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Current status of clinical laser applications in periodontal therapy

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Periodontal disease is a chronic inflammatory disorder caused by bacterial infection. Laser treatment demonstrates specific characteristics that may be valuable in managing periodontal disease. In addition, lasers reduce stress and uncomfortable conditions for patients during and after treatment compared to other conventional tools. This article reviews the literature to describe the current clinical applications of lasers for gingival tissue management—including esthetic treatment, non-surgical and surgical periodontal pocket therapy, osseous surgery, and implant therapy.

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The unique characteristics of lasers make it possible to perform treatment modalities beyond those available via conventional techniques; these modalities include ablation of biological tissues, hemostasis, and pain relief. Lasers are being used with greater frequency in dentistry to treat both soft and hard tissues.[1-4]

Lasers are effective for the treatment of periodontitis due to various advantageous characteristics that include ablation/vaporization, hemostasis, and bactericidal effect; in addition, laser treatment has the potential to reduce a patient's physical and mental stress.[5-8] At present, different laser systems are used in periodontics, mostly for the treatment of soft tissues. Furthermore, the Erbium:Yttrium-Aluminum-Garnet (Er:YAG) and the Erbium, Chromium:Yttrium-Scandium-Gallium-Garnet (Er,Cr:YSGG) lasers have an extremely low thermal effect, which makes it possible to perform laser applications on hard tissues (such as tooth roots and bone). As a result, laser surgery has attracted more attention in the realm of current clinical practice.[7]

This article outlines the particulars of each currently used laser system and examines the recent applications in periodontal therapy based on current basic and clinical scientific evidence.

Laser

Laser light possesses three basic characteristics: It is coherent, collimated, and monochromatic.[9] These characteristics provide laser light with special biological properties. When the laser reaches biological tissue, the light can be reflected, scattered, absorbed, or transmitted to the surrounding tissues (Fig. 1). The specific interaction between laser light and biological tissue is determined by the wavelength of the laser.

Water absorption is the most important factor influencing the conversion of energy for surgical lasers operating in the infrared spectrum. Most tissues are 60–80% water; as a result, the degree of water absorption determines the laser's ability to penetrate biological tissue. To understand the different mechanisms of action for the various laser systems, as well as the wavelength suitable for each treatment modality, it is necessary to know the degree of water absorption for each wavelength (Chart 1).[10] In terms of tissue penetration, lasers can be classified into two types based on wavelength: those that penetrate deep into tissue (such as the Neodymium (Nd):YAG and diode lasers) and those that are absorbed superficially, including CO_2, Er:YAG, and Er,Cr:YSGG lasers.

The laser systems developed to date are classified according to the active medium that is stimulated to emit photon energy. This divides

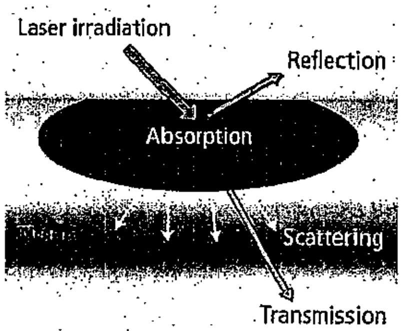

Fig. 1. Spectrum of light absorption in water.[10]

laser systems into solid-state (Nd:YAG, Er:YAG, Er,Cr:YSGG), gas (CO_2, Argon, Helium-Neon), diode, excimer, and dye lasers. Laser systems also can be classified by their maximum output level; that is, low output (soft) or high output (hard). Lasers also may be classified according to their oscillation mode (continuous or pulsed-wave). The pulsed-wave mode can be used by producing independent pulses (a free-running pulse), as with the Nd:YAG, Er:YAG, and Er,Cr:YSGG lasers, or by interrupting a continuous wave (gated or chopped pulse), as seen in CO_2 and diode lasers. The digital pulse mode of diode lasers may be increased to an extremely high frequency by switching the electric current on the base compound on and off digitally, reducing the thermal side effect considerably.

Lasers in periodontal therapy

Periodontitis is a chronic inflammatory disease caused by bacterial infection; as a result, it is possible that laser irradiation (with its bactericidal and detoxifying effects) would be highly advantageous for treating this disease. Some of the technical advantages of employing lasers in periodontal therapy include the ability to disinfect, ease of tissue ablation, hemostasis, and other potential biological effects to stimulate or modulate cells and tissues.[5,11-13] These advantages occasionally result in better treatment outcomes, such as reduced periodontal pocket depth and greater periodontal tissue regeneration.[8,14] Lasers also reduce noise, vibration, and trans- and postoperative pain, greatly improving the patient's comfort during treatment.[15] In addition, the use of lasers is expected to bring new hope to hitherto intractable conditions such as peri-implantitis or to enable treatments deemed impossible by conventional methods, such as removal of metal tattoos.[16,17]

The use of lasers for soft tissue applications in clinical periodontal therapy started in the 1980s with the CO_2 laser and continued in the 1990s with the Nd:YAG laser. The introduction of erbium lasers made it possible to use lasers for hard tissue applications as well.[17,18] At present, the FDA has approved using lasers for a wide range of clinical applications, including using erbium lasers for bone cutting (see the table).[19]

Table. U.S. FDA marketing clearances for periodontal treatment, by wavelength.[19]

Laser type	Treatment options
CO_2	Intraoral soft tissue surgery (ablating, incising, excising, coagulating) Aphthous ulcer treatment
Nd:YAG	Intraoral soft tissue surgery (ablating, incising, excising, coagulating) Aphthous ulcer treatment Sulcular debridement LANAP
Argon	Intraoral soft tissue surgery (ablating, incising, excising, coagulating)
Er:YAG/Er,Cr:YSGG	Intraoral soft tissue surgery (ablating, incising, excising, coagulating) Aphthous ulcer treatment Sulcular debridement Cutting, shaving, contouring, and resection of oral osseous tissue (bone) Osteotomy, osseous crown lengthening, osteoplasty
Diode	Intraoral soft tissue surgery (ablating, incising, excising, coagulating) Aphthous ulcer treatment Sulcular debridement Aid in detection and localization of subgingival dental calculus
Nd:Yttrium-Aluminum-Perovskite (YAP)	Intraoral soft tissue surgery (ablating, incising, excising, coagulating)

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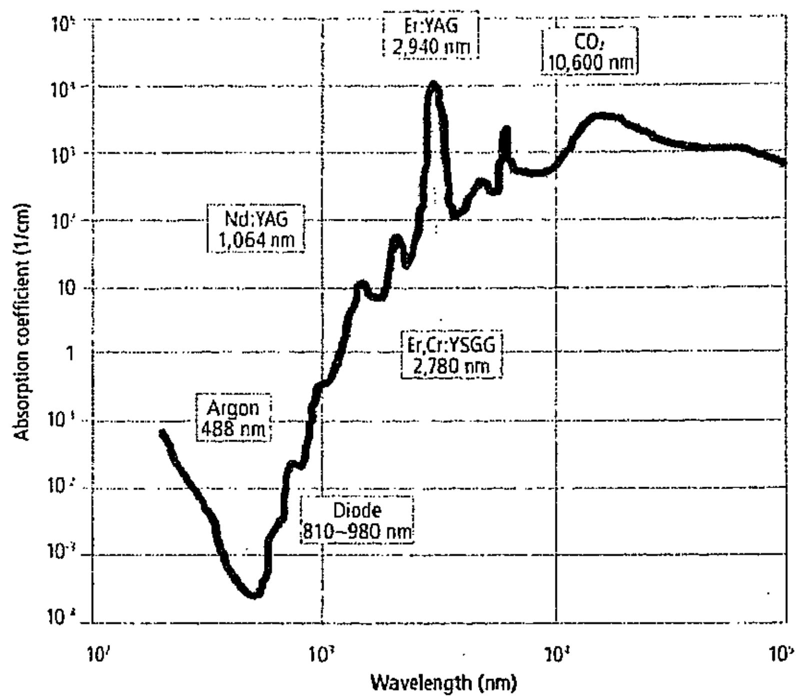
Characteristics of the major laser systems

CO_2 laser

The CO_2 laser has a wavelength of 10,600 nm and can be used in both pulsed or continuous wave modes. This laser is extremely efficient in soft tissue vaporization, as most soft tissues have a high water content and the CO_2 laser is absorbed easily by water (Chart 1).[10,20,21] Compared to traditional scalpel surgery, CO_2 laser surgery offers speedy ablation with strong hemostatic and bactericidal effects in addition to minimal wound contraction and scarring.[22]

Chart 1. Mechanism of Er:YAG laser ablation of hard tissues.



The scattering of laser energy toward the surrounding tissues is low and the layer of heat-altered tissue that remains after vaporization is relatively thin; however, the vaporization temperature is high and the irradiated surface is carbonized easily.

The CO_2 laser is not recommended for hard tissue applications, as the extremely high temperature it produces causes too much carbonization and melting on the root and bone surfaces, impairing both tissue ablation as well as wound healing in periodontal tissues.[23,24] Heat accumulates rapidly in the inorganic components of hard tissues because apatite crystals, a major component of hard tissues, absorb even more of the CO_2 laser's energy than water.[25] The recently introduced super pulse mode reduces the side effects of the excessive heat generation during interaction with tissues.[26]

Nd:YAG laser

The Nd:YAG laser operates in the near-infrared spectrum of light, with a wavelength of 1,064 nm, in free-running pulsed mode. It is used in periodontal therapy to incise and excise soft tissues as well as for curettage and disinfection of periodontal pockets.[21,27,28] In soft tissue treatments, this laser is very effective at producing coagulation and hemostasis; however, these effects are primarily because of the heat; the irradiated surfaces usually exhibit a thick layer of coagulated tissue. Unlike the CO_2 and Er:YAG lasers, the Nd:YAG laser is poorly absorbed by water (Chart 1).[10] As a result, light from the Nd:YAG laser is more likely transmitted and scattered (rather than absorbed) when it enters the biological tissue.

Because of its high penetrability, the possible thermal effects of this laser on tissues lying below the irradiated area, such as temperature elevation or thermal necrosis of dental pulp or bone tissue, can be a matter of concern during periodontal treatment.[29-32] However, the deep penetration of this laser (compared to other superficially absorbed lasers) could produce stronger positive biological effects (photobiomodulation) in the surrounding tissues during pocket treatment. The Nd:YAG laser is absorbed selectively by certain pigments, including melanin and hemoglobin and possibly the pigments contained in germs and bacteria, which could make it ideal for killing bacteria. The Nd:YAG laser light can be guided by flexible optic fibers as thin as 320 µm in diameter, providing exceptional operability in the treatment of periodontal pockets. This flexibility makes it suitable for inserting into and curetting periodontal pockets.

Erbium family of lasers (Er:YAG, Er,Cr:YSGG)

Two types of erbium lasers have been developed for clinical use, the Er:YAG (2,940 nm) and the Er,Cr:YSGG (2,780 nm). Both lasers operate in a free-running pulsed mode. The Er:YAG laser has an excellent capacity for ablating both soft and hard tissues with minimal heat-related side effects. Since its introduction in dentistry, the Er:YAG laser has allowed dentists to remove caries, prepare cavities, and treat diseased root surfaces and alveolar bone.[33-38] Currently, the Er:YAG laser system has the broadest range of applications in dentistry and remains one of the most suitable lasers for periodontal therapy.[5-8,17]

The Er:YAG laser's basic mechanism of tissue ablation begins with thermal evaporation, since the laser is readily absorbed in water and organic molecules within the biological tissues (Chart 1).[10] With hard tissues, the Er:YAG laser exerts a so-called *thermo-mechanical* or *photo-mechanical effect*, in which water molecules within the hard tissues are vaporized as they absorb the laser energy, thus increasing the intratissue pressure, producing vapor within the tissue, and provoking "micro-explosions" that cause mechanical tissue to break down and physically contribute to the ablation process.[5]

Since absorption occurs superficially on the surface of the irradiated tissue and the amount of heat generated is low, the remaining layer of tissue affected by heat is extremely thin. Heat is generated more easily with hard tissue applications, since the water concentration within the hard tissues is relatively low; however, the amount of heat generated can be prevented or controlled by spraying water or saline solution during hard tissue irradiation.[5]

The Er,Cr:YSGG laser is a new laser system whose performance is similar to the Er:YAG laser, although hydroxyl (OH-) ions absorb more of the Er,Cr:YSGG laser's energy than water molecules.[25]

Diode lasers

The wavelength of diode lasers is defined by the composition of the base compound. The most widely used lasers in this family are the Gallium-Aluminum-Arsenide (GaAlAs) laser (810 nm) and the Indium-Gallium-Arsenide (InGaAs) laser (980 nm). Diode lasers operate in continuous and/or pulsed modes and are very effective for soft tissue applications, offering excellent incision, hemostasis, and coagulation.[39] With these wavelengths, the penetration into biological tissues is relatively high and the penetration depth is estimated to be approximately 0.5–3 mm.[10,40] Some newer diode laser systems offer reduced device size (Ezlase, Biolase, Irvine, CA; 888.424.6527), while others offer increased output energy and digital pulse mode with extremely high frequency (Claros, Elexxion, Radolfzell, Germany; 800.873.7683).

The diode laser has characteristics similar to those of the Nd:YAG laser. Since both lasers offer high penetrability into biological tissues, it may be suggested that the tissue effect is due to the energy that penetrates into the tissues; however, this is not always the case. Part of the light that these lasers emit is converted into heat by refraction or diffused reflection at the tip end, creating a condition called *hot tip*. When the tip touches soft tissue, carbonized debris adheres to the tip's end, increasing the temperature to more than 500°C. The tissue is coagulated and vaporized due to contact of the overheated tip rather than from the laser light itself. The hot tip effect is not a true and direct laser effect; rather, it is a secondary effect.

The Nd:YAG laser is activated by a flash lamp and has a sharp, high peak energy with a long pulse interval; by comparison, the diode laser is activated by an electric discharge and has a comparatively low, basically continuous output energy. The maximum peak power of the Nd:YAG laser can penetrate the carbonized debris at the laser tip, whereas much of the energy of the diode laser is consumed at the contact tip, which means that less laser light reaches the targeted tissue. As a result, diode lasers' effect on soft tissue depends more on the hot tip effect.

In terms of their ability to cut through tissue, diode lasers are particularly unreliable when output settings are 3 W or less. To correct this problem, diode lasers have been developed that increase the energy output (up to 10 W or more) and improve switching to reduce the amount of time it takes for electric current to pass through the base compound. Such laser devices provide high output energy together with longer cooling time by employing the pulsed mode with a short pulse duration. These features improve reliability in cutting tissue while reducing the thermal effect. Although the output energy is increased, the transmission into deeper tissues and consequent thermal effect remain lower than those of the Nd:YAG laser.

Argon laser

The argon laser emits a visible blue-green radiation at a wavelength of approximately 500 nm. Although the FDA has approved using argon lasers for oral soft tissue surgery, these lasers have not been used widely in periodontal therapy. One of the most striking characteristics of the argon laser is that it is well-absorbed in pigmented tissues (including hemoglobin and melanin) and pigmented bacteria.[41] As a result, this laser may be useful for periodontal pocket treatment due to its potentially high bactericidal effect.

Laser applications in periodontal therapy

Soft tissue applications

Lasers can cut, ablate, and reshape oral soft tissues easily; in addition, they promote hemostasis by coagulating and occluding small blood vessels instantly, which helps to keep the surgical field clear of blood and fully visible.[18] The bactericidal effect of lasers is another benefit; in addition, it has been reported that laser surgery reduces pain, swelling,

Fig. 2. An occlusal view of a 55-year-old man with a large incisal papilla at the mesiopalatal sites of the maxillary incisors.

Fig. 3. The patient in Figure 2 after a CO_2 laser is used for ablation of the incisal papilla.

Fig. 4. The patient in Figure 2 after the carbonized tissue is removed from the irradiated surface.

Fig. 5. The patient in Figure 2, one week after surgery.

Fig. 6. The patient in Figure 2, approximately six weeks after surgery.

and wound contraction while allowing wounds to heal faster.[22,27,42-44] Intraoral tissues, particularly gingiva, display a complex topography and often cannot be reached by conventional scalpel blades.

Another option, the electrosurgical instrument, must be handled with extreme caution, since it can cut soft tissues too quickly and may cause severe heat-coagulation on the treated surface. In addition, electrosurgery may cause acute and severe pulpal pain if the electrode makes contact with the dental root surface under weak local anesthesia or bone necrosis (due to the high thermogenesis) if the electrode makes contact with alveolar bone.[45,46] By contrast, lasers can be used effectively and successfully for general soft tissue procedures such as gingivectomy and frenectomy, with fewer risks and stresses compared to electrosurgery.

One of the authors (AA) has performed a gingivectomy using a CO_2 laser. Recently, a 55-year-old man with a large incisal papilla at the mesiopalatal sites of the maxillary incisors had 6 mm deep pockets with bleeding on probing (BOP) (Fig. 2). The diseased root surfaces were treated by scaling and root planing using mechanical scalers and the incisal papilla was removed to help reduce the depth of the periodontal pockets. The patient was given infiltrative local anesthesia and a CO_2 laser (Opelaser, Yoshida Dental Trade Dist. Co., Tokyo, Japan; 03.3633.9427) was used at 3–4 W in non-contact, continuous wave mode. The fibrous, relatively hard gingival papilla was vaporized very easily without any bleeding. The papilla was removed and leveled out, leaving a moderate layer of carbonized and coagulated tissue on the surface (Fig. 3). The carbonized tissue was removed easily with a cotton swab, leaving a moderately coagulated surface (Fig. 4).

One week after surgery, a white pseudomembrane was observed on the surface of the wound during epithelization (Fig. 5). At a follow-up visit approximately six weeks postsurgery, the tissue was stabilized and the periodontal pocket was reduced to 2–3 mm with no BOP (Fig. 6).

Depending on the operative conditions, some minor procedures can be carried out painlessly without local anesthesia.[27] Pain is even less common when Er:YAG or Er,Cr:YSGG lasers are used concomitantly with water spray.[47] In addition, laser wounds heal favorably as open wounds without the need for sutures or surgical dressings.

Other applications for lasers include esthetic procedures such as recontouring, reshaping of gingiva, and crown lengthening. As a clinical experience, depth and amount of soft tissue ablation are more precisely and delicately controlled with some lasers than with mechanical or electrosurgical instruments. The Er:YAG laser is especially safe and useful for esthetic periodontal

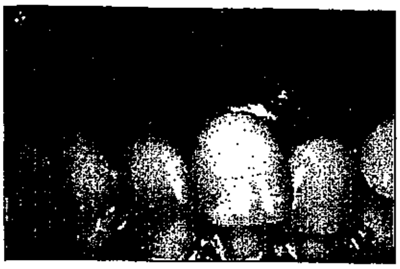


Fig. 7. A 27-year-old woman with severe melanin pigmentation of the maxillary gingiva.

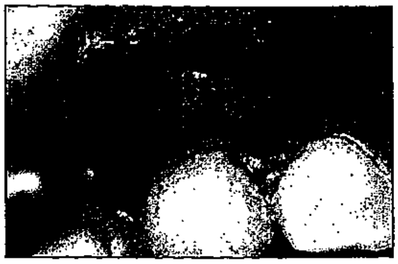


Fig. 8. The pigmented tissue is removed by using an Er:YAG laser under water spray.

Fig. 9. The patient in Figure 7, three months after surgery.

soft tissue management, since it is capable of ablating soft tissues precisely (using various delicate contact tips) and wound healing is fast and favorable due to the minimal thermal alteration to the treated surface.[5,17,48]

The CO_2, diode, and Nd:YAG lasers may be utilized effectively for treating melanin pigmentation.[49-51] However, these lasers may produce gingival ulceration and recession when the gingiva is thin, due to the deep penetration and the relatively strong thermal effect they offer.[49] By comparison, the Er:YAG laser is safe for removing gingival pigmentation, such as that resulting from excessive melanin or from metal tattoo (an iatrogenic discoloration of gingival tissue induced by remaining metal fragments that were embedded into the connective tissue during metal abutment preparation).[17,48] A study of dogs revealed that melanin depigmentation performed using an Er:YAG laser at 30 mJ/pulse (10.7 J/cm^2 per pulse) and 30 Hz with water spray in contact mode produced a thermally affected layer of gingival connective tissue approximately 5–20 µm wide and favorable and fast wound healing.[48] The Er:YAG laser's ability to remove gingival melanin pigmentation safely with significantly improved gingival discoloration has been reported in the literature.[17,48,52,53]

In a recent case report, one of the authors (AA) treated a 27-year-old woman who had severe melanin pigmentation of the maxillary gingiva (Fig. 7). Using an Er:YAG laser system (Versawave, HOYA ConBio, Fremont, CA; 800.532.1064) with a contact tip with an 80 degree curve, the pigmented tissue was removed (Fig. 8). Laser irradiation was performed at 40 mJ/pulse (panel setting 80 mJ/pulse, energy density 14.2 J/cm^2/pulse) and 30 Hz with water spray under local infiltrative anesthesia. The epithelial tissue was selectively and easily removed without significant bleeding. Wound healing was rapid and uneventful. Re-epithelialization was completed within a week and the wound was completely healed in two weeks. At a three-month follow-up visit, the esthetic appearance of the gingiva had improved significantly, with no signs of gingival recession or other abnormalities (Fig. 9).

Applying the Er:YAG laser in combination with a surgical microscope makes the procedure even more precise. The laser microsurgery facilitates the thorough detection and complete elimination of pigmented tissues and metal fragments as well as careful ablation of the delicate areas of the marginal gingiva and papilla, which cannot be achieved by conventional treatment.[17,48] Furthermore, postoperative pain and gingival recession can be reduced or avoided by minimizing the tissue damage with a careful irradiation technique.

Treatment of periodontal pockets

The exposed root surfaces of periodontal pockets are contaminated by an accumulation of bacterial plaque and calculus, in addition to bacteria and bacterial endotoxins infiltrating the cementum.[54] For periodontal tissue to heal, it is essential to remove these harmful substances completely. Plaque biofilms on the exposed root surface within periodontal pockets are relatively solid and impede the infiltration of antibiotics; mechanical disruption of the biofilm is necessary to guarantee its removal.[55] High-power lasers are considered one of the most promising new technical modalities for the decontamination of periodontal pockets in nonsurgical treatment due to their strong bactericidal and detoxification effects.[5,42,43,56] In addition, photodynamic therapy (which utilizes a low-power laser in combination with a photosensitizer) holds great promise as a procedure for decontaminating periodontal pockets.[57]

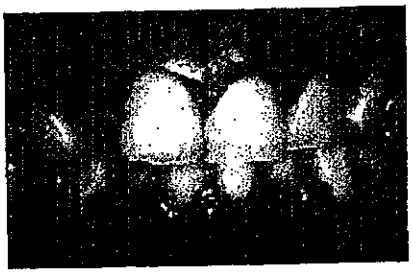


Fig. 10. A 23-year-old man with red, swollen marginal gingival and papilla.

Fig. 11. The maxillary gingiva showing bleeding after periodontal probing.

Fig. 12. Intra-pocket irradiation and gingivoplasty is performed using a Nd:YAG laser.

Fig. 13. The patient in Figure 10, immediately after surgery.

Fig. 14. The patient in Figure 10, one week post-surgery. Note that epithelization is almost complete.

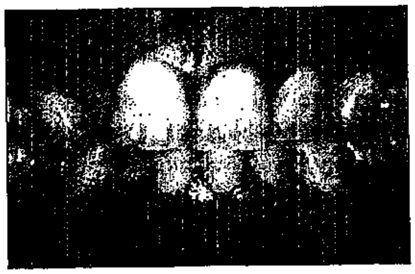


Fig. 15. The patient in Figure 10, six months post-surgery.

With the Nd:YAG laser, irradiation of periodontal pockets has been used basically as auxiliary treatment following mechanical debridement with curettes or an ultrasonic scaler. One of the authors (SN) treated a 23-year-old man who had red and swollen marginal gingiva and papilla (Fig. 10). An Nd:YAG laser with a 320 µm probe in contact mode (at 100 mJ/pulse and 20 Hz) was used for intra-pocket irradiation and gingivoplasty (Fig. 11). The root surface was debrided using ultrasonic scaling and the Nd:YAG laser was used to disinfect and scrape the gingival wall of the pocket (Fig. 12). The periodontal pockets were irrigated with povidone-iodine; at that point, a gingivectomy was performed on the swollen gingival papillae. Neither topical nor local infiltrative anesthesia were used during treatment. The gingival tissues were ablated easily and painlessly. The total irradiation time and energy dose was approximately 10 minutes and 1,200 J. There was no bleeding and the irradiated surface showed no signs of carbonization or severe heat-coagulation (Fig. 13).

One day after surgery, epithelization had already started and the patient reported no spontaneous pain or discomfort except for the contact pain. Epithelialization was almost fully complete when the patient returned for a one-week follow-up (Fig. 14) and wound healing progressed uneventfully. At six months, the proximal probing depths were 2 mm with no BOP (Fig. 15).

One of the advantages of applying a laser to a periodontal pocket is the laser's ability to debride the soft tissue wall, since conventional mechanical tools cannot complete curettage of soft tissue effectively. The Nd:YAG laser is delivered via a thin and flexible fiber and can decontaminate and vaporize the pocket-lining epithelium in periodontal pockets without causing necrosis or carbonization of the underlying connective tissue.[42,58] Since the Nd:YAG laser is absorbed selectively by pigments, it is conceivable that this laser would be very effective against some of the pigmented bacteria (such as *Porphyromonas gingivalis*) involved in periodontal disease. Clinically, satisfactory results can be obtained when the Nd:YAG laser is used in combination with the ultrasonic scaler and medicated irrigation.[59,60]

Recently, a laser-assisted new attachment procedure (LANAP) that utilizes an Nd:YAG laser has been advocated to remove diseased soft tissue from the inner gingival surface of periodontal pockets (FDA

510k clearance K030290).[61]

Various irradiation parameters for pocket treatment using the Nd:YAG laser have been reported. White *et al* recommended 1.5 W (100 mJ/pulse, 15 Hz) irradiation for removing the sulcular diseased tissue and 2 W (100 mJ/pulse, 20 Hz) irradiation for coagulation of the soft tissue wall.[62] Coluzzi recommended mechanical debridement followed by soft tissue curettage at 1.8 W (30 mJ/pulse, 60 Hz) and irradiation at 2 W (100 mJ/pulse, 20 Hz) for hemostasis and bacterial reduction.[60] Gutknecht *et al* suggested 2 W (100 mJ/pulse, 20 Hz) for curettage prior to mechanical debridement, to reduce the risk of bacteremia after scaling and root planing and to facilitate mechanical debridement.[59]

However, despite widespread use of the Nd:YAG laser for treating periodontal pockets, scientific clinical studies are limited and the number and quality of the studies indicating positive clinical effects of this laser beyond conventional treatments are still insufficient.[63-66] There are concerns of thermal side effects from the Nd:YAG laser due to the wavelength's ability to penetrate tissue deeply; as a result, practitioners should take care to avoid heat accumulation and excessive thermal damage.[29-32] However, the Nd:YAG laser usually is safe as long as the appropriate technique and irradiation parameters are observed.

The Nd:YAG laser is *not* appropriate for debriding periodontally affected root surfaces, since the Nd:YAG laser's ability to remove calculus is insufficient and the root surfaces are susceptible to thermal damage when a high energy output is applied.[67-69] Similarly, the CO_2 laser is not appropriate for root debridement, as both calculus and root surface are carbonized instantly.[70] By contrast, the Er:YAG laser is capable of removing dental calculus effectively, reacting with the water contained within the structural micropores (as well as in the intrinsic components of the calculus) without causing significant thermal damage (such as melting or carbonization) to the root surface.[5,36,71]

In addition, a frequency-doubled Alexandrite laser (wavelength 337 nm, pulse duration of 100 nanoseconds, double spikes, q-switched) is promising for scaling, since it is capable of completely and selectively removing both sub- and supragingival calculus.[72] The Alexandrite laser is a solid-state Nd:YAG laser that utilizes a chromium-doped:Beryllium-Aluminum-Oxide chrysoberyl (Cr^{+3}:$BeAl_2O_4$) gemstone called *Alexandrite*, one of the few trichroic minerals; however, this particular laser's clinical apparatus has not been developed yet. Additional research is necessary to determine the potential of laser scaling.

A 2001 study by Schwartz *et al* reviewed clinical outcomes using a chisel-type laser tip designed especially for the nonsurgical treatment of periodontal pockets. This randomly controlled trial used a split-mouth design to compare the results of 20 periodontal patients who received scaling and root planing therapy (SRP) with either an Er:YAG laser or a conventional curette. The authors reported that laser treatment took less time than conventional therapy; in addition, pocket depths between treatment groups were similar six months after treatment and the laser treatment yielded significantly better results in terms of BOP and clinical attachment level (CAL).[73] Two years later, it was confirmed that these results were maintained.[74]

A 2004 study by Sculean *et al* compared Er:YAG laser treatment and ultrasonic scaling, reporting equal clinical improvements following therapy.[75] Conversely, Crespi *et al* reported better results following Er:YAG laser treatment.[76] More recently, a 2006 study by Tomasi *et al* reported that a site treated with an Er:YAG laser produced faster healing (probing depth reduction and CAL gain) and less discomfort during treatment than an ultrasonically scaled site, although the final clinical outcomes for both treatments were similar.[15] These studies suggest that the Er:YAG laser could be used as an alternative to conventional mechanical treatments.[5,8]

The Er:YAG laser's accuracy in terms of detecting and removing calculus via blind subgingival scaling has not been established completely.[77] Additional *in vivo* studies are necessary to obtain detailed histological evidence concerning the attachment of periodontal tissues to the lased root surfaces.

Disinfection and debridement of complex periodontal pockets is limited when conventional mechanical treatment is used. Complementary therapy with lasers helps to eliminate or inactivate bacterial toxic substances by providing a more extensive disinfection of both root and soft tissue walls of periodontal pockets.[5,78] At the same time, laser therapy may stimulate the surrounding cells, alleviate the inflammatory process, and improve the recovery and regeneration of periodontal tissues through the modulation of cell metabolism and the promotion of cell proliferation and differentiation.[78] Laser therapy may provide a more comprehensive method of treatment for moderate to severe cases of periodontal disease as well as for supportive periodontal therapy of recurring or remaining periodontal pockets.[5] A 2006 review recognized the positive effects of using Er:YAG and Nd:YAG lasers

Fig. 16. Using an Er:YAG laser with water spray, bone exostosis is removed from a 43-year-old woman.

Fig. 17. The patient in Figure 16, immediately after laser treatment. Note that there is no major thermal injury to the bone tissue.

Fig. 18. A 34-year-old woman with an uneven gingival contour of the maxillary right incisors.

Fig. 19. A closed-flap crown lengthening procedure is performed, using an Er:YAG laser with water spray.

Fig. 20. An eight-month postoperative view of the patient in Figure 18.

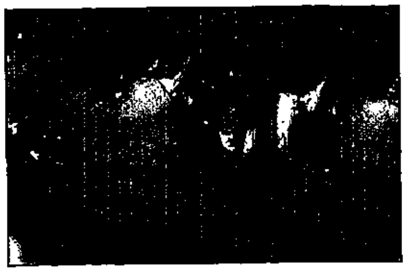


Fig. 21. A 44-year-old woman prior to flap surgery of the second molar.

for treating periodontal pockets.[18]

A 2007 article reported that LANAP could be associated with cementum-mediated new connective tissue attachment and apparent periodontal regeneration of diseased root surfaces in humans.[14] A 2007 animal study suggests that using the Er:YAG laser under water irrigation (at 18.0 or 20.4 J/cm^2 per pulse and 10 Hz) supports the new cementum formation after pocket irradiation.[79] Based on the literature, it appears that adjunctive or alternative use of laser treatment in periodontal pockets may be superior to conventional mechanical treatment in promoting periodontal tissue regeneration.

Periodontal surgery

In periodontal surgery, it is necessary not only to debride the root surfaces but also to efficiently remove the diseased granulated tissue from the bone defects, correct the contour of the alveolar bone, and disinfect the surgical field. The curettage of all diseased granulated tissue is indispensable for the regeneration of the bone tissue; however, attempting to access the bottom of narrow intrabony defects and root furcations with conventional tools can be extremely difficult, time-consuming, and ineffective. The hand chisels and rotary cutting instruments used for alveoloplasty cause significant noise and vibration that can affect the patient's stress levels; in addition, these instruments cannot access the molar region easily.

Erbium lasers may be useful for osseous surgery, as they are capable of vaporizing bone tissue with minimal thermal side effects and can provide histologically favorable postoperative healing.[37,38,80-83] Accessibility to the molar region is improved during osteoplasty, which makes it possible to ablate the alveolar bone with no detectable signs of carbonization or necrosis on the irradiated surface (Fig. 16 and 17, case: AA). In addition, erbium lasers have been applied effectively for the flapless crown-lengthening procedure (Fig. 18–20, case: SN).

Erbium lasers can be used as adjunctive treatment when debriding granulated tissue from bone defects during conventional and regenerative flap surgeries.[17,84-86] Laser surgery produces less noise and vibration than the tools utilized in conventional surgery and postoperative healing progresses favorably. A recent clinical study treated single-rooted teeth with chronic periodontitis using an Er:YAG laser,

Fig. 22. The patient in Figure 21 after flap reflection, revealing a two-wall bone defect filled with granulation tissue.

Fig. 23. Root surface and bone defect debridement is performed using an Er:YAG laser under water spray.

Fig. 24. The patient in Figure 21 after debridement is complete. Note that there is no noticeable thermal damage on the root or bone surfaces.

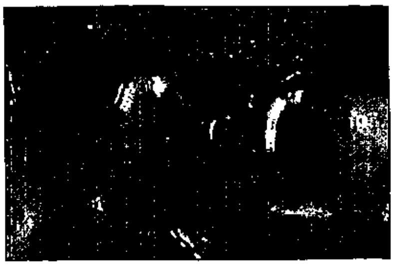


Fig. 25. The patient in Figure 21, 2.5 years after surgery.

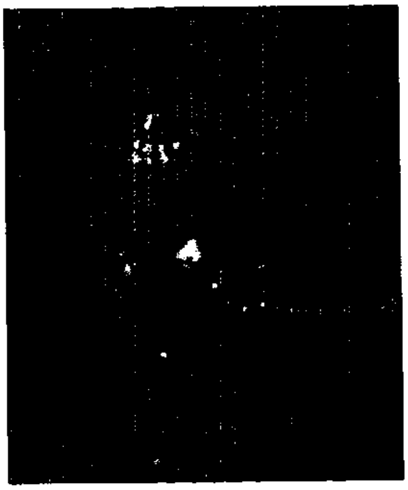


Fig. 26. The Er:YAG laser is used to expose dental implants in a 58-year-old woman.

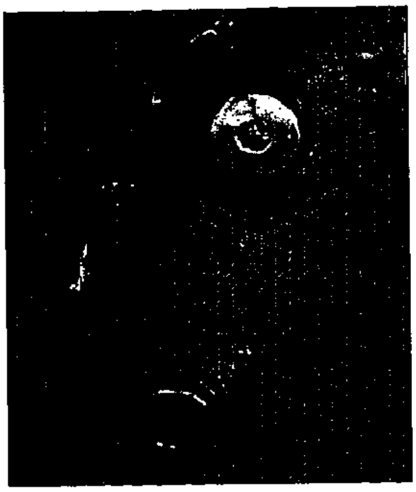


Fig. 27. The patient in Figure 26, immediately following attachment of the abutments for magnet.

resulting in greater probing depth reduction and CAL gains for up to three years, compared to conventional Widman flap surgery.[87]

One of the authors (KM) used an Er:YAG laser to debride root surfaces and degranulate periodontal bone defects during periodontal surgery. A 44-year-old woman had a suppurating (8 mm depth) periodontal pocket with BOP (Fig. 21). A two-wall bone defect was filled with granulation tissue and regenerative therapy, by means of an enamel matrix derivative protein (Emdogain, Straumann, Andover, MA; 800.448.8168), was performed (Fig. 22). An Er:YAG laser with an 80 degree curved tip (diameter = 0.6 mm) was used (40 mJ/pulse and 20 Hz), in a contact mode, to debride the root surfaces and bone defects (Fig. 23). The dental calculus on the root surface and the granulation tissue on the bone defect were removed completely and the root and bone surfaces showed no noticeable thermal damage (Fig. 24). Emdogain was applied to the root surface following ethylene diamine tetraacetic acid (EDTA) treatment. Thirty months after treatment, the periodontal pocket had improved with bone regeneration and the pocket depth had been reduced to 3 mm with no BOP (Fig. 25).

Implants

Lasers are widely used to cut gingival tissue and expose the implant body for the placement of suprastructure during the second phase of implant surgery. Using a laser at this stage is likely to improve hemostasis in the area, with less patient discomfort during the postoperative period and favorable and rapid healing following the placement of abutments.[88] Figure 26 shows an Er:YAG laser exposing an implant fixture via gingival ablation (case: TE). The gingiva was removed painlessly without anesthesia and no signs of carbonization or coagulation were detected at the ablated surface. Wound healing progressed favorably and the gingiva surrounding the implants was sound and stable seven days postsurgery (Fig. 27).

More recently, it has been suggested that lasers can be used for treating peri-implantitis to decontaminate the gingiva and the peri-implant pocket.[16] Ultrasonic scalers, metallic hand scalers, and the Nd:YAG laser are contraindicated for peri-implant applications, as they may damage the titanium surface of dental implants.[89] The CO_2, diode, and Er:YAG lasers seem to be safe and are used for managing peri-implant diseases (mucositis and peri-implantitis).

The irradiation produced by the CO_2 laser does not appear to lead to morphological changes on the implant surface; in addition, the irradiated surface does not negatively influence osteoblast attachment.[90] Previous *in vivo* and clinical studies showed safe wound healing with bone regeneration after CO_2 laser treatment.[91,92] The elevated temperature of the titanium implant surface and carbonization of the adjacent bone tissue during CO_2 laser irradiation remain concerns.[93,94] Semiconductor diode lasers do not damage the titanium surface and effectively decontaminate rough implant surfaces, but there is a risk of generating heat on the peri-implant bone when the diode laser is applied with improper irradiation parameters.[89,95]

According to the literature, the Er:YAG laser provided effective debridement of a contaminated implant surface with no damage following irradiation; however, the Er:YAG laser may alter the implant surface if it is used at very high energy output, so appropriate irradiation parameters should be observed.[96,97] Recent clinical and experimental studies have demonstrated that applying erbium laser irradiation to treat peri-implantitis is very effective for debriding both the complex microstructure of the implant surface and bone defects.[98-101]

Furthermore, the Er:YAG laser has been used recently to prepare fixture holes in bone tissue to obtain greater implant osseointegration with less mechanical stress to bone tissue during surgery, based on the ability of effective bone tissue ablation with erbium lasers. Previous animal studies showed favorable wound healing and increased osseointegration for the laser-prepared fixture holes compared to those prepared by conventional methods using drilling burs.[102-104]

Safety issues

Although lasers are extremely useful therapeutic tools, they are not without risk. Lasers differ from conventional mechanical tools in that lasers exert their effects in both contact and non-contact mode. Dentists must be aware of the possible risks and must exercise precaution to minimize these risks. Special care has to be taken to prevent accidentally irradiating the eyes; both doctor and patient (as well as assisting staff) must wear protective goggles and all parties should avoid the irradiation of reflective surfaces, such as metallic crowns or dental mirrors.[5,105]

Thermogenesis during tissue interaction also must be considered and controlled. Thermal injury can be prevented by using proper irradiation techniques, especially for lasers that can penetrate tissue deeply. During irradiation of periodontal pockets, there is a risk of excessive tissue destruction by direct ablation and of thermal side effects of periodontal tissues.[5] Improper laser use could cause further destruction of the intact periodontal attachment at the bottom of the pocket wall in addition to excessive ablation of root surface and gingival walls.[5]

The oral cavity is a very complex anatomical area and the irradiation target usually is minute and surrounded by important structures. As a result, understanding laser irradiation techniques and output settings is vitally important for a successful treatment.

Conclusion

As of this writing, no laser system is capable of completely replacing conventional mechanical instruments with improved clinical results. Additional studies are necessary to precisely understand the laser light's biological effects and mechanisms of action. Based on the concept of evidence-based medicine, more comparative clinical studies should be conducted to clarify the effectiveness and outcomes of laser periodontal therapy and to support its application in clinical practice.[5,8]

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