is used at 100–150 ls pulse duration, 3.6–4.0 W average power and 20 Hz repetition rate, delivering 180–200 mJ/pulse through a 360 lm optical fiber held parallel to the pocket wall. This ‘first pass’ selectively removes the epithelium lining the pocket without affecting the underlying connective tissue, as shown by Gold & Valardi (40) and Ting et al. (134), and kills a large proportion of periodontal pathogens (50, 64). This reflects a gingival flap similar to that produced by the excisional new attachment procedure (ENAP) (141). (C) The root surfaces are then debrided, primarily with piezoelectric ultrasonic tips, to remove accretions. (D) The flap is further deepened to the alveolar

bone by means of blunt dissection to modify the bone contour, obtain bleeding into the pocket and perform intramarrow penetration to release stem cells and growth factors from the cancellous bone and periodontal ligament. No granulation tissue is purposely removed during LANAP[®]. (E) The Nd:YAG laser is then used at a longer pulse duration (550–650 ls) ‘second pass’, with other settings staying the same, to heat the blood in the pocket to obtain a sticky, thick fibrin clot. The desired/safe range of energy delivery is 12–17 J/mm of probing depth (48). (F) Flaps are secured to tooth and bone with a fibrin clot. No sutures are needed. (G) Extensive occlusal adjustment is then performed to eliminate any heavy, grabbing or depressive contacts and fremitus, and to allow for passive eruption (56, 137). (H) Anticipated healing. (LANAP[®] is a patented and registered trademark of Millennium Dental Technologies, Cerritos, CA, USA.) [Modified pictures and legend from Aoki et al. (9). Reproduced with permission from John Wiley & Sons A/S.]

Table 3. Minimally invasive periodontal pocket surgery with laser therapy

Author (ref. no.)	Laser used	Number of subjects/sites (if given)	Length of study	Summary of authors' conclusion
Yukna et al. (142)	Nd:YAG	6/12	3 months	LANAP [®] protocol produced cementum-mediated new attachment
Nevins et al. (86)	Nd:YAG	8/10	9 months	LANAP [®] can produce periodontal regeneration
Nevins et al. (85)	Nd:YAG	8/all full-mouth treatment	9 months	LANAP [®] produced clinical attachment level gain and probing depth reduction

Nd:YAG, neodymium-doped yttrium aluminium garnet.

(42–44, 49, 70, 85, 142). Recently, Nevins et al. (85) published the clinical results at 9 months after full-mouth LANAP, showing significant pocket depth reduction in 73% of sites and improved clinical attachment levels in 58% of sites. One co-author of this manuscript (R.Y.) has used LANAP for 15 years, with success rates of over 90% at reducing probing

depths to ≤ 3 mm, improving attachment levels by ≥ 2 mm more than 50% of the time and observing consistently positive radiographic changes (Fig. 4). These case reports and histologic results do show beneficial results for treatment of moderate-to-advanced periodontitis with LANAP. Randomized controlled clinical trials and comparative studies with other therapies

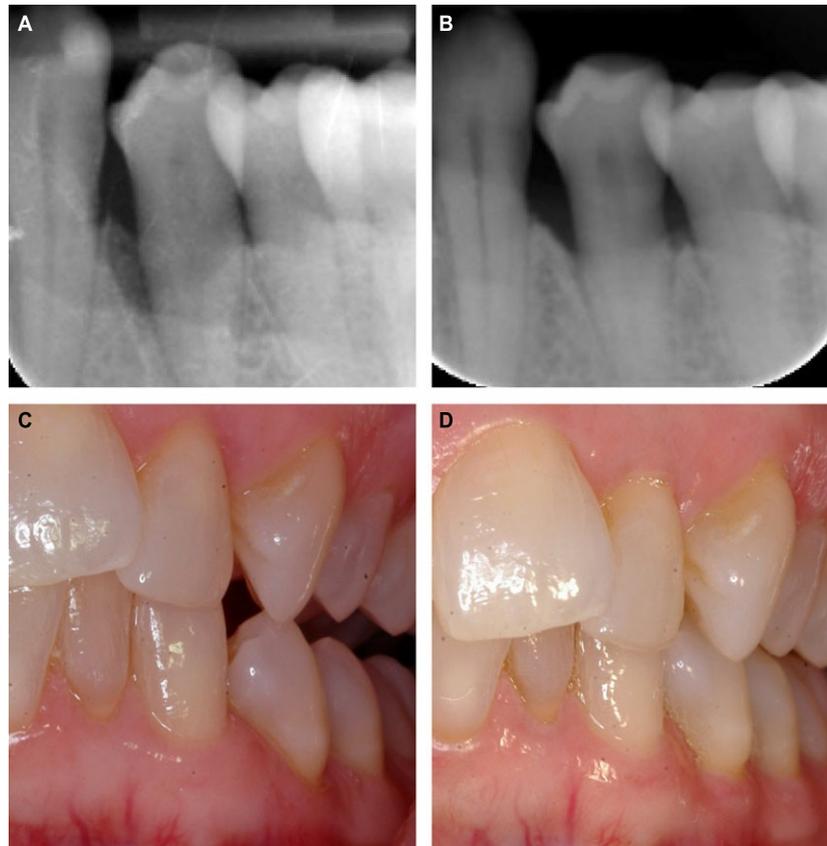


Fig. 4. Clinical application of the Laser Assisted New Attachment Procedure (LANAP[®]) using a neodymium-doped yttrium aluminium garnet (Nd:YAG) laser. The patient is a 49-year-old Caucasian woman with a history of hypertension, but no prescribed medications, who takes natural supplements. Generalized moderate-to-severe chronic periodontitis was diagnosed with deep pockets, furcation involvement and tooth mobility. Tooth # 21 was considered hopeless. (A) Pretreatment radiograph of tooth #21 shows a large bony defect on the mesial surface, 8 mm

probing depth and 8 mm clinical attachment level with mobility II. (B) Radiograph at 5.5 years post-treatment shows appreciable bone formation, 3 mm probing depth and 4 mm clinical attachment level with mobility I. A single session of LANAP[®] was performed. (C) Pretreatment clinical photograph. Note the free gingival margin levels on tooth #21. (D) Clinical photograph at 5.5 years post-treatment. The patient was on a 3-month periodontal maintenance program. There is no noticeable gingival recession. (Case details provided by Raymond Yukna.)

are needed. Although one long-term evaluation has been published (133), the longevity of therapeutic effect needs to be verified.

The Laser Assisted Peri-Implantitis Procedure (LAPIP[™]) protocol for treating peri-implantitis with a minimally invasive surgical approach adapts the LANAP protocol used to treat teeth for the treatment of ailing dental implants. A typical result is shown in Fig. 5. Although anecdotal data have typically been positive regarding the results with LAPIP, further scientific clinical evaluation is needed.

Laser-assisted comprehensive pocket treatment using erbium lasers

Erbium lasers can safely and effectively remove granulation tissue, even from the bone defects difficult to

access without harming the osseous tissue (80). In addition, these wavelengths, when used in nonsurgical therapy, can aid in restoring periodontal health (9). From these observations described above, Aoki et al. (7, 9) proposed the concept of 'laser-assisted comprehensive pocket therapy' (LCPT) (Fig. 6). The main features of this procedure have been previously published (12). Successful clinical results were obtained with this therapy, occasionally accompanied by bone regeneration in the vertical bone defects (Figs 7 and 8) (9, 11). The 'laser-assisted comprehensive pocket therapy' technique might be an effective, minimally invasive approach as a flapless surgical procedure for the treatment of moderate-to-deep periodontal pockets with vertical bone defects and might reduce the necessity for subsequent conventional flap surgery. Thus, this concept of a minimally invasive periodontal flapless procedure continues to

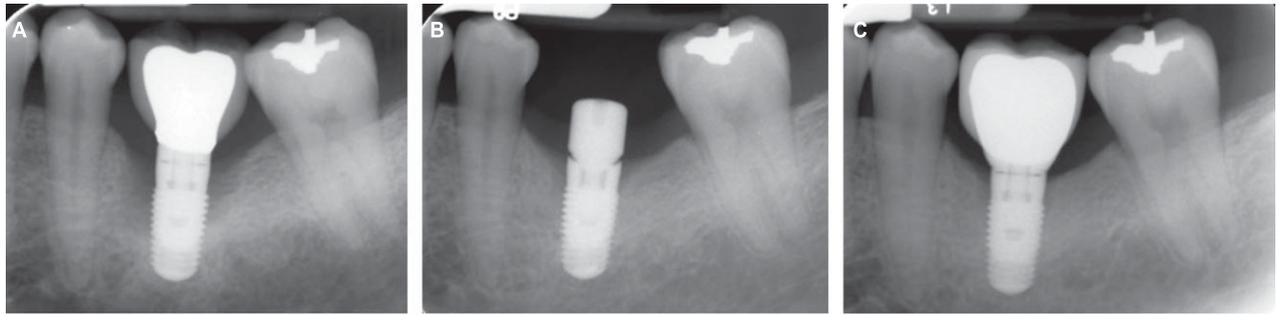


Fig. 5. Clinical application of the Laser Assisted Peri-Implantitis Procedure (LAPIP™) using a neodymium-doped yttrium aluminium garnet (Nd:YAG) laser. The patient was a 48-year-old Hispanic woman with no significant medical history. She had an implant, of unknown type, placed 10 years previously. (A) Initial radiograph on presentation. The implant was slightly mobile with 8–9 mm probing depths and bleeding on probing. The cement-retained crown was removed to allow proper access and a short healing abutment was placed. A single-session of LAPIP™ was performed. The settings and techniques are the same as those of the Laser Assisted New Attachment Procedure (LANAP®), but much less energy is applied around dental implants

than around natural teeth (4 J/mm of probing depth for implants compared with 12–17 J/mm of probing depth around teeth). This is performed for safety reasons as the dark metal of the dental implant will absorb and reflect the laser energy more than the tooth root, and extra care must be taken not to overheat or damage the implant. Accordingly, the laser fiber must be as parallel as possible to the implant body. (B) A 7-month post-treatment radiograph showing improving bone profile with substantial repair of the bony defect. (C) Three-year radiograph. A new crown was delivered at 1 year. Clinical conditions, implant and crown were stable, probing depth was 2–3 mm and there was no bleeding on probing. (Case details provided by Raymond Yukna.)

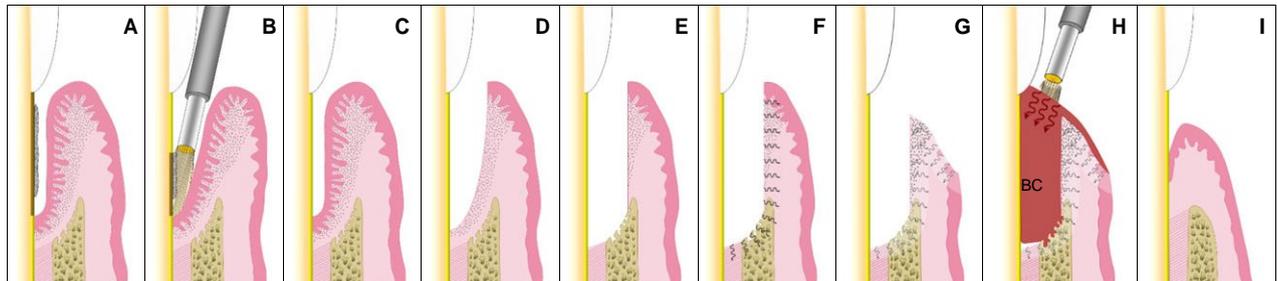


Fig. 6. Schematic illustration of the procedures of erbium-doped yttrium aluminium garnet (Er:YAG) laser-assisted comprehensive periodontal pocket therapy (Er-LCPT). (A) Advanced periodontal pocket showing gingival tissue detachment, subgingival calculus deposition and contamination of the tooth-root surface, epithelial downgrowth and lining of the inner surface of diseased gingival connective tissue with inflammation, vertical bone resorption and diseased connective tissue formation in the bone defect. (B, C) Laser-assisted debridement (or laser-only debridement) following mechanical instrumentation (curettes and ultrasonic scalers) of the diseased root surface for removal of the deposits of subgingival calculus and decontamination and detoxification of the root surface. (D, E) Ablation of lining epithelium and diseased connective tissue on the inner surface of the gingival tissue, as well as diseased connective tissue in the vertical bone defect during pocket irradiation for comprehensive treatment, with the goal of thorough decontamination of the whole pocket and induction of increased bleeding in the bone defect from the bone surface, which may be advantageous for tissue regeneration. Adjunctive use of a mini-curette and/or a mini bone curette is helpful for completion of this procedure. (F) Expected simultaneous photobiomodulation effects that activate the surrounding gingival and bone tissues from

the inside by low-level laser penetration during pocket irradiation. (G) Laser ablation of the epithelial tissue from the external gingival surface. Depending on the case, the underlying connective tissue is also ablated to some extent, helping in pocket-depth reduction. Exposure of connective tissue delays epithelial tissue migration from the external surface into the pocket, and production of the ablated rough surface enhances retention of the blood clot formed at the pocket entrance, thereby assuring sealing of the pocket entrance. At the same time, stimulation of the surrounding gingival tissue from the external surface is expected by simultaneous penetration of low-level laser during irradiation with a high-level laser. (H) Blood clot (BC) coagulation at the pocket entrance by defocused irradiation without water spray, which may stabilize blood clot formation and sealing of the pocket entrance, and also may activate the blood clot and the surrounding gingival tissue. (I) Favorable pocket healing with gingival connective tissue attachment and bone tissue regeneration. The above procedure should be used for moderate-to-advanced periodontal pockets as a flapless procedure. This treatment concept can also be applied to peri-implant mucositis or the initial stage of peri-implantitis. [Modified pictures and legend from Aoki et al. (9). Reproduced with permission from John Wiley & Sons A/S.]



Fig. 7. Clinical application of erbium-doped yttrium aluminium garnet (Er:YAG) laser-assisted comprehensive periodontal pocket therapy (Er-LCPT); Case 1. A 66-year-old man. (A) Deep pockets with an intrabony defect in the mesial sites of the upper-right second incisor after scaling and root planing as phase one therapy. The deepest probing pocket depth, immediately before laser treatment, was 8 mm with bleeding on probing. (B) Following local anesthesia, the inflamed connective tissue in the periodontal pocket was removed with an Er:YAG laser, used at approximately 50 mJ/pulse (panel setting: 80 mJ/pulse; energy density: 17.7 J/cm²/pulse) and 20 Hz in contact mode with an 80° curved contact tip, of 600- μ m diameter, and water spray. Then, the root surface was debrided using a Gracey curette and an Er:YAG laser, and the inner surface of the

gingival wall and bone defect were also debrided by an Er:YAG laser. Immediately after debridement, defocus laser irradiation to blood within the defect was performed to stabilize the blood clot by heat coagulation of the clot surface. De-epithelialization around the original pocket was performed to avoid the down-growth of epithelial cells. (C) After treatment, uneventful healing was observed at 2 weeks, but the interdental papilla was slightly inverted. (D) Three months after treatment, pocket reduction of 6 mm was obtained. One year after treatment, the periodontal pocket was well maintained with a depth of 2 mm, without bleeding on probing. (E, F) The dental radiograph shows a marked change in alveolar bone height in the vertical bone defect at the mesial site (ARROWS). (Case details provided by Koji Mizutani.)

receive widespread attention and requires further scientific evaluation.

Nonsurgical peri-implant therapy

The role of lasers in nonsurgical treatment of peri-implant disease

Implant failure does occur, with one study describing a rate estimated at 10%. One review analyzed data and concluded that up to 43% of implants will develop peri-implant disease over 5 years (83, 144). The disease can be divided into two groups: peri-implant mucositis, a soft-tissue inflammation; and peri-implantitis, where that inflammation is accompanied with bone loss. Within the general category of implant failure, peri-implant disease has one similar etiology to periodontitis, namely the presence of biofilm and its associated pathogenic microorganisms (68). Con-

ventional mechanical instrumentation, such as the use of steel curettes and ultrasonic scalers, debride pockets readily but could damage the implant surface. Plastic and carbon-fiber curettes will not damage the implant surface but are not completely effective in debridement of the bone defects and implant surfaces. The use of adjunctive chemical agents (such as irrigation or polishing with local disinfectants) and local or systemic antibiotic therapy have been shown to have considerable success (101). However, the emergence of bacterial resistance to antibiotics, owing to frequent doses of antibiotics, is a matter of concern.

Recently, laser therapy has been introduced for the treatment of peri-implant disease. One concern with the use of lasers has been how a particular wavelength will affect the surface of the implant. A sampling of the literature illustrates the results of *in vitro* studies, namely: diode laser (at 809 and 980 nm) does not cause damage to the titanium surface (21, 126); Nd:YAG may or may not produce melting (39, 66, 99); and erbium

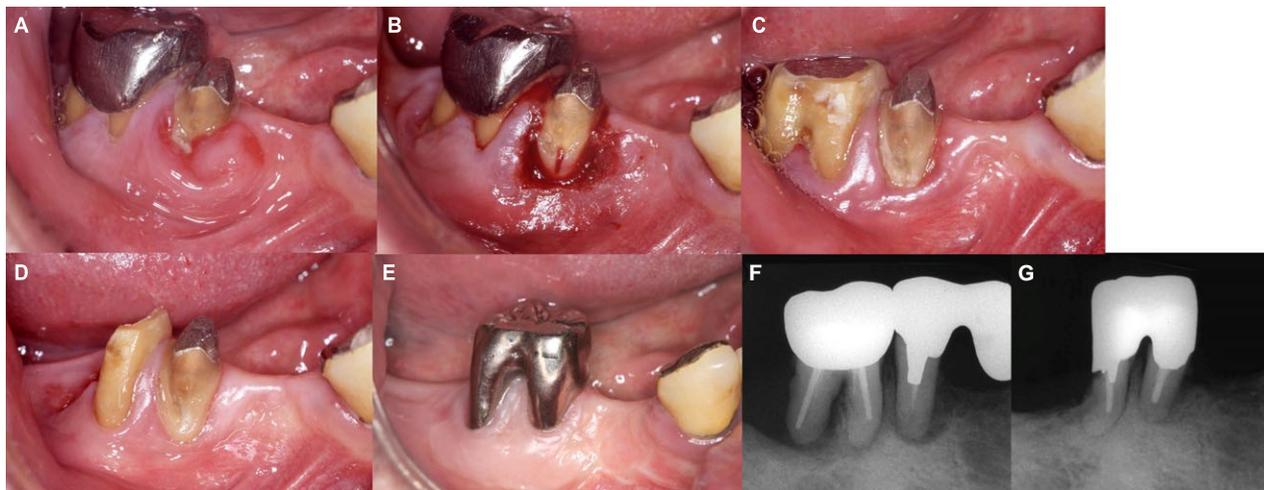


Fig. 8. Clinical application of erbium-doped yttrium aluminium garnet (Er:YAG) laser-assisted comprehensive periodontal pocket therapy (Er-LCPT): Case 2. A 61-year-old man. (A) Gingival enlargement and inflammation with deep pockets were observed around mesial to buccal sites of the lower-right second premolar. The deepest probing pocket depth before treatment was 10 mm, with bleeding on probing at the mesial–buccal site (February 2005). (B) Following local anesthesia, ~~enlarged excessive gingival tissue was excised~~ with an Er:YAG laser at approximately 50 mJ/pulse (panel setting: 80 mJ/pulse; energy density: 17.7 J/cm²/pulse) and 30 Hz without water spray in contact mode with a 80° curved contact tip of diameter 600 μ m (energy output from the tip is usually lower than the panel setting). Then, the root surface was debrided using a mini-curette, an ultrasonic scaler and an Er:YAG laser, and the inner surface of the gingival wall and bone defect was debrided using a mini-curette and an Er:YAG laser. ~~Granulation tissue removal~~, and root surface and bone defect debridement, were effectively and safely performed using an Er:YAG laser at 50 mJ/pulse and 30 Hz in contact mode under water spray, without any visible major thermal denaturation, such as carbonization or coagulation. Immediately after debridement, a

(Er:YAG and Er,Cr:YSGG) and CO₂ lasers should be used with low power parameters (66, 126). Zirconia implants are increasing in popularity, and one study suggests that it is safe to irradiate the surface of implants made from zirconia only with diode lasers (127).

Clinical studies of the use of lasers in nonsurgical peri-implant therapy

There are several published reports on the use of various wavelengths of laser in treating peri-implant disease, and most have shown benefits for decontamination of the implant surface (Table 4). Lerario et al. (69) demonstrated that the adjunctive use of diode laser (810 nm) significantly improved the 1-year treatment outcome in probing depth reduction compared with the mechanical debridement group. Although they used manual and ultrasonic instruments in both

sufficient amount of bleeding was obtained from the bone defect, and the gingival defect was filled with a high-viscosity stable blood clot. Therefore, further irradiation for blood clot coagulation and de-epithelialization was not performed in this patient. (C, D) After treatment, uneventful healing was observed at 6 days and 1 month, showing markedly decreased pocket depth of 1 mm without bleeding on probing. (E) **Finally, free gingival grafting,** ~~or~~ tooth movement and prosthetic treatment were performed **(the distal root of the first molar was hemi-sectioned** and the mesial root was splinted with the second premolar). Eight-and-a-half years following treatment, the periodontal pocket is well maintained with a probing depth of 2 mm, without bleeding on probing. Finally, pocket reduction of 8 mm was obtained (September 2013). (F) The dental radiograph taken at the first visit shows vertical bone resorption at the mesial and buccal sites (February 2005). (G) After 8-and-a-half years, ~~the bone defect was favorably repaired by bone regeneration,~~ and no complications or adverse side effects were observed in the irradiated bone tissue (Case details provided by **Akira Aoki and Masayuki Hideshima, Tokyo Medical and Dental University (TMDU)**).

laser and control groups, chlorhexidine mouthwash and topical application of chlorhexidine gel were used only in the laser group. From this study, it was suggested that thorough decontamination with the combination of laser, mechanical debridement and chemical plaque control was successful in the treatment of peri-implantitis in both smoking and non-smoking patients. Erbium lasers (Er:YAG and Er,Cr:YSGG) appear to generate the optimal wavelengths of choice for treating peri-implantitis. These lasers are effective for soft- and hard-tissue ablation without causing adverse thermal damage, and have positive effects on the healing process. Taniguchi et al. (131) investigated the optimal Er:YAG laser irradiation parameters for debridement of different microstructure surfaces of various dental implants. The recommendations given by the authors of that study may help researchers in choosing the appropriate laser

Table 4. Nonsurgical peri-implant laser therapy

Author (ref. no.)	Laser used	No. of subjects/ no. of sites (if given)	Length of study	Summary of authors' conclusion
Schwarz et al. (114)	Er:YAG	10/16	6 months	Er:YAG laser debridement of implants resulted in a higher reduction of bleeding on probing compared with curettes.
Schwarz et al. (109)	Er:YAG	12/12	24 months	Histopathological examination of tissue biopsies revealed that nonsurgical treatment with an Er:YAG laser may not be sufficient for the maintenance of failing implants.
Renvert et al. (97)	Er:YAG	42/100	6 months	Probing depth reduction and proportion of sites with bleeding were similar between laser treatment and air-abrasive device treatment in severe cases of peri-implantitis.
Persson et al. (88)	Er:YAG	42/100	6 months	One month after treatment, lower bacterial counts in the laser-treated group were found. Six-month data demonstrated that both laser and air-abrasive methods failed to reduce bacterial counts.
Lerario et al. (59)	810 nm diode	27/750 in 125 implants	12 months	Mechanical debridement with adjunctive use of diode laser for decontamination showed greater reduction of probing depth and bleeding on probing than conventional debridement.
Schar et al. (104)	660 nm diode/ phenothiazine chloride	20/20	12 months	Mechanical debridement with adjunctive use of antimicrobial photodynamic therapy is effective in nonsurgical management of peri-implant mucositis.

Er:YAG, erbium-doped yttrium aluminium garnet.

parameters for the type of dental implant used. With the use of erbium lasers for decontamination of implant surfaces, conflicting results have been reported, which may partly be a result of the variation in laser parameters used during the *in vitro* (126, 136), animal (111, 129) and clinical (112) studies. Although several *in vitro* and *in vivo* studies indicated the positive effects of erbium lasers on implant surface decontamination, Schwarz et al. (110) reported that the 4-year clinical outcomes obtained following surgical therapy were not influenced by the method of surface decontamination by Er:YAG laser irradiation with sterile saline spray or debridement with a plastic curette whilst wiping with cotton pellets and irrigating with sterile saline solution. Thus, the improved biocompatibility of the implant surface following debridement with an Er:YAG laser compared with nonlaser decontamination approaches is still unresolved.

Nonsurgical application of laser therapy seemed to provide positive effects in clinical studies using an Er:YAG laser (88, 97, 109, 114) and in a case series using an Er,Cr:YSGG laser (2). As mentioned above, Er:YAG and Er,Cr:YSGG lasers can be used for implant surface decontamination and bone defect debridement. Similarly, the erbium-laser-assisted comprehensive pocket therapy procedure can be adapted for treatment of peri-implantitis to an approach similar to minimally invasive periodontal pocket surgery. Long-term successful outcomes can be obtained following laser-

assisted comprehensive pocket therapy for moderate cases of peri-implantitis (see Fig. 9 for a case example). However, controlled trials of nonsurgical laser therapy showing such positive results are still limited. Schwarz et al. (114) demonstrated that treatment with an Er:YAG laser led to significant clinical improvements 6 months after therapy, but these improvements were similar to those obtained with conventional mechanical debridement using plastic curettes. At 6 months, the reduction of bleeding on probing was significantly higher in the Er:YAG laser treatment group; but 12 months after treatment, increases in bleeding on probing and loss of mean clinical attachment level were observed in both laser and mechanical treatment groups. Schwarz et al. (109) also reported that although clinical improvements were achieved following 24 months of healing, histopathological examination revealed the presence of chronic inflammatory conditions. Renvert et al. (97) compared an air-abrasive device and Er:YAG laser monotherapy for nonsurgical treatment in patients with peri-implantitis. At 6 months, bleeding on probing and suppuration showed a significant decrease in both groups. However, the clinical treatment results were limited and similar between the two methods. Persson et al. (88) compared the microbiologic effects of an Er:YAG laser and an air-abrasive subgingival polishing method in the nonsurgical treatment of peri-implantitis. At 1 month, the numbers of some species

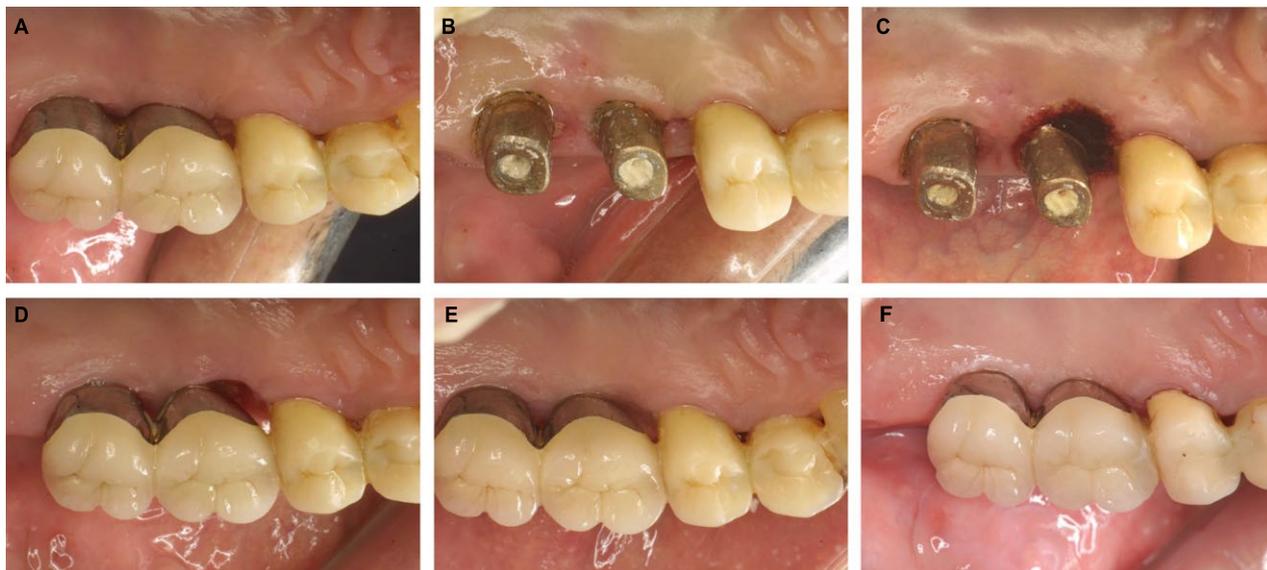


Fig. 9. Clinical application of erbium-doped yttrium aluminium garnet (Er:YAG) laser-assisted comprehensive peri-implantitis therapy (Er-LCPT) in a 57-year-old male patient. (A) After application of systemic antibiotics during the acute phase of peri-implantitis, probing pocket depth at the mesial–palatal site of the upper-left first molar was reduced from 6 mm, 2 weeks earlier, to 5 mm, with bleeding on probing (December 2008). (B) Following crown removal, a gingival cleft was evident in the mesial interdental gingiva. (C) The inflamed gingival tissue was removed and diseased granulation tissue was thoroughly removed from the bone defect in the mesial site using an Er:YAG laser only, at approximately 35 mJ/pulse (panel setting 70 mJ/pulse; energy density approximately 12.0 J/cm²/pulse) and 25 Hz using an 80° curved tip in contact mode under water spray, and two threads of fixture surface were partially exposed. The exposed microstructured fixture surface was also carefully debrided with an Er:YAG laser. The buccal and palatal gingival tissue was further ablated with an Er:YAG laser to prevent distinct production of a gingival defect and to obtain smooth gingival

architecture of the interdental area after wound healing. Effective and safe debridement was achieved without any visible major thermal denaturation, such as carbonization and coagulation, on the laser-treated gingival, bone and implant fixture surfaces. After debridement, a sufficient amount of bleeding was observed in the defect, and noncontact defocused irradiation without water spray was used to perform coagulation according to the erbium-laser-assisted comprehensive pocket therapy procedure; this coagulation should establish a stable blood clot in the gingival defect and surrounding gingival tissue. (D) Following surgery, uneventful healing was observed, and no complications or side effects were observed in the treated tissues. Three weeks after surgery, a concave gingival contour was still observed in the mesial interdental area. (E) The defect gradually diminished and disappeared around 4 months after surgery because of the regeneration of healthy gingival tissue. (F) Six years after surgery, the condition was well maintained and no signs of gingival inflammation were observed. The probing depth decreased to 2 mm without bleeding on probing. (Case details provided by Akira Aoki.)

of bacteria were reduced in the air-abrasive and laser groups. However, at 6 months both methods failed to reduce bacterial counts, and the clinical improvements were limited. Thus, from the comparative clinical studies published to date, the advantages of erbium lasers for implant surface debridement have not been clinically demonstrated. The use of lasers in the non-surgical treatment of peri-implant disease shows limited superior results in literatures of the short-term compared with conventional nonlaser treatment.

Systematic literature review of lasers in nonsurgical peri-implant therapy

Recently, three systematic reviews and meta-analyses have been published which examined the clinical effects of Er:YAG laser, CO₂ laser and antimicrobial photodynamic therapy using diode laser in nonsurgi-

cal peri-implant therapy (Table 5). Two reviews by Mailoa et al. (73) and Kotsakis et al. (63) analyzed different laser therapies as a whole, whilst an analysis by Yan et al. (140) examined the clinical outcomes of using the Er:YAG laser. These three meta-analyses could not find significant superiority of Er:YAG laser therapy over conventional methods, such as debridement with plastic curettes or air abrasion. However, Yan et al. (140) noted that in the subgroup meta-analysis for individual types of laser applications, use of an Er:YAG laser as an alternative to mechanical debridement could potentially provide short-term additional benefits. In individual studies included in these meta-analyses, Er:YAG therapy demonstrated a statistically significant improvement in probing depth reduction at 6 months after treatment compared with conventional nonlaser approaches. These three systematic reviews concluded that there was no

Table 5. Systematic review and meta-analysis of nonsurgical laser therapy for peri-implantitis

Author (ref. no.)	Type of study	Search period	Lasers applied; no. of studies	Main results
Muthukuru et al. (84)	Systematic review	-2011.11	Er:YAG; 3	Nine randomized controlled trials including three different laser therapies. Treatment with the Er:YAG laser, as well as adjunctive local delivery of antibiotics or submucosal glycine powder air polishing, resulted in greater reduction of bleeding on probing compared with submucosal debridement using curettes with adjunctive irrigation with chlorhexidine
Mailoa et al. (73)	Systematic review and meta-analysis	1980 to 1 April 2013	Er:YAG; 4 CO ₂ ; 2 Antimicrobial photodynamic therapy; 1	Seven human prospective clinical trials—four with surgical therapy and three with non surgical therapy—were analyzed. Subgroup results of the meta-analysis of three nonsurgical studies showed no significant differences between use of Er:YAG laser as an alternative to commonly applied detoxification methods in probing depth reduction after 6 months of treatment (mean difference = -0.00 mm; 95% confidence interval: -0.18 to 0.19)
Kotsakis et al. (63)	Systematic review and meta-analysis	1990 to 1 June 2013	Er:YAG; 4 CO ₂ ; 1 Antimicrobial photodynamic therapy; 1	One control study and five randomized controlled trials, including two surgical and four nonsurgical therapy. In nonsurgical therapy, Er:YAG laser application or antimicrobial photodynamic therapy is effective in controlling inflammation around treated implants. Subgroup results of the meta-analysis showed that nonsurgical therapy with the Er:YAG laser had a small effect in probing depth reduction and clinical attachment level gain compared with conventional debridement using a plastic curet or air abrasion after 6 months (probing depth reduction: mean difference = -0.14 mm; 95% confidence interval: -0.35 to 0.64; <i>P</i> = 0.90; and clinical attachment level gain: mean difference = 0.00 mm, 95% confidence interval: -0.26 to 0.40; <i>P</i> = 0.97). There was no evidence for subgroup difference between surgical and nonsurgical treatment in probing depth reduction and clinical attachment level gain
Yan et al. (140)	Systematic review and meta-analysis	-2013.11	Er:YAG; 4	Four randomized controlled trials, including two surgical and two nonsurgical therapy studies. Subgroup result of meta-analysis showed significant differences between nonsurgical Er:YAG laser therapy and mechanical debridement in probing depth reduction and clinical attachment level gain after 6 months of treatment (probing depth reduction: mean difference = -0.10 mm; 95% confidence interval: -0.31 to 0.11; and clinical attachment level gain: mean difference = +0.02 mm; 95% confidence interval: -0.39 to 0.44). Er:YAG laser as an alternative to mechanical debridement could potentially provide short-term additional benefits; there is no evidence of long-term superior effectiveness

Er:YAG, erbium-doped yttrium aluminium garnet.

evidence to support a long-term additional benefit of applying lasers for peri-implantitis. However, based on the current evidence of the short-term benefits of the use of lasers in peri-implant disease, nonsurgical laser therapy might be useful as an initial treatment for controlling the acute inflammation before surgical therapy, including bone grafting around compromised implants with bone defects.

Antimicrobial photodynamic therapy

Nonsurgical mechanical debridement significantly decreases the population of periodontopathogens, including *Porphyromonas gingivalis*, *Aggregatibacter actinomycetemcomitans*, *Prevotella intermedia*,

Tannerella forsythia and *Treponema denticola* (28, 123). However, *A. actinomycetemcomitans* is particularly resistant to mechanical debridement and, after such treatment, the proportion of *A. actinomycetemcomitans* in the total microbiota may increase (82, 98). For this reason, clinicians have tried to incorporate antimicrobials in the treatment of subjects with chronic periodontitis who are receiving scaling and root planing (45). Although the use of antibiotics can significantly reduce the counts of red complex species for several weeks, these counts return to pretreatment levels in several months. Therefore, this antibiotic therapy does not appear to result in long-term changes in clinical parameters and may lead to antimicrobial resistance and a poor response to conventional periodontal therapy (45). Recently, alternative antimicrobial approaches have been developed (89). One of these recent approaches is termed antimicrobial photodynamic therapy. Antimicrobial photodynamic therapy is used as an adjunct to non-surgical mechanical debridement for the treatment of periodontitis (19, 20) and peri-implant disease (75, 104). Antimicrobial photodynamic therapy combines the use of a photosensitizer with low-level light energy (22) to achieve an antimicrobial effect. Commonly used dyes are toluidine blue O, methylene blue and malachite green, which are activated by visible light (4), and indocyanine green, which is activated by near-infrared light (135). As mentioned above, reactive oxygen species produced by the photonic absorption in the dye chemical is toxic to the target bacterial cells.

Antimicrobial photodynamic therapy in periodontal therapy

Antimicrobial photodynamic therapy has demonstrated a greater antimicrobial effect on periodontal pathogens when combined with scaling compared with scaling alone (18, 90). Several studies on the effects of antimicrobial photodynamic therapy, adjunctive to scaling and root planing, on changes in clinical parameters (such as probing depth or clinical attachment level), in the initial therapy of chronic periodontitis, have reported short-term benefits (6, 38). On the other hand, Theodoro et al. (132) reported that the adjunctive use of antimicrobial photodynamic therapy with scaling and root planing in treating chronic periodontitis could significantly reduce the quantities of some of the key periodontal pathogens, but could not provide statistically significant

benefits in clinical outcomes. In one recent randomized clinical trial, Alwaeli et al. (4) demonstrated more long-term clinical improvement in reduction of probing depth and gain of attachment at 3, 6 and 12 months in the group that received scaling and root planing plus antimicrobial photodynamic therapy compared with the group treated with scaling and root planing alone.

Lulic et al. (72) treated residual pockets repeatedly with antimicrobial photodynamic therapy plus scaling and root planing compared with scaling and root planing alone, and Campos et al. (19) treated residual deeper pockets a single session of antimicrobial photodynamic therapy plus scaling and root planing. Both studies reported a greater decrease in probing depth, clinical attachment level and bleeding on probing at 3 months (19) and at 6 months (9). Although Chondros et al. (23) did not find significant differences in changes in probing depth and clinical attachment level between the above two groups at 6 months, greater reduction in bleeding on probing was noted in the antimicrobial photodynamic therapy plus scaling and root planing group.

The effects of antimicrobial photodynamic therapy alone compared with scaling and root planing during maintenance therapy for chronic periodontitis have been evaluated in several published studies. Capuyns et al. (20) compared three approaches: deep scaling and root planing; diode soft-laser therapy; and antimicrobial photodynamic therapy. All three treatments resulted in a significant reduction of residual pockets, with no intergroup statistical significance. In addition, antimicrobial photodynamic therapy and scaling and root planing treatment groups showed reduced counts of *P. gingivalis*, *T. forsythia* and *T. denticola* after 6 months when compared with the diode soft-laser therapy group. Ruhling et al. (102) also showed similar clinical outcomes on pocket depth reduction in antimicrobial photodynamic therapy when compared with non-surgical treatment in periodontal maintenance patients. In addition, a study on periodontal maintenance patients by Lulic et al. (72) demonstrated improved pocket depth reduction and attachment level gain with five applications of antimicrobial photodynamic therapy, with the best improvements shown after 6 months. Thus, there may be added benefit for repeated applications of antimicrobial photodynamic therapy. In terms of combined therapy, a recent split-mouth study by Giannelli et al. (39) showed beneficial results of photoablative and photodynamic diode laser therapy applied in multiple antimicrobial

photodynamic therapy sessions for initial periodontal therapy. Details of these studies are given in Table 6.

Antimicrobial photodynamic therapy in peri-implant therapy

The decontamination of infected implant surfaces is a primary objective for treating peri-implantitis (67) and is necessary before any indicated surgical regenerative procedure. Owing to the difficulties in completely debriding the rough surface, antimicrobial photodynamic therapy has been suggested as a more effective

alternative method than mechanical means for achieving better disinfection (75). One study reported that the application of toluidine blue and activation by means of a diode laser yielded the most significant reductions of *A. actinomycetemcomitans*, *P. gingivalis* and *P. intermedia* (31). In recent studies, several authors compared the effectiveness of antimicrobial photodynamic therapy and locally delivered antibiotics as adjuncts to nonsurgical mechanical debridement in treating peri-implantitis. Both methods were reported to be equally effective in reducing peri-implant mucosal inflammation (16, 104). As presented in a clinical case in Fig. 10, antimicrobial photodynamic therapy can be an effective approach for the

Table 6. Antimicrobial photodynamic therapy adjunctive to scaling and root planing

Author (ref. no.)	Laser used	Number of subjects/sites (if given)	Length of study	Summary of authors' conclusion
Alwaeli et al. (4)	660 nm/ phenothiazine chloride	16/136	1 year	Probing depth reduction, clinical attachment level gain, reduced bleeding on probing with scaling and root planing + antimicrobial photodynamic therapy compared with scaling and root planing alone
Andersen et al. (6)	670 nm/ methylene blue	28/full-mouth treatment	12 weeks	Antimicrobial photodynamic therapy + scaling and root planing showed probing depth reduction and clinical attachment level gain
Braun et al. (18)	660 nm/ phenothiazine chloride	20/two quadrants added antimicrobial photodynamic therapy	3 months	Antimicrobial photodynamic therapy plus scaling and root planing improved probing depth reduction, clinical attachment level gain and bleeding on probing reduction compared with scaling and root planing alone
Chondros et al. (23)	670 nm/ phenothiazine chloride	24/only sites ≥ 4 mm (approximately 240)	6 months	Single application of antimicrobial photodynamic therapy with scaling and root planing produced significant reduction of bleeding on probing compared with scaling and root planing alone
Campos et al. (19)	660 nm/ methylene blue	13/at least two single-rooted teeth with residual pockets of ≥ 5 mm	3 months	Single application of antimicrobial photodynamic therapy with scaling and root planing produced improved probing depth reduction and clinical attachment level gain in residual pockets ≥ 5 mm
Ge et al. (38)	670 nm/ methylene blue	58/full-mouth treatment	12 weeks	Antimicrobial photodynamic therapy + scaling and root planing showed bleeding on probing reduction compared with scaling and root planing alone
Giannelli et al. (39)	810 nm diode, 635 nm/ methylene blue	26/two quadrants (six teeth per quadrant)	1 year	Diode laser – photoablative (810nm) and antimicrobial photodynamic therapy (635nm) – adjunctive to scaling and root planing improved probing depth reduction, clinical attachment level and bleeding on probing reduction
Lulic et al. (72)	670 nm/ phenothiazine chloride	10/70	1 year	Application of antimicrobial photodynamic therapy five times improved probing depth reduction, clinical attachment level gain and bleeding on probing reduction, noted especially after 6 months
Schar et al. (104)	660 nm/ phenothiazine chloride	20/20	12 months	Mechanical debridement with adjunctive use of antimicrobial photodynamic therapy was effective in nonsurgical management of peri-implant mucositis



Fig. 10. Clinical application of antimicrobial photodynamic therapy in peri-implantitis therapy of a 50-year-old woman. (A) Peri-implantitis was diagnosed 10 years after loading. In dental implant 43, an implant sulcus depth of 7 mm and bleeding on probing (+) were observed. (B) At the lingual aspect, pus discharged from the 7-mm implant sulcus. (C) Application of photosensitizer following manual debridement using a carbon curette. The photosensitizer, phenothiazine chloride, was placed in the implant sulcus for 3 min. (D) After rinsing the sulcus to remove the excess photosensitizer with water, irradiation was performed with a diode laser of 670 nm wavelength at 75 mW power output for

1 min. (E, F) The clinical situation, 8 months after performing antimicrobial photodynamic therapy. The treated site showed reduction of the implant sulcus to 3 mm and absence of bleeding on probing. (G) Radiograph of the treated implant before treatment showed angular bony defects at the mesial and distal aspects. (H) Radiograph of the treated implant, 8 months later, showed bone gain at mesial and distal aspects. (I) Radiograph of the treated implant, 19 months later, showed more bone gain at mesial and distal aspects. (J) Radiograph of the treated implant, 31 months later, showed maintenance of the bone level at mesial and distal aspects. (Case details provided by Chen-Ying Wang.)

control of inflammation in peri-implantitis. Following treatment, a stable condition was clinically observed. Although a surgical approach could be one of the treatment modalities for reducing pockets in peri-implantitis (106), antimicrobial photodynamic therapy may also be considered as a more minimally invasive approach for managing these cases. However, complete resolution of inflammation may not be a predictable outcome.

Systematic literature review of antimicrobial photodynamic therapy in periodontal therapy

Four systematic reviews and meta-analyses have been published to assess the clinical effects of use of antimicrobial photodynamic therapy in nonsurgical periodontal therapy. Almost all of these analyses included

studies that examined antimicrobial photodynamic therapy as an adjunctive modality to conventional mechanical debridement (Table 7). The latest meta-analysis by Sgolastra et al. (118), which included 14 studies with a total of 360 patients, demonstrated mean differences of 0.19 mm in pocket depth reduction and 0.37 mm clinical attachment level gain in favor of antimicrobial photodynamic therapy plus scaling and root planing compared with scaling and root planing alone at 3 months. At 6 months, there were no significant differences between the two groups. These clinical improvements, although statistically significant, did not provide sufficient clinical efficacy. Furthermore, two studies failed to show any additional effect in pocket depth reduction and clinical attachment gain using the antimicrobial photodynamic therapy plus scaling and root planing approach (24, 91). In conclusion, the effect of adjunctive antimicrobial photodynamic therapy with conventional mechanical treatment in chronic periodontitis during initial and maintenance stages appears to have short-term beneficial effects in reducing periodontal microbiota and probing pocket depth, and in improving clinical attachment levels. In addition, a recent randomized clinical trial demonstrated additional clinical benefits of antimicrobial photodynamic therapy and scaling and root planing, compared with scaling and root planing alone, at 12 months (4). A combination approach of antimicrobial photodynamic therapy plus scaling and root planing may reduce the extent of bleeding on probing by more than that of scaling and root planing alone. For those patients who find periodontal treatment a stressful and painful experience, antimicrobial photodynamic therapy may make it more pleasant for both patient and dentist through this minimally invasive approach. Further clinical studies are warranted to demonstrate if antimicrobial photodynamic therapy is consistently effective in treating periodontal and peri-implant diseases.

Photobiomodulation (low-level laser therapy)

Photobiomodulation, also conventionally termed low-level laser therapy, delivers light energy (photons) to targeted tissue and produces specific, non-thermal and biostimulative effects at the cellular level. These effects were first reported 30 years ago (60, 78). It has been reported that photobiomodulation (or low-level laser therapy) produces chemical and metabolic changes in tissue by light absorption without heat or temperature rise (89). However, the

real underlying cell mechanisms following laser therapy are still not completely understood. Since the mid-1980's there have been many claims for the therapeutic effects of laser photonic energy on a wide range of disorders in dentistry, including treatment of mild and moderate periodontitis, by improving periodontal tissue healing (128). To date, several articles have demonstrated that photobiomodulation or low-level laser therapy can be successfully used as an adjunctive treatment approach to nonsurgical periodontal therapy (5). Significant reductions of pocket depth and improvement in clinical attachment level and/or significantly greater improvement in plaque, gingival and bleeding indices have been reported with the adjunctive use of a photobiomodulation/low-level laser therapy approach when compared with mechanical debridement alone (14, 74, 94). The photobiomodulation effect has also been shown to accelerate tissue repair and regeneration in nonsurgical therapy (9, 104).

The beneficial outcomes seen in clinical studies using photobiomodulation/low-level laser therapy may be a result of the effects of low-level laser irradiation on accelerating cellular metabolism, thereby stimulating hard- and soft-tissue healing and regeneration (3, 32, 36) and/or having an anti-inflammatory effect (53). Other possible advantages of using photobiomodulation/low-level laser therapy are the reduction of operative and postoperative pain (analgesia), as well as a decrease in patient discomfort and mental stress (35, 90).

Photobiomodulation/low-level laser therapy could significantly improve the outcome of periodontal therapy, either when used alone or as an adjunct to conventional nonsurgical therapy, in the treatment of mild and moderate periodontitis (Table 8). However, these studies have limitations, such as the different laser apparatus wavelengths used in each study, the different single-laser irradiation parameter settings used in each study and the small number of patients in these clinical trials. Therefore, these results should be interpreted with caution. To be able to provide any solid recommendation on the use of photobiomodulation/low-level laser therapy, and to support the effectiveness of photobiomodulation/low-level laser therapy in everyday dental practice, further clinical studies with a well-designed, long-term follow-up, and a large-scale randomized controlled clinical trial design, need to be performed. In addition, future research designs should include carefully selected and standardized outcome measures, using different irradiation conditions, to allow better evaluation of the results and to define the most suitable

Table 7. Systematic review and meta-analysis of antimicrobial photodynamic treatment in periodontal therapy

Author (ref. no.)	Type of study	Search period	Lasers applied; no. of studies	Main results
Atieh et al. (13)	Systematic review and meta-analysis	-2008.10	Antimicrobial photodynamic therapy; 4 (including 3 adjunctive to scaling and root planing)	Four randomized controlled trials. Heterogeneities among included studies for periodontal disease classification, photosensitizer used. Antimicrobial photodynamic therapy as an independent treatment or as an adjunct to scaling and root planing did not demonstrate statistically or clinically significant advantages compared with a control group of scaling and root planing only. Meta-analysis of studies comparing antimicrobial photodynamic therapy + scaling and root planing and scaling and root planing only showed clinical, but not statistical, improvement in probing depth reduction (mean difference = -0.29 mm; 95% confidence interval: -0.50 to 0.08) and clinical attachment level gain (mean difference = +0.11 mm; 95% confidence interval: -0.12 to 0.35)
Azarpazhooh et al. (15)	Systematic review and meta-analysis	-2009.5	Antimicrobial photodynamic therapy; 5 (including 4 adjunctive to scaling and root planing)	Five randomized controlled trials [including the same four randomized controlled trials as in Atieh et al. (13)]. Added one randomized controlled trial with subjected aggressive periodontitis. Heterogeneities among included studies for periodontal disease classification, photosensitizer used. Antimicrobial photodynamic therapy as an independent treatment or as an adjunct to scaling and root planing vs. a control group of scaling and root planing only did not demonstrate statistically or clinically significant advantages. Meta-analysis of four studies showed that combined therapy of antimicrobial photodynamic therapy + scaling and root planing indicated a probable efficacy in probing depth reduction (mean difference = -0.25 mm; 95% confidence interval: -0.45 to 0.04) and clinical attachment level gain (mean difference = +0.34 mm; 95% confidence interval: 0.05–0.63)
Sgolastra et al. (116)	Systematic review and meta-analysis	-2011.7	Antimicrobial photodynamic therapy; 7 (including 6 adjunctive to scaling and root planing)	Seven randomized controlled trials. Meta-analysis of 3-month outcomes showed clinically and statistically significant differences between antimicrobial photodynamic therapy adjunctive to scaling and root planing and conventional scaling and root planing only in probing depth reduction (mean difference = -0.21 mm; 95% confidence interval: -0.34 to 0.04; $P = 0.02$) and clinical attachment level gain (mean difference = +0.23 mm; 95% confidence interval: 0.04–0.34; $P = 0.006$). At 6 months, no significant differences were observed in clinical attachment level gain and probing depth reduction. Antimicrobial photodynamic therapy adjunctive to conventional treatment provided short-term benefits. There was no evidence of the effectiveness for antimicrobial photodynamic therapy alone
Sgolastra et al. (118)	Systematic review and meta-analysis	-2012.8	Antimicrobial photodynamic therapy adjunctive to scaling and root planing; 14	Fourteen randomized controlled trials, including six parallel and four split-mouth studies. Meta-analysis of 10 studies showed clinically and statistically significant differences between antimicrobial photodynamic therapy adjunctive to scaling and root planing and conventional scaling and root planing in probing depth reduction (mean difference = -0.19 mm; 95% confidence interval: -0.31 to -0.07; $P = 0.002$) and clinical attachment level gain (mean difference = +0.37 mm; 95% confidence interval: 0.26–0.47; $P < 0.0001$). Antimicrobial photodynamic therapy adjunctive to conventional scaling and root planing provided short-term benefits

Table 8. Photobiomodulation adjunctive to scaling and root planing

Author (ref. no.)	Laser used	Number of subjects/sites (if given)	Length of study	Summary of authors' conclusion
Aykol et al. (14)	Diode 808 nm	18/full-mouth Three applications of photobiomodulation	6 months	Photobiomodulation + scaling and root planing significantly improved probing depth reduction, clinical attachment level gain and bleeding on probing reduction compared with scaling and root planing alone
Pejcic et al. (87)	Diode 670 nm	30/full mouth Ten applications of photobiomodulation	6 months	Photobiomodulation + scaling and root planing significantly improved gingival index and bleeding on probing reduction compared with scaling and root planing alone

set of laser-irradiation parameters for photobiomodulation/low-level laser therapy.

Summary

Laser therapy has been considered to have the potential to be an effective, minimally invasive, procedure in periodontal therapy. The aim of the present review was to survey the relevant literature of the clinical application of lasers for periodontitis and peri-implant disease. The article describes the removal of diseased sulcular tissue and bacterial reduction using diode, CO₂ and Nd:YAG lasers, or comprehensive debridement within periodontal pockets and contaminated implants using Er:YAG/Er,Cr:YSGG or Nd:YAG lasers following scaling and root planing. Moreover, antimicrobial photodynamic therapy can be adjunctively applied to conventional mechanical debridement. These procedures are expected not only to control the inflammation but also to provide biostimulation effects with photonic energy. Currently, a large number of clinical studies and case reports have been published to evaluate the adjunctive use of lasers for nonsurgical and minimally invasive flapless surgical periodontal therapy.

Systematic literature approaches describe the limited positive effects of adjunctive laser therapy. However, the currently published meta-analyses have shown high risk of bias and heterogeneity of studies, and generally do not report statistically significant differences in pocket reduction and clinical attachment gain compared with mechanical debridement alone. For the treatment of peri-implant disease, long-term observation studies demonstrate the difficulty in evaluating and comparing the various nonsurgical laser therapies using nonlaser approaches.

To date, although clinical reports of successful laser applications in periodontal and peri-implant diseases have been published, evidence supporting the thera-

peutic benefit of laser use from larger clinical trials and meta-analyses has not yet been conclusively established. The disparity between statistical results and individual clinical outcomes might reveal the possibility that the protocols were not sufficient in the larger clinical studies and/or that the indications for use were not suitable for every case in the clinical study. On the other hand, two wavelength-specific techniques – LANAP[®], using a Nd:YAG laser, and Er:YAG laser-assisted comprehensive pocket treatment (Er-LCPT) using erbium lasers – might be more effective and suitable approaches for minimally invasive surgery of periodontal pockets and may reduce the need for a conventional surgical option for treatment of moderate or advanced periodontitis. One other future goal for assessing and validating the effectiveness of these laser approaches would be to continue to develop optimal laser-treatment modalities with wavelength specificities and better-defined indications.

Conclusion

As reported by Cobb et al. (27), 'appropriate and timely treatment of chronic periodontitis [has] not significantly improved over time'. Clearly, practitioners continue to strive for both new and better methods to treat periodontal and peri-implant diseases. Novel approaches for periodontal therapy, following the minimally invasive concept, are needed as developed countries are facing aging societies that may require some form of periodontal treatment together with treatment for other age-related chronic conditions and diseases. Specifically, clinicians may have to treat, more frequently, patients with periodontitis or peri-implantitis who also have various chronic diseases, such as diabetes, cardiovascular disease and chronic kidney disease.

Adjunctive or alternative use of lasers has the potential to promote better wound healing and tissue

generation compared with conventional mechanical methods alone, by providing a more comprehensive method of treatment for moderate-to-severe cases of periodontal disease with deeper periodontal pockets (9, 10, 55). Therefore, periodontal laser therapy, especially several modalities of minimally invasive periodontal pocket surgery, might reduce the necessity for additional conventional surgical treatment. This procedure can also be applied for the treatment of peri-implant mucotitis as well as initial peri-implantitis (9, 100).

Future directions for new uses of lasers for establishing more effective and efficient minimally invasive therapeutic modalities include the development of a calculus detection system using laser fluorescence (11) or optical coherence tomography (52), as well as a new laser system providing complete and selective removal of plaque and calculus (96). Application of antimicrobial photodynamic therapy for routine plaque control (54) by patients in a 'photo-brushing' approach is also under development.

New treatment modalities are not without controversy, and the use of lasers for treatment of periodontal and peri-implant disease has certainly been the subject of many discussions in the literature. At present, as mentioned in a number of systematic reviews, more evidence-based studies need to be performed to support the integration of various laser therapies into the treatment of periodontal and peri-implant diseases.

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