Laser Energy in Oral Soft Tissue Applications

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J Laser Dent 2010;18(3):123-131

Editor's Note

This is the third of a series of position papers on the uses of lasers in dentistry, written by the Science and Research Committee of the Academy of Laser Dentistry (ALD). This position paper was approved by the ALD Board in November 2010. The paper is not designed as a comprehensive literature review or as a detailed historical document. It covers aspects of soft tissue laser surgery and treatment utilizing lasers currently available. The document will be revised and updated as needed.

The authors of this document are all members of the Science and Research Committee of the ALD. Their biographies and disclosures are available upon request to the Academy.

Readers are encouraged to review the Academy's other position papers published in the Journal of Laser Dentistry:

- *The Use of Laser Energy for Therapeutic Ablation of Intraoral Hard Tissues.* J Laser Dent *2007;15(2):78-86.*
- *Laser Safety in Dentistry: A Position Paper.* J Laser Dent *2009;17(1):39-49.*

INTRODUCTION

Lasers have been used for oral soft tissue dental procedures for more than 30 years, and have been researched since the middle 1960s.[1-4] Their reported benefits over conventional treatment modalities include: reducing numbers of appointments, reducing stress, improving visibility, improving patient comfort, and reducing complications. Critics have commented that most of these advantages are anecdotal and need to be substantiated with further research. With scientific references, this paper will show:

- Fundamental laser-tissue interaction with oral soft tissue;
- Laser use can be minimally invasive compared to conventional modalities;
- Laser energy can aid in hemostasis, providing for improved visibility during a surgical procedure;
- Laser irradiation can reduce bacteria;
- Laser use can help in wound healing and can produce other photobiomodulation effects;
- Laser energy can reduce pain when compared to conventional methods.

MECHANISM OF LASER INTERACTION WITH SOFT TISSUE

The oral cavity contains a variety of soft tissue types including but not limited to dental pulp, mucosa, keratinized and non-keratinized gingiva. Furthermore, specific differences can exist for each tissue type, depending on location, tissue thickness, and degree of health.[5-6]

Depending on the wavelength of the laser device, the following interactions can be seen in varying degrees:[7]

- Reflection – no interaction occurs as the beam reflects off the surface
- Transmission – no interaction occurs as the beam passes directly through the tissue
- Scattering – an interaction as the beam disperses in a non-uniform manner throughout the tissue
- Absorption – light radiation is absorbed by specific tissue elements.

The predominant laser interactions within oral soft tissue are absorption and scattering.[8-10] As will be explained further, tissue composition, laser emission mode, fluence, and thermal relaxation also affect tissue interaction.

Wavelength and Tissue Type

Laser wavelengths have been shown to be absorbed by different components such as hemoglobin, melanin, water, and hydroxyapatite. Currently available dental lasers operate in the visible or near-infrared region (532-1340 nm), near the boundary of the mid-infrared (2780 and 2940 nm), and far-infrared (10,600 nm) regions of the electromagnetic spectrum. With respect to the light radiation interacting at the tissue surface (incident beam), interaction is primarily determined by the laser irradiation affinity for specific chromophores comprising the tissue.[11-12] A chromophore is a molecule or substance capable of absorbing specific laser wavelengths.[13] Table 1 lists each available Class IV laser, wave-

Table 1: Class IV Laser Devices Currently Available to the Dental Profession

Laser Device	Wavelength(s)	Emission mode(s)	Delivery system(s)	Primary soft tissue chromophore
KTP (Potassium Titanyl Phosphate)	532 nm	Continuous Wave (CW) / gated CW	Optic fiber	Melanin / hemoglobin
Diode	810, 940, 980, 1064 nm	CW / gated CW	Optic fiber	Melanin / hemoglobin
Neodymium (Nd):YAG	1064 nm	Free-running pulsed (FRP)	Optic fiber	Melanin / hemoglobin
Nd:YAP ($YAlO_3$ Perovskite)	1340 nm	FRP	Optic fiber	Melanin / hemoglobin
Erbium Chromium (Er,Cr):YSGG	2780 nm	FRP	Optic fiber	Water
Er:YAG	2940 nm	FRP	Waveguide / Optic fiber, Articulated arm	Water
CO_2	10,600 nm	CW / gated CW	Waveguide, Articulated arm	Water

length, emission mode, delivery system, and primary chromophores. Whenever feasible it is best to match the appropriate wavelength to the main chromophore within the target tissue to maximize the absorption and achieve an enhanced treatment efficiency. For example, inflamed tissue, which can contain dark pigment and hemoglobin chromophores, readily absorbs wavelengths in the visible and near-infrared regions.[14] Furthermore, in situations of healthy or minimally pigmented tissue, wavelengths highly absorbed in water often will provide more efficient ablation.[7]

Emission Mode

The temporal emission mode of a laser is the propagation of a stream of photonic energy from the site of the beam origin, relative to time. Depending on how the laser active medium is energized, the laser photonic emission can occur – inherently – in a continuous wave (CW) or free-running pulsed (FRP) emission mode. Typically, the energizing component of the laser is referred to as the pumping mechanism, which can be a flash lamp, electric current, or electric coils. The CW lasers can be further manipulated through device-specific mechanical, optical, or alternating current electro-optical interruption of the beam. This interruption of the CW laser beam can be termed 'gated' or 'chopped,' with each pulse identical in power and duration. Currently available CW dental lasers include KTP, all diodes, and CO_2 lasers; and all have gated properties that vary by device. Some of these instruments have pulse durations as short as micro- and milli-seconds, and some manufacturers have coined different terms, such as 'super-pulse' and 'ultraspeed,' in describing their devices. With very short pulse durations, peak powers several times higher than CW powers can be produced. However, typical average powers for CW lasers can range from 0.5 to 5.0 W.

If gating can be an optional operator choice in a continuous-wave laser, free-running pulsed emission is inherent to the device and the result of the pulsed excitation source. Currently, FRP is a characteristic seen in Nd:YAG, Nd:YAP, Er,Cr:YSGG, and Er:YAG lasers whose pulses have peak powers in the 1000 W range. Despite high peak powers, a FRP laser delivers low average power through extremely short pulse durations in the range of a few hundred microseconds.

Thermal Relaxation

The emission mode will have an effect on laser-tissue interaction through average power and peak power in relation to thermal relaxation factors of the target tissue.[15] The pulse length, pause length, and penetration depth (the extent of the laser beam's interaction within the tissue) also influence thermal relaxation of the target tissue.

Thermal relaxation can be defined as the time required for the irradiated tissue to cool by 50% of its original temperature immediately after the laser pulse.[16] The ability of the irradiated tissue to cool can be influenced directly by the laser operating parameters and the inherent thermal diffusivity (convection and conduction) of the tissue. Other factors are: area or volume of tissue exposure; technique and speed of movement of the laser beam over the target tissue; blood flow within the tissue; and the use of high-speed evacuation. Supplemental irrigation, application of ice, or a co-axial water spray can also be utilized to achieve cooling.[17] Gating or chopping a continuous-wave device provides reduced risk of tissue damage due to less energy delivered to the tissue at a given time.[18]

Energy Density (Fluence)
Energy density is defined as energy (Joules) per square centimeter of spot size (J/cm^2). Through the use of various techniques and delivery systems, the laser beam spot size can be either de-focused or focused. Depending on the degree of beam focus, the laser beam spot size can be altered and fluence will accordingly change. Decreasing the area of the laser spot size will increase the energy density and then (presuming optimal absorption characteristics in the tissue) the rate of ablation of the target tissue will increase up to a maximum ablation rate.

LASER USE IS MINIMALLY INVASIVE

When compared to conventional techniques, laser procedures can be minimally invasive due to the principles stated previously – wavelength (see Table 1), emission mode, fluence, operating parameters, and technique. Understanding how photonic energy is minimally invasive requires a basic knowledge of laser physics and how different wavelengths interact with various chromophores such as hemoglobin, melanin, and water. Inflamed tissue contains increased vascularity and increased inflammatory cells with fewer collagen bundles in the underlying connective tissue.[19] Furthermore, by choosing appropriate parameters and carefully observing the tissue response, the practitioner can cause different tissue responses with varying temperatures. Biologically, different effects can be seen at various temperature gradients. Many nonsporulating bacteria are inactivated at 50°C and above.[20] Coagulation occurs and proteins begin to denature at approximately 60ºC.[21] Higher temperatures such as 90-100°C will lead to irreversible changes in cellular protoplasm and proteins which will be seen as tissue shrinkage and desiccation.[21-22] At 100°C, boiling occurs and all water-based tissue elements will vaporize and ablation (removal of tissue) occurs.[23]

With appropriate technique and proper laser parameters, it has been reported that soft tissue procedures can be accomplished and the possibility of thermal damage to the surrounding tissue can be minimized.[24-25] However, current guidelines advise the use of the lowest average fluence to avoid risks of excessive heat complications whenever possible. Depending on operating parameters and choice of wavelength, effects from heat can vary. For example, Er:YAG lasers have shown thermally affected layers in tissue to be in the range of 10 to 50 microns[26-27] which is in contrast to surgical diode lasers in the range of 0.5-3 mm.[28] Underlying periosteum and hard tissue are particularly vulnerable to excessive heat in sites with overlying thin oral mucosa.[29]

LASER USE OFFERS IMPROVED HEMOSTASIS COMPARED TO SCALPEL

Improved hemostasis through enhanced coagulation can occur with laser use.[30-35] (The erbium lasers [Er:YAG and Er,Cr:YSGG] are the exception to this general statement, since they provide limited hemostasis.)[36-37] This mechanism occurs when at least two conditions occur: tissue absorption and a controlled heat build-up, resulting in coagulation of blood proteins and sealing of small diameter vessels.[38-42] The warming of tissue to more than 60°C will result in protein denaturation and coagulation,[21] which are properties useful in controlling bleeding.

Consideration should be given to the use of a hot-tip technique, which converts light energy into thermal energy at the end of the fiber, thus limiting the ability of photonic energy to penetrate into the tissue.[43] Care should be exercised to avoid collateral thermal damage from excessive power and pulse repetition rate.[44] The use of a surface coolant (water or saline) to aid in reducing surface temperatures has been described.[23] Surface coolants can be used for temperature control of the surface and to minimize subsurface overheating, thus helping to optimize coagulation.[42]

LASER IRRADIATION CAN REDUCE BACTERIA

Since a predominant cause of dental disease is attributed to pathogenic bacteria, treatment success often involves reducing such species. Using lasers for surgical techniques can produce tissue temperatures effective for reducing bacteria.[20] However, bacterial reduction has been found to occur at temperatures as low as 50°C.[20] Furthermore, bacterial reduction has been demonstrated in both *in vitro*[45-47] and *in vivo*[48-52] clinical studies. Antimicrobial activity occurs primarily through photothermal effects due to absorption and has been shown to be effective in *in vivo* biofilm.[53] Studies have shown that combining photo-initiators with specific wavelengths can enhance bactericidal properties.[54-59] An *in vivo* study using an Nd:YAG laser has shown bacterial reduction to be effective for up to 3 months.[60]

It is generally accepted that opportunistic bacteria can contribute to postoperative infections, oral lesions, and periodontal disease. Treatment success often involves reducing such pathogenic bacterial species through prescription antibiotics and rinses. However, side effects of medications do occur and may range from the development of antibiotic-resistant strains of bacteria,[61-63] drug sensitivity,[64] altered taste, and staining of the dentition.[65] These problems can result in patient noncompliance and serious allergic reactions. Because laser energy has been shown to reduce bacteria, fewer risks of postoperative infections occur.

LASER ENERGY CAN AID HEALING THROUGH PHOTO-BIOMODULATION

Laser procedures will have varying degrees of irradiation effects surrounding the treatment site. Through scattering of certain wavelengths, surrounding tissue adjacent to the treatment site will not receive the maximum energy density.[42] Providing laser treatment at low energy levels can be useful and beneficial for healing and regeneration. When desired, reducing the energy density can also be accomplished by using the laser in a de-focused mode. At energy levels (measured in mW) incapable of tissue removal, the stimulation of cellular metabolism known as low-level laser therapy (LLLT)[66-68] or photobiomodulation (PBM) can be observed. The PBM effect has been shown to stimulate mitochondria, enhancing ATP production.[69-72] This effect can lead to increased wound healing through increased fibroblast proliferation[73] and collagen formation; thus, low-level biostimulation can promote gingival healing or reduction of gingival inflammation,[74-75] increased release of growth factors,[70] and pain relief.[76-77] Healing times have been reported to be reduced.[78]

The predominance of literature suggests that PBM occurs with visible and near-infrared wavelengths from 633 to 904 nm, though defocused modes of higher wavelengths have also been investigated.[79] Thus, most of the lasers listed in Table 1 do not apply to this discussion. PBM is not a thermal effect, which is the primary focus of this paper.

LASER ENERGY CAN REDUCE PAIN

Associated reported laser benefits are reduced pain and discomfort after surgery.[80] Reports of pain relief mechanisms appear to originate in stimulating oxidative phosphorylation in mitochondria and through modulating inflammatory responses.[81]

Reports of positive patient responses to laser treatment[80,82-86] are usually dismissed by critics because of the impossibility of implementing a controlled study. However, one study reported on patients who experienced both CO_2 laser and conventional methods; these patients indicated fewer complaints and/or expressed complete freedom from postsurgical afflictions with the laser procedures.[87] Another study examined patients receiving both Nd:YAG laser and scalpel surgical techniques; most laser-treated sites evoked minimal discomfort without anesthesia, while scalpel surgery required anesthesia.[31] One animal study showed promising results of less pain (by quantifying nociceptive response as measured by a muscle mass electromyogram) from an Er:YAG laser oral tissue incision when compared to a similar scalpel incision.[88] The value of using animal studies to evaluate pain relief is that any placebo effect is nullified.[81]

OTHER CONSIDERATIONS FOR THE USE OF LASERS

Laser surgical margins are less precise than scalpel surgical margins, since the incision is at least as wide as the beam diameter.

Postoperatively, both laser and electrosurgery procedures will heal by secondary intention. It has been reported that soft tissue healing following a laser[89] is slower than with the scalpel. In a study comparing wound healing after scalpel, electrosurgery, and Nd:YAG laser surgery in beagle dogs, it was shown that surgical sites appeared to be clinically healed 14 days postoperatively. However, histologically the electrosurgery site continued to have a high degree of inflammatory infiltrate.[90] Immediately postoperatively the laser can offer protection to the surgical site through a coagulum surface[91] and, as mentioned previously, bacterial reduction.

Studies have shown additional benefits with laser use, such as minimal wound contraction[91] and minimal scarring when compared to scalpel surgery.[92] Researchers comparing CO_2 laser vs. scalpel and electrosurgery demonstrated less tissue damage with the laser compared to electrosurgery or conventional instruments[93] and a higher production and release of growth factors in laser sites compared to scalpel sites.[94]

Avoiding Complications

If soft tissue temperatures increase above 100°C, protein-based elements will be reduced to hydrocarbon and carbon residues. Charring and carbonization occurs above 200°C[95] and should be avoided. Carbon, when present as a build-up on the distal end of the delivery system or tissue surface, absorbs the laser energy, creating a heat sink, which can lead to collateral thermal damage.[43]

Ignoring laser physics and not understanding the limitations of each laser device can result in complications and poor results.

Consideration of the following can minimize the risk of collateral thermal damage during laser surgery:

1. Keep the fiber or other delivery systems moving while directing the laser beam appropriately
2. Remove any char build-up regularly with water-moistened gauze
3. Allow for tissue cooling (thermal relaxation) by adjusting the pulse repetition rate, interrupting the energy delivery, using high-volume evacuation, utilizing water spray, or applying ice near the surgical site.

Knowledge of various characteristics associated with each laser wavelength can prevent complications. For example, since soft tissue is predominantly composed of water, dental lasers used for soft

tissue surgery can be grouped into two categories according to their depth of penetration into pure water: deeper-penetrating, visible and near-infrared wavelengths (KTP, diode, Nd:YAG, and Nd:YAP) and shallower-penetrating, mid-to-far-infrared wavelengths (Er,Cr:YSGG, Er:YAG, and CO_2).[22,96]

Caution should be exercised with all wavelengths, as tissue effects occur beyond the visibility of the clinician. For example, with improper choice of parameters, edema can occur, and its extent can vary from shallower to deeper in the tissue, depending on the wavelength.[97]

Anatomical Aspects

Oral epithelium varies in thickness from 0.3 to 6.7 mm.[98] Gingival tissue is associated with underling bone or adjacent dental hard tissue. The thickness of the keratin layer should be considered as well; the thinner the keratin, the closer the laser tip is to the underlying pigmented and vascularized tissues.

Other Soft Tissue Considerations

Good laser practice necessitates consideration of other soft tissue-related procedures and aspects, such as:

- Gingivectomy procedures – Care should be given to the possibility of compromising the biologic width of the periodontal/dental complex.[99]
- Excisions and biopsies – It is often advantageous to place tissue to be excised under tension as this serves to accelerate the laser incision and promote the use of lower power settings. Minimal penetration depths of mid-infrared to far-infrared wavelengths can be utilized in the excision of shallow lesions such as nonerosive lichen planus. It is imperative that an accurate histological diagnosis be made to confirm the nature of the lesion.
- Aphthous and herpetic lesions – Defocusing techniques and using subablative power values can reduce pain, stimulate cellular repair, and reduce any inflammatory reaction. Care should be taken during laser treatment of herpetic lesions; surface coagulum may inhibit laser energy absorption during treatment. Any claims of the laser's ability to reduce viruses remain speculative.
- Postoperative Appearance – The optimal appearance of a postoperative laser surgical site will be pink in the zone of ablation that may be accompanied with a superficial layer of coagulum, which may serve to protect the surface. Depending on different laser parameters and the type of wavelength, coagulum layers can range from 0.01-1.0 mm thick, which aids in hemostasis.[100-101] As healing occurs, regardless of device, physiologically a zone of reversible edema surrounds the surgical site.[97]

Safety Aspects

It is beyond the scope of this paper to analyze all aspects of laser safety. However, pertinent to the use of lasers in surgical soft tissue management would be the use of appropriate safety eyewear by all operatory personnel including the patient; wearing of gloves, gowns, and laser masks by the operator and assistant; use of high-volume evacuation to help capture laser plume; avoidance of flammable agents; and recording all details of laser use in the patient's record. Furthermore, any instrument that is used in a manner involving penetrating tissue or around blood products should be heat-sterilized or disposed of in an appropriate sharps container.[102-103]

One of the most important aspects of safe laser use is that the clinician be properly trained on the instrument that he/she utilizes. Moreover, that use should be in accordance with one's scope of practice, experience, and skill.

SUMMARY AND CONCLUSION

The use of laser technology has been shown to be a viable and effective adjunct to conventional dental surgical techniques, and a useful alternative in certain situations. Because of its documented advantages, laser technology should be utilized wherever clinically indicated in soft tissue procedures. When the practitioner adheres to sound principles and good technique, the benefits of laser use that have been proven with valid research can be seen clinically by the dental personnel and by the ultimate beneficiaries – the patients.

GLOSSARY

Ablation: Removal of a segment of tissue using thermal energy; also termed vaporization or thermal decomposition.

Absorption: The transfer of radiant energy into the target tissue resulting in a change in that tissue.

Active Medium: Any material within the optical cavity of a laser that, when energized, emits photons (radiant energy).

Attenuation: The decline in energy or power as a beam passes through an absorbing or scattering medium.

Average Power: An expression of the average power emission over time expressed in Watts; total amount of laser energy delivered divided by the duration of the laser exposure. For a pulsed laser, the product of the energy per pulse (Joule) and the pulse frequency (Hertz).

Beam: Radiant electromagnetic rays that may be divergent, convergent, or collimated (parallel).

Chopped Pulse: See Gated Pulse Mode.

Chromophore: A substance or

molecule exhibiting selective light-absorbing qualities, often to specific wavelengths.

Class IV Laser: A surgical laser that requires safety personnel to monitor the nominal hazard zone, eye protection, and training. This class of laser poses significant risk of damage to eyes, any nontarget tissue, and can produce plume hazards.

Coagulation: An observed denaturation of soft tissue proteins that occurs at 60°C.

Contact Mode: The direct touching/contact of the laser delivery system to the target tissue.

Continuous Mode: A manner of applying laser energy in an uninterrupted (non-pulsed) fashion, in which beam power density remains constant over time; also termed continuous wave, and abbreviated as 'CW.' Contrast with 'Pulsed Mode.'

Energy: The ability to perform work, expressed in Joules. The product of power (Watts) and duration (seconds). One Watt second = one Joule; 1 J = 1 Watt x 1 second.

Energy Density: The measurement of energy per area of spot size, usually expressed as Joules per square centimeter; also known as fluence.

Fluence: See Energy Density.

Free-Running Pulse Mode: A laser operating mode where the emission is truly pulsed and not gated. A flashlamp is used as the external energy source so that very short pulse durations and peak powers of thousands of Watts are possible. A laser operating in this mode cannot be operated in continuous wave.

Gated Pulse Mode: A laser operating mode where the emission is a repetitive on-and-off cycle. The laser beam is actually emitted continuously, but a mechanical shutter or electronic control 'chops' the laser beam into pulses. This term is synonymous with chopped pulse mode.

Intensity: See Power Density.

Irradiance: See Power Density.

Joule: See Energy. A unit of energy or work equal to an exposure of 1 Watt of power for 1 second.

Low-Level Laser Therapy (LLLT): See Photobiomodulation (PBM).

Noncontact Mode: A laser technique in which the delivery system is used without touching the target tissue; light radiation may be defocused or focused, depending on operator's technique and procedure.

Photobiomodulation (PBM): The use of light radiation to elicit biological responses in living cells.

Peak Power: The highest power in each pulse.

Plume: Essentially the smoke produced from aerosolization of by-products due to laser-tissue interaction. It is composed of particulate matter, cellular debris, carbonaceous and inorganic materials, and potentially biohazardous products.

Power: The amount of work performed per unit time, expressed in Watts (Joules per second). 1 Watt = 1 Joule x 1 Second.

Power Density: The measurement of power per area of spot size, usually expressed as Watts per square centimeter; also known as intensity, irradiance, and radiance.

Pulse Duration: A measurement of the total amount of time that a pulse is emitted; also known as pulse width.

Pulse Width: See Pulse Duration.

Pulsed Mode: Laser radiation that is emitted intermittently as short bursts or pulses of energy rather than in a continuous fashion. Contrast with 'Continuous Mode.'

Repetition Rate: Number of pulses per second, also known as pulse rate; usually expressed in Hertz (Hz) or pulses per second (PPS).

Scattering: An interaction as the laser beam disperses in a non-uniform manner throughout the tissue.

Superpulse: A variation of gated pulsed mode in which the pulse durations are very short, producing high peak power; also termed very short pulse.

Thermal Effect: For lasers, the absorption of the radiant energy by tissue producing an increase in temperature.

Thermal Relaxation Time: The amount of time required for temperature of the tissue that was raised by absorbed laser radiation to cool down to one half of that value after the laser pulse.

Vaporization: The physical process of converting a solid or liquid into a gas; for dental procedures, it describes conversion of liquid water into steam.

Watt: See Power.

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