Nd:YAG and Er:YAG Wavelengths Used as a Therapeutic Tool in Periodontal Disease

SUMMARY
Laser treatment is expected to serve as an alternative or adjunctive to conventional mechanical periodontal treatment. Currently there are different types of lasers available, which possess characteristics suitable for dental treatment, due to its dual ability to ablate soft and hard tissues with minimal damage. In addition, their bactericidal effect with elimination of lipo-polysaccharide, ability to remove bacterial plaque and calculus, irradiation effect limited to an ultra-thin layer of tissue, faster bone and soft tissue repair, make laser to be a promising tool for periodontal treatment, including scaling and root surface debridement. Hereof arise that laser therapy, or laser-assisted periodontal therapy, may be promising new approaches in periodontics.

The application of Nd:YAG wavelength has been recommended for bacterial elimination, as well as for soft tissue debridement within periodontal pockets as an adjunct in nonsurgical pocket therapy, in combination with mechanical instrumentation. The Er:YAG laser hold the most promise and might be a potential approach to provide comprehensive treatment for both soft and hard tissues within periodontal pockets. The Er:YAG laser has also been shown to be effective for a broad range of biological responses that are suitable for treating a variety of periodontal conditions, such as ablation, microbial inhibition and destruction, cell stimulation, as well as modulation of metabolic activity.

As understanding of the nature of laser light develops, lasers will be used more effectively in the treatment of periodontal diseases. Laser systems, applying the ablation effect of light energy, which is completely different from conventional mechanical debridement, may emerge as a new technical modality for nonsurgical periodontal therapy in the near future.

Keywords: Periodontal Disease; Periodontal Pocket; Laser Therapy; Nd:YAG Wavelength; Er:YAG Wavelength

Introduction
The 21st century is reaching a new understanding of the nature of periodontal diseases, based on a notable era of discovery. There is a promising future for preventing and treating this common and troubling condition that affects not just the mouth but also the whole body. The foundation of our knowledge of periodontal disease(s) is a result of bringing theories together, discoveries, and advances that have occurred in parallel. Research has provided evidence that periodontal diseases are treatable. Studies have also been directed at providing information to permit better understanding of mechanisms of the disease progression and pathogenesis, in order to make treatment more effective and predictable. Basic knowledge and understanding of the pathogenesis of plaque-induced periodontal disease continues to evolve12. It is well established that periodontal disease is an infectious disease and that the host’s immune and inflammatory response to microbial challenge mediates tissue destructions. Therefore primary goal of periodontal therapy is to arrest the inflammatory process of the
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lasers can achieve excellent tissue ablation with strong
assisted periodontal therapy became an alternative
directed toward different and complementary paths:
antimicrobial therapy and host modulation.

In general terms, the ideal antibiotic (local delivery
or systemic use) does not exist because antibiotics are
effective against certain periodontal pathogens only;
moreover, they may have side effects and can induce
bacterial resistance; finally, they can be toxic and
sometimes lack argumentation. Considering the fact that
microorganisms which cause the periodontal disease are
very susceptible to infrared light, it seems logical that
laser irradiation will achieve an excellent bactericidal
effect and, in combination with scaling and root planning,
would provoke significant reduction in inflammation.

Since first lasers were introduced over 40 years
ago, many medical and dental specialists have made the
daily use of lasers widely accepted. The first lasers were
developed in 1964 and, almost immediately, the desire
to use this new technology in dental practice began. The
acceptance of lasers as possible alternatives to traditional
treatment methods in dentistry was one of the events that
created an explosion of interest in the last decades.

With introduction of laser in dentistry, the laser-
assisted periodontal therapy became an alternative
or adjunctive therapy to mechanical approaches. As
lasers can achieve excellent tissue ablation with strong
bactericidal and detoxification effects, they are one of the
most promising new technical modalities for nonsurgical
treatment. Based on these concepts, clinicians and
researchers have published clinical observations and
designed studies to validate the use of laser light as an
adjunct to periodontal therapy. Research suggests that
the use of lasers as a supplement to scaling and root
planning may improve the effectiveness of non-surgical
periodontal treatment. There are many different types of lasers, and each
produces a specific wavelength of light. Throughout the
last decades, different dental laser wavelengths have
been used by clinicians in the treatment of periodontitis.
Each wavelength has a somewhat unique effect on dental
structures, due to the specific absorption of laser energy
by the tissue. The wavelengths of light produced by lasers
intended for periodontal or dental applications can be
categorized into 3 groups: (1) Erbium lasers (Er,Cr:YSGG
at 2,780 nm and Er:YAG at 2,940 nm; (2) Carbon dioxide
lasers at 10,600 nm; (3) Diodes (800 to 980 nm) and
Nd:YAG lasers (1,064 nm).

What is Laser Energy?
The physical principle of laser was developed from
Einstein’s theories in the early 1900s, and the first device
was introduced in 1960 by Maiman. The term LASER
is an acronym for Light Amplification by Stimulated
Emission of Radiation. Energy emitted by a laser is
essentially a light of 1 colour (i.e. monochromatic)
and, therefore, of 1 wavelength. A laser is a device that
produces coherent electromagnetic radiation through a
process called stimulated emission. The monochromatic
light can be collimated into an intensively focused beam
that exhibits little divergence.

The laser energy is tissue dependent. The focused
energy beam will interact with a target matter by being
transmitted, reflected, scattered or absorbed. In biologic
tissues, the laser energy is absorbed by the target surface
tissues and will only exhibit scattering in cases of deep
tissue penetration. Absorption is mainly due to the
presence of free water molecules, proteins, pigments,
and other macromolecules. The absorption coefficient
strongly depends on the wavelength of the incoming laser
irradiation.

Absorption of the light by target tissue is the
primary and beneficial effect of laser energy. Absorbed
light energy is converted to heat and prescribes the
photothermal event or ‘photothermolysis’. Depending
on various parameters, the absorbed energy can result in
simple warming, coagulation, or excision and incision
through tissue vaporization. Photopyrolysis happens
when temperature change from 60°C to 90°C, target
tissue proteins undergo morphologic change, which
is predominately permanent. When the target tissue
containing water is elevated to a temperature of 100°C,
vaporization of the inter- and intra-cellular water in soft
tissue and interstitial water in hard tissue occurs. The
process is also called ablation or ‘photovaporolysis’.
If tissue temperature continues to be raised to about
200°C, it is dehydrated and then burned in the presence
of air. In general, the exact temperature for the onset of
cell necrosis is rather difficult to determine. As a matter
of fact, it was observed that not only the temperature
achieved, but also the temporal duration of this
temperature, play a significant role for induction of
irreversible damage.

The conversion of electromagnetic energy to heat
in target tissue can only be predicted if unwanted change
through conductive thermal spread is prevented. Thermal
relaxation is the term applied to the ability to control a
progressively increasing heat loading of target tissue.
Factors that are important for thermal relaxation can be listed as follows: laser emission mode, duty cycle, laser incident power (joules per second), laser power density (watts per square cm), beam movement, endogenous coolant (blood flow), exogenous coolant (water, air, tissue pre-cooling)\textsuperscript{15,16}. The following factors will, each and collectively, affect the absorption of laser light by a target tissue: laser wavelength, tissue (composition), tissue thickness, surface wetness, incident angle of beam, exposure time, and contact vs. non-contact modes\textsuperscript{17}.

Generally speaking, there are 2 laser wavelengths: short and long. A distinct difference between them can be observed in their interaction with soft tissue. Longer wavelengths, being maximally absorbed by water-based chromophores, and shorter wavelengths give rise to a greater zone of deeper disruption, accentuated through conductive heat transfer. Each wavelength has its own unique interactive qualities.

The existence of water as a constituent of all living tissue will influence the penetration of longer wavelength laser light, while non-pigmented surface components will be transmissive to shorter wavelengths, leading to potentially deep penetration. In this way, shorter wavelength can result in an equivalent-power penetration of 4-6 mm\textsuperscript{18}.

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The Nd:YAG laser is one of the most popular procedures carried out using this laser wavelength. The results from \textit{in vitro} study of the effects of Nd:YAG laser on bovine oral soft tissue indicate that excision width ranged from 0.63 mm to 0.79 mm at 3-10 W, cutting depths from 0.19 mm to 0.49 mm, lateral and deep coagulation from 0.27 mm to 0.62 mm without detrimental and unacceptable temperature rise\textsuperscript{31-33}. The incision line at best, equal the beam diameter and the production of a surface coagulum avoid need for sutures. Healing will always be by secondary intention and little or no scar formation is seen to occur. Compared to scalpel incisions, the healing time is delayed, although, due to the coagulum layer, there is little potential for bacterial contamination of the wound\textsuperscript{34,35}. The Nd:YAG laser is contraindicated for the management of peri-implant soft tissue because this laser interacts readily with titanium\textsuperscript{36}.

\textbf{Therapeutic effects.} The Nd:YAG laser is basically effective for ablation of potentially hemorrhagic granulation tissue due to creation of relatively thick coagulation layer, and thereby strong haemostasis. Gingival curettage after scaling and root planning using mechanical instruments has been shown to have no added benefit over routine scaling and root planning. However, the poor clinical outcome of gingival curettage may have been due to the lack of an effective tool for soft tissue debridement. Contrary to mechanical treatment with conventional instruments, the excellent ablation of tissue with laser treatment is expected to promote healing of periodontal tissues, ablating the inflamed lesions and epithelial lining of the soft tissue wall within periodontal pockets. This procedure might be more effective for the
treatment of residual pockets after initial therapy and during maintenance.

Part of the laser energy scatters and penetrates during irradiation into periodontal pockets. The attenuated laser at a low energy level might then stimulate the cells of surrounding tissue, resulting in reduction of the inflammatory conditions, in cell proliferation and in the increased flow of lymph, improving the periodontal tissue attachment and, possibly, reducing postoperative pain.

Unlike conventional mechanical debridement, which is not effective for the complete curettage of soft tissue, the data indicates safe application of the Nd:YAG laser for removal of the pocket-lining epithelium in periodontal pockets, without causing necrosis or carbonization of the underlying connective tissue in vivo.

Recently, use of an Nd:YAG laser in a Laser-Assisted New Attachment Procedure (LANAP) has been advocated to remove the diseased soft tissue on the inner gingival surface of periodontal pockets and Yukna et al. reported that the LANAP could be associated with cementum-mediated new connective tissue attachment and apparent periodontal regeneration on previously diseased root surfaces in humans.

Conventional methods for the treatment of periodontal disease are not completely effective in eliminating all types of bacteria. Although systemic and local administration of antibiotics into periodontal pockets is occasionally effective for disinfection, the frequent usage of antibiotics bears the potential risk of producing various resistant microorganisms.

These limitations have led to a shift in emphasis to the use of novel technical modalities having additional bactericidal effects, such as lasers. Regarding the Nd:YAG laser, several researchers reported a decontamination effect and inactivation of the endotoxins in the diseased root surface. It is evident from numerous studies undertaken in this field that levels of incident energy employed are essentially sufficient to ablate bacterial cellular structure; what appears to be difficult to quantify is the protocol required to render any periodontal pocket “sterile”. The Nd:YAG laser is absorbed selectively by certain pigments, including melanin and haemoglobin. Given this selective absorption in darker pigments, proponents of this wavelength have promoted the laser as being effective against the pigmented bacteria frequently associated with periodontal diseases, e.g. Porphyromonas spp, Prevotella spp, and Tannerella spp.

**Er:YAG Wavelength**

Unlike laser wavelengths for targeting only the soft tissue chromophores, there are wavelengths that will interact with hard tissue as well. The predominant are Er:YAG wavelengths (2,940 nm; 2,780 nm). These wavelengths have an affinity for (carbonated) hydroxyapatite and water chromophores. However, although the water content of enamel and dentine is very low (3-5% in enamel and 13-15% in dentine), it is the configuration of the lasers emission modes that defines the underlying nature of tissue ablation. These inherent absorption qualities allow erbium lasers to ablate tooth and bone.

During Er:YAG laser irradiation, the laser energy is absorbed selectively by water molecules and hydrous organic components of biological tissues, causing evaporation of water and organic components and resulting in thermal effects due to the heat generated by this process - ‘photothermal evaporation’. Moreover, in hard tissue procedures, the water vapour production induces an increase of internal pressure within the tissue, resulting in explosive expansion called ‘water mediated explosive ablation’. These dynamic effects cause mechanical tissue collapse, resulting in a ‘thermo-mechanical’ or ‘photo-mechanical’ ablation. This phenomenon has also been referred to as ‘water mediated explosive ablation’.

**Therapeutic effects.** Erbium lasers are unique as they are the only lasers that can cut both hard and soft tissues with minimal heat-related side effects. It has been suggested that the erbium wavelengths present the broadest range of application for dental dentistry and are likely the most suitable lasers for periodontal therapy.

The erbium lasers are effective in removing calculus and reducing PPD. Dental calculus contains water in its structural micro-pores, as well as in its intrinsic components. Since the Er:YAG laser has the ability to ablate dental hard tissues, it was expected to be capable of removing dental calculus at much lower energy levels. Several researchers have already reported the promising ability of the Er:YAG laser to remove subgingival calculus in vitro.

Several studies have demonstrated safe and effective root substance removal without negative thermal effects, comparable with conventional instrumentation. Keller and Hibs reported effectively removal of calculus from the root surface without thermal alteration of the surface using Er:YAG laser scaling at 120 and 150 mJ/pulse (calculated energy density 15.0 and 18.8 J/cm² per pulse) and 10 and 15 Hz under water irrigation using the rotatable fibre tip with a chisel shaped profile.

A high bactericidal effect against periodontopathic bacteria at a low energy level can be accomplish with Er:YAG and this laser also has the potential to remove toxins diffused into the root cementum, such as bacterial lipopolysaccharides. Not surprisingly, these lasers are bactericidal against in vitro cultures of Porphyromonas gingivalis and Aggregatibacter (formerly Actinobacillus) actinomycetemcomitans, and effective in removing the absorbed root surface endotoxins.

The haemostatic effect is weaker than for other lasers, but the healing of the laser wound is relatively fast and comparable to that of a scalpel wound. Laser irradiation has been reported to exhibit bactericidal and
detoxification effects without producing a smear layer and the laser treated root surface might therefore provide favourable conditions for the attachment of periodontal tissue.

With respect to laser-mediated periodontal regeneration, in a study by Schwartz et al,64 periodontitis patients were treated with an Er:YAG laser; ultrasonic scaling was used as a control. Both treatment groups exhibited a new cementum formation with embedded collagen fibres. The investigators concluded that both therapies supported the formation of new connective tissue attachment. Studies that employed periodontally diseased root surfaces showed that the micro-structurally and thermally changed root surface produced by Er:YAG laser irradiation may influence the attachment of soft periodontal tissues. Schoop et al67 reported that the surface structure of periodontally diseased root after Er:YAG laser irradiation at 100 mJ/pulse (energy density 5.98 J/cm²) and 15 Hz with water spray offered better conditions for the adherence of fibroblasts in vitro than a root surface after mechanical scaling only.

Root substance removal during laser scaling was explored in a preliminary in vitro study by Aoki et al65. They reported that the average depth of cementum ablation was approximately 40-136 μm following Er:YAG laser scaling in a straight line at 20-120 mJ/pulse (7.1-42.4 J/cm² per pulse) and 10 Hz in perpendicular contact irradiation using a conventional tip.

Pourzarandian et al70 investigated the effect of low-level Er:YAG laser irradiation on human gingival fibroblast (HGFs) proliferation. The results showed that the low-level Er:YAG laser irradiation stimulated proliferation of cultured HGFs, suggesting that the low-level Er:YAG laser irradiation may be of therapeutic benefit for wound healing. Pourzarandian et al71 investigated the change of PGE2 production and COX-2 gene expression in HGF after Er:YAG laser irradiation in vitro. The results showed that the Er:YAG laser irradiation appears to exert simulative action on HGF proliferation through the production of PGE2 via the expression of COX-2. This is one of the important regulatory pathways that enhance cell proliferation for tissue regeneration. It is considered that laser energy would help the diseased tissue to rapidly change from the inflammatory and destructive state into that of healing and regeneration by modulating or activating cell metabolism.

Supra-gingival laser scaling on enamel surface using the Er:YAG laser is contraindicated, since complete calculus removal without affecting the underlying enamel is difficult during Er:YAG laser scaling. However, in subgingival scaling, not only the removal of calculus but also removal of contaminated cementum may be clinically acceptable to some extent.

Research conducted so far has indicated the safety and effectiveness of clinical application of the Er:YAG laser for periodontal pocket treatment, including root surface debridement. Er:YAG laser irradiation may be a promising, useful adjunctive or alternative method to the conventional technique of root preparation and pocket curettage.

**Conclusions**

Laser light is a unique, non-ionizing form of electromagnetic radiation that can be employed as a controlled source of tissue stimulation, cutting or ablation, depending on specific parameters of wavelength, power and target tissue. Laser-tissue interaction is multifaceted, and is based on the fundamental physical characteristics of laser energy, the composition of the target tissue, and the laser operating parameters. The primary interaction is a thermal one - the tissue temperature is increased to achieve a variety of results. Due to the characteristics of penetration and thermogenesis, when laser light is used for periodontal treatment, it may have a positive adjunctive effect on periodontal regeneration by decreasing number of bacteria, producing an etching effect on root surfaces, removing granulation tissue, and de-epithelization of the pocket soft-tissue wall.

Basically, the bactericidal effect, detoxification effect, removal of the epithelium lining and granulation tissue, removal of calculus from the root surface with extremely low mechanical stress and no formation of a smear layer are beneficial outcomes for the periodontal treatment. Laser energy also stimulates or activates the surrounding gingival and bone tissues and, if properly used, this would result in an improved pocket healing with soft and bone tissue regeneration by reduction of inflammatory condition and promotion of cell proliferation and differentiation.

Considering the various advantages of laser irradiation, its use in combination with conventional mechanical treatment or alone has the potential to improve the condition of the periodontal tissue more than mechanical therapy alone. Based on the up to now research, the Er:YAG laser holds promise as a useful tool to debride safely and effectively both the root surface and gingival tissue of the periodontal pockets, and the Nd:YAG laser has a potential for soft tissue curettage and disinfection of periodontal pockets.

**References**


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