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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

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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 evolve[1,2]. 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 disease. Creation of a clean tooth and a clean, biologically compatible root surface, which is as smooth as possible, and the removal of the diseased or infected tissues are essential in treatment.

The treatment guidelines emphasize that periodontal health should be achieved in the least invasive manner. Knowing that the primary aetiology of the disease is bacteria in the dental plaque or biofilm and their products, mechanical and chemical approaches to reduce the presence of periodontal pathogens in this plaque have been largely used in the treatment of periodontal patients[3]. Based on these data, the therapeutic strategies for the treatment of periodontal disease have been directed toward 2 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[4] 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[5,6]. 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[7-9]. Research suggests that the use of lasers as a supplement to scaling and root planning may improve the effectiveness of non-surgical periodontal treatment[10-12].

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[13]. 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[14]. 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 60ºC to 90ºC, 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 200ºC, 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[15].

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)[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[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[18].

So, lasers can be used to cut, incise, and ablate hard and soft tissues. The essential properties of laser light - such as selective absorption, coagulation, sterilization, and stimulatory effects on vital structures - make lasers to be a treatment of choice in certain clinical scenarios[19].

ND:YAG AND ER:YAG Wavelengths and Periodontal Therapy

The use of lasers in periodontal therapy is explored in treatment of hard and soft tissue. The supposed advantages of lasers have been enumerated by lot of authors and include increased coagulation that yields a dry surgical field, tissue surface sterilization and, therefore, reduction in bacteraemia, decreased swelling, oedema and scarring, decreased pain, faster healing response, and increased patient acceptance.

Lasers are used as a tool for hard and soft tissue management (for removal of diseased pocket lining epithelium and diseased soft tissue) and for reduction of bacteremia[20,21]. Generally, laser-mediated periodontal therapy is based on the supposed benefits derived from subgingival soft-tissue curettage and significant decreases in subgingival bacterial loads.

Nd:YAG Wavelength

The Nd:YAG laser belongs to short laser wavelength, has a wavelength of 1,064 nm and operates in a free running pulsed mode. In water, the Nd:YAG laser will theoretically penetrate to a depth of 6 mm before it is attenuated to 10% of its original strength. The Nd:YAG lasers are used primarily for the specific reasons, such as: laser-assisted subgingival soft-tissue curettage, and reduction of subgingival microbial populations[22-25]. The photo-thermal effect of the Nd:YAG laser is useful for soft tissue surgery. In dentistry, soft tissue surgery uses deeply penetrating lasers, such as the Nd:YAG laser[26-28], because they can cut and reshape soft tissues[29,30].

When using the laser light for soft tissue cutting, the heat generated seals small blood and lymphatic vessels, reducing or eliminating bleeding and oedema. Denatured proteins within tissue and plasma give rise to a surface zone of a tenacious layer, termed ‘coagulum’ or ‘char’, which serves to protect the surgical wound from frictional or bacterial action. Clinically, during 48-72 hours post-surgery, this layer undergoes hydration from saliva, swells and disintegrates and eventually is lost to reveal an early healing bed of new tissue. Usually, with laser use on soft tissue, there is minimal or no bleeding. Little wound contraction and minimal scarring are other advantages of laser surgery that are not observed in scalpel surgery. Gingivectomy, gingivoplasty and frenectomy are the most popular procedures carried out using this laser wavelength.

The results from *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[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[34,35]. The Nd:YAG laser is contraindicated for the management of peri-implant soft tissue because this laser interacts readily with titanium[36].

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[68], in cell proliferation and in the increased flow of lymph[69], 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*[37].

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[38] 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[39] and inactivation of the endotoxins in the diseased root surface[40]. 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[41,42].

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 ‘micro explosion’[50,51]. These dynamic effects cause mechanical tissue collapse, resulting in a ‘thermo-mechanical’ or ‘photo-mechanical’ ablation[52]. This phenomenon has also been referred to as ‘water mediated explosive ablation’[53, 54].

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 clinical dentistry and are likely the most suitable lasers for periodontal therapy[55-58].

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*[46-49].

Several studies have demonstrated safe and effective root substance removal without negative thermal effects, comparable with conventional instrumentation[62,63]. Keller and Hibst[66] 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/cm^2 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[43,44] 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[45]. Not surprisingly, these lasers are bactericidal against *in vitro* cultures of Porphyromonas gingivalis and Aggregatibacter (formally Actinobacillus) actinomycetemcomitans[61], and effective in removing the absorbed root surface endotoxins[62,63].

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 al[67] reported that the surface structure of periodontally diseased root after Er:YAG laser irradiation at 100 mJ/ pulse (energy density 5.98 J/cm^2) 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 al[65]. 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/cm^2 per pulse) and 10 Hz in perpendicular contact irradiation using a conventional tip.

Pourzarandian et al[70] 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 al[71] investigated the change of PGE_2 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 PGE_2 *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 sub-gingival 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.

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