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I am extremely pleased to report that the previous issue of the Journal has been very well received by our members. I trust that all of you have read my last editorial so that you will be aware of the direction I plan to take our Journal and the reasons for it. That being said, I have decided to prepare a special collection of articles for this issue which is planned for distribution coinciding with ALD’s presence at the American Dental Association meeting in San Francisco, October 18-21, 2012.

It is true that my goal for the future of the Journal is its becoming indexed for MEDLINE®, the U.S. National Library of Medicine’s® (NLM’s) bibliographic database of journal articles in the life sciences. But we must never lose sight of the fact that the primary reason for the Journal’s existence is to benefit the Academy’s membership as well as the entire dental community.

With this in mind, I have decided to produce a “Reference Issue,” a toolkit of sorts, which includes:

- a compilation of the Academy’s three Position Papers:
  - The Use of Laser Energy for Therapeutic Ablation of Intraoral Hard Tissues (2007)
  - Laser Safety in Dentistry (2009)
- ALD’s Statement on the Use of Lasers by Licensed Dental Professionals (2004)
- a new bibliography of laser dentistry reference materials, prepared especially for this issue.

The Position Papers are reprinted just as they were originally published in previous issues of the Journal, and reflect the standing of the Academy in each of their respective areas. The Statement has been posted online on ALD’s Web site, but this is the first time it has appeared in the Journal. The new bibliography incorporates numerous texts, periodicals, conference proceedings, and organizations of interest to dental laser professionals.

Because some of these documents have been developed several years ago, I invite all interested parties, whether members of the Academy or not, to submit suggested revisions or additions to this reference material to help ensure that ALD continues to be responsive to our members’ needs. Your suggestions will be relayed to the appropriate committee for consideration and action.

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Stuart Coleton, DDS
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The Use of Laser Energy for Therapeutic Ablation of Intraoral Hard Tissues

Position Paper: Science and Research Committee, Academy of Laser Dentistry

Adopted March 2007

Steven P.A. Parker, BDS, LDS, MFGDP (Committee Chair); Arun A. Darbar, BDS; John D.B. Featherstone, MSc, PhD; Giuseppe Iaria, DMD, PhD; Gabi Kesler, DMD; Peter Rechmann, Prof. Dr. med. dent.; Michael D. Swick, DMD; Joel M. White, DDS, MS; Harvey A. Wigdor, DDS, MS


EDITOR’S NOTE
This is the first of a series of position papers on various uses of lasers in dentistry, developed by the Science and Research Committee of the Academy of Laser Dentistry (ALD). This position paper was approved by the ALD Board of Directors in March 2007. The paper is not designed as a comprehensive literature review or as a detailed historical document. It covers aspects of the ablation of hard tissues relevant to dentistry, utilizing lasers currently available. The document will be revised and updated as technology changes and improves. The reader is referred initially to the bulleted summary that highlights the key points of the paper, and then to the body of the text for supporting details.

SYNOPSIS
The present use of lasers in dentistry for the ablation of hard tissues is summarized in this publication together with a brief statement of scientific rationale.

SUMMARY
- When the wavelength of incident laser light is matched to the absorption band(s) of a target tissue component, light energy is converted primarily to heat which causes tissue change and/or ablation.
- To be therapeutically effective and efficient, it is necessary to deliver light of sufficient energy over time to effect tissue change, without causing unwanted collateral thermal damage by conduction of excess heat into the surrounding tissues.
- Neodymium YAG (Nd:YAG, 1064 nm). While published studies have indicated some safe and effective usage, the clinical significance of the Nd:YAG laser wavelength was shown to be of only marginal benefit to the restorative dentist because of its very low absorption in hard tissues.
- Continuous wave (CW) carbon dioxide laser (CW CO₂, 10,600 nm). The commonly available continuous wave CO₂ laser showed poor interactions with enamel, with reports of charring, cracking, and damaging heat buildup within tooth and bone structure.
- Erbium YAG (Er:YAG, 2940 nm) and Erbium, Chromium YSGG (Er,Cr:YSGG, 2780 nm). The pulsed Er:YAG and Er,Cr:YSGG laser wavelengths are well absorbed by target hard tissue components, primarily water. These wavelengths offer safe use in cavity preparation.
- Both Er,Cr:YSGG and Er:YAG laser wavelengths are absorbed well in water, with the Er:YAG being somewhat more strongly absorbed in water than the Er,Cr:YSGG.
- The absorption in water is the primary absorption for these two wavelengths due to a relatively broad water band around 3,000 nm.
- In addition, there is a small absorption at around 2,800 nm by the hydroxyl group of the (carbonated) hydroxyapatite mineral of the tissues, but this is far outweighed by the water effects.
- Water is naturally present among the crystals in enamel, dentin, cementum, and bone deep into the tissue, filling every available pore. Enamel, dentin, bone, cementum, and carious tissue have, relatively, descending mineral density and ascending water composition.
• For both Er:YAG and Er,Cr:YSGG laser wavelengths, the laser energy is absorbed primarily by the water and is rapidly converted to heat, which causes superheating of the subsurface water, resulting in a disruptive expansion in the tissue.
  • The currently marketed mid-infrared (IR) laser wavelength lasers (around 3,000 nm) are free-running pulsed lasers. If the correct energy is used, application results in safe pulpal temperature rises of less than 5°C.
• Laser irradiation of enamel and dentin by Er:YAG or Er,Cr:YSGG lasers produces a “super-rough,” micro-cavitated surface.
• Studies have identified the fragility of laser-irradiated enamel, relative to the stability of the post-restoration margins. A combined approach of laser-irradiation and acid-etch techniques, to overcome such potential problems, is suggested. Regardless, there is the need to remove grossly overhanging and unsupported enamel to provide a stable post-restoration margin.
• The rate (speed) of ablation of dental hard tissue is a consequence of the amount of incident laser energy delivered to the tissue as well as the effects of wavelength, pulse duration, pulse shape, repetition rate, power density, the thermal relaxation time of the tissue, and delivery mode.
• Fluoridation of the tissue, incident angle of the delivery tip relative to the tooth, and presence of ablation products will affect the speed of ablation.
• The ablation threshold of human enamel has been reported to be in the range of 12-20 Joules/cm², and for dentin 8-14 Joules/cm² for the Er:YAG and Er,Cr:YSGG laser wavelengths, respectively.
• Ablation of bone. The development of Er:YAG and Er,Cr:YSGG lasers has enabled bone ablation to be carried out with minimal adjacent damage, and the use of erbium lasers in dento-alveolar surgery represents a less-traumatic experience for the patient.
• As with tooth tissue ablation, bone tissue cutting is a thermally induced explosive process and it is essential to maintain a coaxial water spray to prevent heat damage, which delays healing.
• Bone composition is very similar to dentin from the perspective of laser-tissue interactions. In maxillary alveolar bone, the speed of laser cutting is comparable with that of a bur, and slightly slower in the mandible.
• Future developments and applications. Several exciting new possibilities for the use of lasers on hard tissues are likely to become available to the practicing dentist in the near future. Two such examples are:
  • Selective ablation of calculus by wavelengths in the ultraviolet/blue region will offer less invasive dentistry.
  • Low microsecond-pulsed carbon dioxide lasers with a 9.3- or 9.6-µm wavelength have great potential for efficient and effective ablation of sound and pathological hard tissues, as well as modification of the mineral to increase resistance to caries attack.

INTRODUCTION
Laser light is unique in being emitted as a monochromatic, coherent, and collimated beam of non-ionizing electromagnetic (EM) energy which, for current dental purposes, spans the visible and infrared regions of the EM spectrum. Through a correct matching of incident laser wavelength with a target tissue element, light energy is converted primarily to heat, which causes tissue change or ablation.

For the present document the use of laser light for intra-oral hard tissue ablation will be the treatment that is primarily discussed. Other uses and mechanisms are known, but these are not the topic of the present paper.

In order for any laser-tissue interaction to be therapeutically effective and efficient, it is necessary to deliver light energy of sufficient value over time to effect tissue change, without causing unwanted collateral thermal damage by conduction of excess heat into the surrounding tissues.

LASER ENERGY AND DENTAL HARD TISSUES
Healthy oral hard tissues include enamel, primary and secondary dentin, cementum and alveolar bone. For the purposes of the application of laser energy in restorative dental procedures, demineralized and carious hard tissue must also be considered.

In addition to the prime interaction of laser energy with these tissues, there also exists a need to establish a rate of interaction that is commensurate with a time frame that allows such interaction to be clinically acceptable, by limiting the time for conduction of excess energy to occur, while at the same time being fast enough to be clinically acceptable.

Early investigations into the use of lasers for the ablation or modification of dental hard tissue were carried out using a ruby laser (red, visible, 694.3 nm), a carbon dioxide continuous-wave laser (infrared, 10.6 µm), and subsequently the neodymium:YAG laser (infrared, 1064 nm).
The Nd:YAG laser was the first to be marketed for soft tissue laser dentistry in the USA and numerous investigations were done to investigate its utility for hard tissue use.1-9 Investigations included the ablation of (pigmented) diseased tissue, the antibacterial effect of this laser wavelength, and the possible effects on the vital dental pulp. While studies were published to establish some safe and effective usage, the clinical significance of this wavelength was shown to be of only marginal benefit to the restorative dentist, because of its very low absorption in sound enamel or dentin.9 High fluences are needed for ablation unless the region to be ablated is pigmented or a pigment is applied to the surface. Furthermore, several studies drew conclusions that the Nd:YAG wavelength could cause unwanted heating side effects, such as cracking and melting of composite mineral structures.1-9 Conversely, some workers published reports of the beneficial acid-resistance in enamel following exposure to low-power Nd:YAG energy and the resulting reconstitution of melted mineral in enamel.10-12 However, what is not commonly realized is that an absorbing material (e.g., black ink) must be applied first for this wavelength to effectively increase the acid resistance of dental enamel, due to the very low absorption of Nd:YAG in enamel and dentin.

Other early studies on enamel ablation used the other commonly available laser wavelength, carbon dioxide (10,600 nm), but this laser gave poor interactions, with reports of charring, cracking and damaging heat buildup within tooth and bone structure.13-14 The available carbon dioxide lasers at that time were continuous wave with no cooling water, which resulted in very high energy deposition in the hard tissue due to the combined absorption of this wavelength in both the mineral and in the water component. Excess heat was rapidly deposited with the continuous-wave mode rather than pulsed mode where there is time for the tissue to cool between pulses, and the energy density of the pulses can be better tailored to the needs. The continuous-wave CO2 laser use resulted in reports of poor clinical benefit of this wavelength. The successful use of pulsed CO2 lasers for ablation is expected to become a clinical reality in the near future.

The work of workers such as Keller and Hibst,29 among others, illustrated the potential of the Er:YAG (2.94-µm wavelength) for effective ablation of dental hard tissues. This led to the development and marketing of free-running, mid-infrared wavelength (around 3,000 nm) lasers during the mid-1990s. This was a real achievement in addressing laser wavelengths that were complementary to target tissue elements, and offered clinically significant ablation rates that did not cause pulpal or collateral thermal injury if the right energy levels were used. The erbium:YAG (2,940 nm) and erbium, chromium:YSGG (2,780 nm) laser wavelengths are well absorbed by target hard tissue elements and appeared to offer safe use in cavity preparation.15-17

ABLATION OF HARD DENTAL TISSUES BY MID-INFRARED LASERS

It may seem incongruous, but to any clinician who may wish to use a laser in restorative dentistry, the high-speed rotary drill is seen as the “gold standard.” Ease of use and speed are often accepted as plausible, even when several studies have shown that high-speed drilling gives rise to surface and pulpal temperature rise, tissue cracking, and unnecessary removal of healthy surrounding tissue during cavity preparation.18-21 Such incongruity is compounded by the number of papers attesting to the precision, low thermal rise, and selectivity of mid-infrared laser wavelengths when used on dental tissue. Generally, the only drawback would appear to be the lower “speed” of cutting, when compared to the drill.22-25

Notwithstanding, the use of Er:YAG and Er,Cr:YSGG lasers in restorative dental procedures has progressed during the past 10 years, and within a given clinical setting the following factors will be significant in determining effective treatment outcomes:

- Target chromophores
- Mechanism of interaction
- Emission mode
- Pulse duration (pulsed or continuous wave, chopped)
- General thermal effects
- Relationship of laser action to cavity design and restoration retention
- Speed of “cutting”
- Power values.

a) Target chromophores

Both Er,Cr:YSGG and Er:YAG laser wavelengths are absorbed well in water, with the Er:YAG being somewhat more strongly absorbed in water than the Er,Cr:YSGG. This absorption is several orders of magnitude greater than that seen with the Nd:YAG wavelength. The absorption in water is the primary absorption for these two wavelengths due to a relatively broad water band around 3,000 nm.9,31

This is water that is naturally present among the crystals in enamel, dentin, cementum, and bone deep into the tissue, filling every available pore. In carious tissue there is an even higher quantity of water that replaces the lost mineral. The key to understanding hard tissue ablation by these wavelengths is that it is primarily due to this absorption in water and superheating of the water below the surface (see below, and Figure 1). Enamel, dentin, bone, cementum and carious tissue have, relatively, descending mineral density and ascending water composition.26-27

In addition, there is a small absorption at around 2,800 nm by the hydroxyl group of the (carbonated) hydroxyapatite mineral of the tissues.28-32 but this is far outweighed by the water effects. Unfortunately many publications about laser effects on hard tissues have perpetuated the erroneous statements that dental mineral strongly absorbs these wavelengths. Not only is this incorrect, but it misleads us in understanding the mechanism of how ablation occurs due to laser application at these wavelengths and misdirects the use of these laser wavelengths.
b) Mechanism of interaction

When incident laser energy directed onto hard dental tissue is absorbed by the prime chromophores, either water or carbonated hydroxyapatite, one of two effects occur. For both Er:YAG and Er,Cr:YSGG wavelengths this energy is absorbed primarily by the water and is rapidly converted to heat, which causes superheating and a phase transfer in the subsurface water, resulting in a disruptive expansion in the tissue. Through this mechanism, whole tissue fragments are ejected and a hole is cut in the tooth, with little or no alteration to the mineral itself.

If laser light is effectively absorbed by the mineral, the crystals themselves may be heated above their melting point and some disruption of the crystal structure occurs with subsequent resolidification in a different form, or direct ablation of the mineral, but there is also conductive heat transfer to interstitial free water. Relatively high fluences are needed at these wavelengths for this to occur.

c) Emission mode and pulse duration

The emission mode of currently marketed mid-infrared wavelength lasers is defined as free-running pulsed. Currently commercially available lasers emit a pulse train of 50-250 microsecond pulses on average which, when delivered in rates of 3-50 Hz (pulses per second) values, represent duty cycle values of approximately 80%. While pulse durations are close to the thermal relaxation times of enamel and dentin, it is evident that there exists a need to examine further ultrashort pulse durations – and associated high peak power values – in an attempt to create sufficient ablative force without inducing collateral thermal damage.

d) General thermal effects

The vital dental pulp is acutely sensitive to thermal change. Studies have established that rotary instrumentation can cause conductive thermal rise in excess of 20°C above 37.4°C. With regard to laser irradiation of dental tissue, the explosive defragmentation resulting from water-assisted mid-infrared laser wavelengths allows much of the heat to escape from the cavity carried in the ablated particles, resulting in pulpal thermal rise of less than 5°C. The affinity of mid-infrared laser wavelengths with water allows the main absorption to take place in demineralized tissue richer in organic material and with a higher percentage of water, thus protecting the sound underlying tissue with a reduced penetration of the beam. Contrary to this, the accumulation of ablation debris within a deep cavity can lead to “super-heating” which can lead to conductive heat damage.
e) Relationship of laser action to cavity design and restoration retention

The emergence of conservative restorative cavity design, at variance with the classical “G.V. Black” model, represents a move toward minimal intervention with the development of acid-etch retention of composite resin restoratives. Laser irradiation of enamel and dentin by Er:YAG or Er,Cr:YSGG lasers results in a “super-rough,” micro-cavitated surface that may predispose to ideal retention of composite resin. A succession of studies has identified the fragility of laser-irradiated enamel, relative to the stability of the post-restoration margins. Studies have proposed a combined approach of laser-irradiation and acid-etch techniques to overcome such potential problems. Irrespective, there may well remain the need to remove grossly overhanging and unsupported enamel with a rotary bur, in order to either expedite cavity preparation or provide a stable post-restoration margin. Such consideration places patient care above the ideology of “pure” laser dentistry.

Furthermore, mention should be made as to the suitability of current lasers in the provision of full-veneer crowns. With regard to the preparation of single-surface veneers, using either direct or indirect materials, there is acceptance of the benefits that current lasers may bring. Conversely, the use of lasers alone to the preparation of single-surface veneers, using either direct or indirect materials, there is acceptance of the benefits that current lasers may bring. Conversely, the use of lasers alone in the preparation of full-coverage indirect restorations is to be deprecated, due to the time required, the very large total energy input that would be required, and the possible irreversible damage to the pulp.

f) Speed of “cutting” as related to laser parameters

The rate (speed) of ablation of dental hard tissue is a consequence of the amount of incident laser energy delivered to the tissue as well as the effects of wavelength, pulse duration, pulse shape, repetition rate, power density, the thermal relaxation time of the tissue, and emission mode. In addition, it is necessary to avoid the possibility of heat buildup in the tissue (and undesirable heat conduction to the pulp) and also to prevent the accumulation of products of ablation, or char.

Mid-infrared ablation of dental hard tissue has given rise to the concept of the existence of two wave fronts of interaction – an ablation front and a thermal front. It is important that the ablation front should always precede the thermal front, if the possibility of damaging heat rise is to be avoided. Studies, therefore, have looked at the effects of too much incident power and the buildup of ablation products, or their removal by means of a coaxial water spray. It is also evident that the desire to match cutting speeds with those of rotary instruments has led to power delivery far in excess of that postulated by Keller and Hibst, relative to the ablation threshold of enamel. Coexistent with such power levels is the need to remove grossly overhanging and unsupported enamel with a rotary bur, in order to either expedite cavity preparation or provide a stable post-restoration margin. Such consideration places patient care above the ideology of “pure” laser dentistry.

In addition to the above, other factors such as fluoridation of the tissue, incident angle of the delivery tip relative to the tooth, and presence of ablation products will all affect the speed of ablation. Several reports have shown the effectiveness of addressing the delivery tip parallel to the axis of the enamel prisms in order to access the inter-prismatic, higher-water content structure.

Generally, the rate of tissue ablation with a laser, when compared to a high-speed rotary instrument, has given rise to claims of 80% slower in enamel, and comparable speed in dentin, when matched against a slow-speed drill. In addition, the use of sharp curettes in removing gross caries can allow lasers to be used within an acceptable time frame.

The debate over what constitutes a “recommended” power value for laser-assisted ablation of dental hard tissue is compromised by many conflicting factors, not least the danger of the anecdote. The ablation threshold of human enamel has been reported to be in the range of 12.20 J/cm², and for dentin, 8.14 J/cm² for the Er:YAG and Er,Cr:YSGG laser wavelengths, respectively. For an average laser delivery spot size, with the use of a free-running pulsed emission mode, this may equate to approximately 150-250 mJ/pulse. What is of paramount concern is the delivery of sufficient laser energy, within a minimal time, to achieve clinically acceptable ablation rates without causing adjacent tissue damage. Apart from those studies that have determined minimal levels of power necessary, there does seem to be a plethora of anecdotal reports. It would seem prudent for the clinician to follow the manufacturer’s guidelines in establishing laser treatment protocols for a given laser, bearing in mind the differing operating parameters of air, water, spot size, and any power losses that may occur within differing delivery systems.

g) Bone ablation

Clinical procedures that may involve the cutting or ablation of bone include surgical extraction, periodontal surgery and infrabony pockets, clinical crown lengthening, and apicoectomy. The development of Er:YAG and Er,Cr:YSGG wavelengths has enabled bone ablation to be carried out with minimal adjacent damage, and the use of erbium lasers in dentoalveolar surgery represents a less traumatic experience for the patient when compared to the intense vibration of the slow-speed surgical bur.

As with tooth tissue ablation, tissue cutting is a thermally induced explosive process and it is essential to maintain a coaxial water spray to prevent heat damage which would delay healing. Bone composition is very similar to dentin from the perspective of laser-tissue interactions. The mineral is similar, the protein content is similar, as is the water content.

In maxillary alveolar bone, the speed of laser cutting is comparable with that of a bur and slightly slower in the mandible, reflecting the greater mineral density of cortical bone. It is considered important that excessive power parameters be avoided to reduce the “stall-out” effect of debris and minimize blood spatter. Laser parameters of 350-500 mJ, 10-20 Hz (average power range 3.5-7.0 Watts) with maximal water spray appear to effect good ablation rates.
Studies into the healing of laser-ablated bone support the contention that the reduction in effects such as physical trauma, tissue heating, and bacterial contamination may lead to uncomplicated healing processes, when compared to conventional use of a surgical bur.

The microanalysis of the surface of bone that has been ablated using lasers shows little evidence of thermal damage, and any char layer appears to be restricted to a minimal zone of 20-30 µm in depth.

**FUTURE DEVELOPMENTS**

There are several exciting new possibilities for the use of lasers on hard tissues that are likely to become available to the practicing dentist in the near future. A couple of examples are presented here. In each area years of research have set the stage for the development of commercially viable lasers.

Selective ablation of calculus by wavelengths in the ultraviolet/blue region is one example. Ablation of carious enamel, dentin, and cementum, as well as bone may be more efficiently done with wavelengths not currently available commercially. The strongest absorption bands for the carbonated hydroxyapatite mineral of teeth and bone are in the 9.3 - 10.6-µm wavelength region, with 9.6 µm being the strongest. Pulsed carbon dioxide lasers have great potential for ablation and modification of mineral to increase caries resistance. Recent studies have shown that by matching the pulse duration to the thermal relaxation time of the tissue and optimizing the fluence per pulse, very efficient ablation of enamel, dentin, and carious tissue can be achieved with little peripheral damage.

Low microsecond pulse-duration lasers (e.g., 5-10 µs) of 9.3- or 9.6-µm wavelength have great potential. Furthermore, laboratory studies have shown that similar irradiation conditions, but at lower fluences, can beneficially alter the mineral of enamel to make it more resistant to acid and consequently to inhibit caries progression. Clinical studies will be needed to confirm the viability of this methodology in the mouth. It will be possible to produce lasers that can ablate dental hard tissues and bone, while at the same time inhibiting subsequent caries progression, and keeping peripheral damage to a minimum.

**SAFETY CONSIDERATIONS**

All laser-tissue interaction using surgical lasers carries general and specific safety concerns. With regard to the statutory instruments ANSI 136.1 (2007) and IEC 60825-1/A2:2001, suitable precautions to protect intraoral nontarget tissue and patients' and operator's eyes and skin should be employed.

**REFERENCES**


Laser Safety in Dentistry: A Position Paper

Laser Safety Committee, Academy of Laser Dentistry
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ABSTRACT
In oral health care, the number and range of laser-based technologies have expanded enormously over the past two decades. The scope of this paper is to alert the dental professional to the extent, application, and responsibilities associated with safety when using lasers designed for use in dentistry. By far, the majority of laser instruments are within the private (nonhospital) clinic setting. Laser use extends from those procedures of a diagnostic or nonsurgical (biostimulatory or photochemical) nature, to more powerful devices that are used in surgical procedures. Low-powered lasers may deliver energy of a few millijoules, whereas surgical lasers may have pulsed emission modes capable of peak power delivery in excess of 1,000 Watts. Laser radiation can be dangerous, because it is concentrated and powerful.


In addition, interpretation of these standards complements the core of knowledge outlined in the Curriculum Guidelines and Standards for Dental Laser Education that is required by the certification examinations of the Academy of Laser Dentistry.
INTRODUCTION

There is a basic requirement of the clinician and associated staff to ensure that laser use is carried out within a safe environment. Key to this requirement is an understanding of the device being used, laser physics, and adherence to federal, national, and international statutes. These regulations may apply either specifically to laser use or within broader health and safety legislation.

Laser safety considerations are proportional to established and recognized risk. The potential maximum power output will define a basic approach, but specific to more powerful lasers are measures taken to add additional risks of laser damage to nontarget oral tissue, skin, and eyes. Such damage may be the result of direct exposure to the laser beam or through the combustion of chemicals, gases, and materials used in dentistry. The protection of those personnel involved in laser treatment – patient and staff – is a prime consideration, but it is also important to consider those measures required to safeguard against any risk events.

History can provide us with records of injuries occurring to people due to lasers. The U.S. military, FDA, U.S. Department of Energy, U.K. Medicines and Healthcare Regulatory Agency, and Rockwell Laser Industries, to name a few, maintain logs of laser-related incidents through their device-reporting mechanisms. The following anecdotes provide us with some insight into the extent of injuries and consequences of such accidents. Incidents include lasers that fail to stop after the foot pedal has been released; burns to lips, tongue, and cheeks; firemen entering a surgery in response to a smoke alarm, unaware that a laser was in operation. Other incidents include injuries due to the laser beam being reflected off a droplet. Incidents specific to eyes include injury because the manufacturer sent the doctor the wrong goggles specific to the laser wavelength being used and the doctor did not double-check the eyewear designation. Another recorded incident involved a university assistant suing for $39 million after she sustained a laser eye injury in a laboratory setting. A key factor in her case was that the professors were reported as not adhering to wearing the safety goggles, giving subordinates the impression that the protective eyewear was not necessary. The assistant settled for $1 million. These are just some examples of the nature of laser injuries that can occur, the majority of which can be traced back to poor adherence to established safety protocols.

LASER CLASSIFICATIONS

All lasers used in dentistry are categorized with regard to the potential for damage, extending from Class I lasers, which may pose no implicit risk, to Class IV lasers for which all safety measures are applicable. Regardless of the class of laser being used, it is advised that one should never look directly into a laser beam, even if it is considered to be “eye-safe.” The classification ascends from Class I through Class IV, with Class I being considered eye-safe and Class IV being the most dangerous. However, with the increased use of magnification devices – loupes and microscopes – there is a potential for laser beams to be magnified and/or focused. Consequently, Class IM and Class IIM contain refinements.

Class IIIR and IIIB lasers are generally low-level instruments, whose wavelengths are in the red part of the electromagnetic spectrum and whose energy range lies between 1 and 500 milliWatts. They require safety personnel to monitor the Nominal Hazard Zone (NHZ), eye protection, and training.

Class IIIR was recognized to include those continuous-wave lasers that may emit up to five times the power of Class I and II lasers. These lasers pose significant risk of eye damage, and the eyewear must be rated at minimum Optical Density (OD) in the United States (U.S.) or European L6A standard. It is the laser manufacturer’s responsibility to provide the numerical value of the OD, in the operator’s manual, specific to the laser being used.

Table 1 provides an outline of the basic classes of lasers, the delineated emission parameters, examples of uses of each class within dentistry, risks posed to unprotected tissue, and safety measures. For clarification, it should be noted that the blink response is one of the responses that is encompassed within the aversion response. The aversion response consists of blinking and turning one’s head away from the beam path.

Class IV lasers, which are surgical devices, require safety personnel to monitor the NHZ, eye protection, and training. These lasers pose significant risk of damage to eyes, any nontarget tissue, and can produce smoke hazards. Plumes, in the context of this paper, is defined as the gaseous by-products and debris from laser-tissue interaction. It can have a smoky appearance or be completely invisible to the naked eye. With Class IV lasers, eyewear must be rated at a minimum OD 5. It is the laser manufacturer’s responsibility to ensure that the device class is clearly marked on the laser machine and in certain countries it is required to post such information at all access points to the area in which the laser is being operated. It is the responsibility of the Laser Safety Officer (LSO) to ensure that the safety measures appropriate to each laser class are applied and made known to all staff. It is not the manufacturer’s responsibility to provide the dentist with training in this aspect. However, in the United States, federal regulations require manufacturers to provide certain safety information related to their laser in the laser operator’s manual. The computation, in feet or meters, of the NHZ of the laser is a calculation that is generally beyond the scope of the dentist or LSO. Monitoring and calculating the NHZ are two different issues. It is the manufacturers’ responsibility to calculate what the NHZ distance is and have that information posted in the operator’s manual. It is the LSO’s responsibility to read the manual, ensure that the NHZ around the laser in the dental practice is identified, and personnel adhere to the safety measures.
HAZARDS

Laser devices, regardless of class, should be handled with care. With regard to those classes – IIIB and IV – that pose predictable or instantaneous risk, there are dangers associated not only with the laser beam itself, but also arising from the device (electrical, cables, air and/or water supplies) and chemicals either associated with the laser or the ablation of target tissue. Laser hazards may be listed as follows:

- Optical
- Nontarget oral tissue
- Skin
- Chemical
- Fire
- Other collective hazards.

The concept of laser beam collimation may be considered theoretical, as in practice most laser beams exiting a delivery system will undergo some divergence with distance. Based on the power output, amount of divergence, and beam diameter and configuration, a Nominal Ocular Hazard Distance (NOHD) can be assessed.

The possible risk to human tissue is assessed with regard to the Maximum Permissible Exposure (MPE). This is a value of exposure limit above which tissue damage may occur. The MPE value can be applied relative to laser wavelength, power output, beam diameter, possible focusing of the beam, and target and nontarget tissue or structures.

Within a certain space around a Class IV laser, the level of laser radiation that a person is being exposed to is above the MPE. Within this area, called the Nominal Hazard Zone (NHZ), protective measures must be taken. Many factors determine how large the NHZ area is. For example, an 810-nm diode laser with a maximum power output of 3 Watts will have a different NHZ than another 810-nm diode laser with 5 Watts of maximum output power.

Therefore, it is not correct to say that the NHZ for an 810-nm diode laser is, for example, 8 feet for all diode lasers. The same can also be said for other laser wavelengths; it is incorrect to say that the NHZ for all Er:YAG lasers is 2 feet. The manufacturer has the responsibility of informing the dentist and LSO of the dental laser’s specific NHZ by publishing this information in the operator’s manual.

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Table 1: Laser Classification, Power Output, and Risk Analysis

<table>
<thead>
<tr>
<th>Laser Class</th>
<th>Maximum Output</th>
<th>Use in Dentistry</th>
<th>Possible Hazard</th>
<th>Safety Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>40 µWatts (blue)</td>
<td>Laser caries detection scanner</td>
<td>No implicit risk possible risk with magnified beam (Class IM)</td>
<td>Blink response</td>
</tr>
<tr>
<td>Class IM</td>
<td>400 µWatts (red)</td>
<td>Aiming beams</td>
<td>Possible risk with direct viewing significant risk with magnified beam (Class IIM)</td>
<td>Sight aversion response Laser safety labels</td>
</tr>
<tr>
<td>Class II</td>
<td>1.0 milliWatt</td>
<td>Aiming beams laser caries detection</td>
<td>Eye damage eye damage maximum output may pose slight fire and skin risk</td>
<td>Safety eyewear Safety personnel Training for Class IIIR and IIIB lasers</td>
</tr>
<tr>
<td>Class IIR</td>
<td>Visible 5.0 milliWatts invisible 2.0 milliWatts</td>
<td>Aiming beams low-level lasers photodynamic anti-microbial chemotherapy devices mucosal scanning chemofluorescent devices</td>
<td>Eye damage eye damage maximum output may pose slight fire and skin risk</td>
<td>Safety eyewear Safety personnel Training for Class IIIR and IIIB lasers</td>
</tr>
<tr>
<td>Class IIIB</td>
<td>0.5 Watt</td>
<td>Low-level lasers photodynamic anti-microbial chemotherapy devices mucosal scanning chemofluorescent devices</td>
<td>Eye and skin damage nontarget tissue damage fire hazard plume hazard</td>
<td>Safety eyewear Safety personnel Training and local rules Possible registration to comply with national regulations</td>
</tr>
<tr>
<td>Class IV</td>
<td>No upper limit</td>
<td>All surgical lasers</td>
<td>Eye and skin damage nontarget tissue damage fire hazard plume hazard</td>
<td>Safety eyewear Safety personnel Training and local rules Possible registration to comply with national regulations</td>
</tr>
</tbody>
</table>
EYE HAZARDS

The eye is composed of pigmented and nonpigmented tissue that will absorb incident laser radiation relative to the wavelength being used. Damage from a laser beam may be due to direct exposure of the unprotected eye or diffuse reflection and is ever-present in those situations where wavelength-specific protective eyewear is not worn. Damage also depends on the type of laser being used, since a free-running pulsed laser will cause more damage than a continuous laser of equal power. This is because the output power of a free-running pulsed laser can achieve high peak power surges in a short pulse followed by long off-time durations. Its peak power is considerably greater than its average output power. For a continuous-wave laser, the output power and the peak power are the same, regardless of whether it is used in a continuous or gated mode. In addition, the ability of the eye's lens to focus incident light may significantly increase the hazard posed by those wavelengths that may enter the eye. In current clinical dental use, shorter laser wavelengths (visible to near-infrared, 400-1400 nm), being relatively nonabsorbed by water, may result in retinal burns in the area of the optic disc. Some visible wavelengths may selectively damage green or red cones in the retina, producing color blindness. In addition, the 700-1400-nm wavelengths can cause lens damage. The second group of wavelengths, the longer wavelengths (mid- to far-infrared, 1,400-10,600 nm) have high absorption in water, and corneal, aqueous, and lens damage is associated with these wavelengths.

Consequently, it is mandatory that all personnel (clinician, assistant, and patient) within the controlled area of Class IIIB, IIIR, and IV laser use should employ suitable eye protection during laser procedures. Measures must be taken to protect the eyes of the staff and patients when the MPE is exceeded, i.e., when the dental laser is on and people are within the NHZ. Eyewear should be constructed of wavelength-specific material to attenuate the laser energy or to contain the energy within MPE values. Standards that specify the nature and suitability of laser protective eyewear are contained in ANSI (ANSI Z136.1 – 2007) for North American users, EN 207/208 for European users, and IEC (IEC 60825) for all other regions. The manufacturer’s mark must be imprinted on the eyewear. The wavelength or wavelengths that the protective eyewear is specific for must be stamped on the glass or side shields. If the eyewear is marked as 810 nm – 2890 nm, then this means that the eyes exposed to all wavelengths between these two outer limits are protected. If one line states 810 nm and then underneath 2890 nm is stamped, it means that eyes are protected only against these two wavelengths and no protection is provided for wavelengths in between.

In addition, the OD is required to be stamped clearly onto the glass or polycarbonate side frames for North America while references to the OD, CE mark, operation mode (DIR), protective grade (L6A), and Direct Impact Number (DIN) are displayed in Europe.

Please refer to the glossary provided for additional information. Practitioners using loupes must wear the appropriate protective insert or shield. Glasses and goggles must cover the entire periorbital region, be free of any surface scratches or damage, and be fitted with suitable side panels to prevent diffuse laser beam entry. Practitioners using a microscope must fit the appropriate filters and maintain close eye contact with the oculars.

The protocol for use is “patient first on and last off.” This means that as soon as the patient is seated in the dental chair, he or she is to put on the appropriate laser eyewear, which is not to be taken off until the patient is leaving the dental operatory at the end of the procedure. The dental operatory personnel must don the eyewear prior to the laser being turned on and not take them off until the laser is switched off or put into standby mode.

Care must be taken when cleaning laser eyewear and side shields so that their protective coating is not destroyed. The eyewear should be washed with antibacterial soap and dried with a soft cotton cloth in between procedures and patients. Disinfecting solutions generally applied to dental surfaces are too caustic and should be avoided. The eyewear must be inspected frequently to determine whether there is any breakdown (lifting / cracking / flaking) of the protective material that would render the eyewear to be useless.
NONTARGET ORAL TISSUE HAZARDS

The constraints of the oral cavity pose specific risks in access and accidental damage to adjacent or nontarget tissue. The close approximation of multiple chromophores (molecular compounds that absorb light or laser energy such as hemoglobin, water, hydroxyapatite, and melanin in oral tissue) demands care during the use of any surgical laser wavelength to avoid unintentional vaporization of other tissues. During any surgical ablation procedure using laser energy, attention is required to focus the beam onto the target tissue and avoid accidentally damaging adjacent tissues. Anodized, dull, nonreflective, or matte-finished instruments should be employed. Coated (i.e., ebonized) instruments should be inspected regularly to ensure integrity of the coating. Glass mirrors should not be used because they absorb heat from the laser energy and may shatter. Stainless steel or rhodium mirrors may be used safely, providing measures are taken to minimize possible unwanted reflection.

Parallel monitoring of the adjacent tissues by all dental staff present at the time of treatment is to be ensured. Assistants need to be trained in recognizing adverse or unexpected tissue change as they play a role in monitoring the dental situation, especially if the dentist is using a microscope or other accessory that might reduce the clinician’s wider field of vision.

SKIN HAZARDS

Any potential for damage to the skin through inadvertent exposure to Class III B and IV lasers will be relative to the ablation threshold of the skin structure and the incident laser energy. Subablative power levels will pose little threat, other than reversible tissue warming. Visible and near-infrared wavelengths (400-1400 nm) have the potential to pass through the epidermis into the superficial and deeper structures respectively. Mid- to far-infrared wavelengths (1400-10,600 nm) will interact with surface structures. The governing factor in structural damage is the particular laser wavelength’s absorptive potential relative to the tissue elements (chromophores) such as pigment (shorter wavelengths) and water (longer wavelengths), together with the power density value of the laser beam, duration of laser exposure, and spot size. It is important that all those involved in the use of Class III B and IV lasers are adequately protected against inadvertent skin exposure.

CHEMICAL HAZARDS

Laser plume poses a significant hazard and occurs as a result of the development of aerosol by-products due to laser-tissue interaction. These products can contain particulate organic and inorganic matter including viruses, toxic gases, and chemicals.
This is not unique to lasers, as it has been known that surgical instruments, such as electrosurgical equipment and dental handpieces, create surgical debris. American National Standard for the Safe Use of Lasers in Health Care Facilities states that the hazard area for laser-generated airborne contaminants (LGACs) may be greater than the laser’s identified NHZ.23 Examples of the products contained in LGAC include human papilloma virus, human immunodeficiency virus (suspected), carbon monoxide, hydrogen cyanide, formaldehyde, benzene, acrolein, bacterial spores, and cancer cells.24

Of particular importance in restorative dental procedures, other hazardous products may be present in the plume.25 During removal of composite resin with an erbium laser, along with the ejected whole resin particles, small amounts of free methacrylate monomer can be produced. Furthermore, although not an indication for use, directing the erbium laser’s energy onto amalgam can produce mercury vapor, according to an in vitro study.26 This same precaution also applies to other lasers.

The hazard presented by the LGACs may include eye irritation, nausea, breathing difficulties, vomiting, and chest tightness together with the possibility of transfer of infective bacteria and viruses.24, 27-29 To combat such risk, regular surgical protective clothing must be employed and specific fine-mesh face masks capable of filtering 0.1-micron particles must be worn.30 Use of high-speed evacuation must also be used. It has been determined that for carbon dioxide laser surgery, the evacuation tube should be held as close as 1 cm from the target site; at 2 cm, the evacuation ratio had diminished by 50%.31

**FIRE HAZARDS**

The high temperatures that are possible in the use of Class IV and certain Class IIIb lasers can themselves either cause ignition of material and gases or promote flash-point ignition. ANSI Z136.3 has allowed gaseous conscious sedation procedures, such as the use of a nose piece to deliver oxygen and nitrous oxide mixtures to be used during laser operation. However, a closed-circuit delivery system must be used and a scavenging system must be connected to the high-volume evacuation to minimize gas leakage.

Within the NHZ, use of aerosols, alcohol-soaked gauze, and alcohol-based anesthetics is to be avoided.32 Consequently, it is important to request that the patient remove any lip products that may contain an oil-based substance that is considered flammable, such as petroleum jelly. Additionally, tissue cleansing or preparation agents that contain alcohol or other flammable chemicals carry specific risk of burning during laser use. If the patient carries an oxygen tank, then the laser should not be utilized for the dental procedure, unless the patient will remain comfortable with the oxygen turned off and the nose cannula removed during the laser portion of the procedure.

With general anesthetic procedures, there are three aspects to be considered:

1. Ignition sources (of which lasers are an example)
2. Fuel sources (gauze, drapes, preparation fluids, alcohol, and anesthetic gases)
3. Oxygen-enriched atmosphere (more than 21% oxygen).33

The laser energies used in tissue ablation may surpass the flash point of some anesthetic aromatic hydrocarbons used in general anesthesia, and the presence of oxygen and nitrous oxide will support any combustion. Many materials that are not normally flammable may burn in an oxygen-enriched atmosphere.34 Endotracheal tubes need particular consideration to prevent the laser beam from burning a hole in the tube and combusting with the gases. Consequently, the tubes should be resistant to the laser beam and have suitable coating, a wavelength-specific reflective coating if possible, to prevent the possibility of combustion of the material and subsequent airway burns.35 Care should also be taken to prevent the build-up of blood onto endotracheal tubing, as this may lead to an increased fire hazard.36

**OTHER HAZARDS**

Additional hazards associated with laser use include service and mechanical hazards. Potential service hazards include electrical, water, and air supply lines and cables, as well as connectors and filters. The laser should be serviced regularly according to the manufacturer’s recommendations and only by qualified personnel.37 The practitioner should inspect the supply lines and cables, clean and maintain the external portions of the laser, and change necessary filters or other user-serviceable items. In addition, many surgical lasers use a coaxial air or water supply which may be under pressure. No attempt should be made to access internal parts of the machine during use. Capacitors can retain an energy charge, even when the laser is no longer connected to the electrical supply outlet.

Mechanical hazards include moving parts (e.g., articulating arms). Laser machines employ multilevel safety features (fusible plugs, interlocks, pressure relief valves, and warning lights) to inactivate the machine in the event of a component failure. Additional hazards may exist such as heavy articulated-arm delivery systems or the risk of needle-stick injury with fine quartz fiber-optic tips. Care must be taken around the cables and wires associated with the laser, as tripping over and wrenching these cables and fibers can be dangerous. Some machines are portable and, when moved, should be reassembled completely, ensuring stability.

**INFECTION CONTROL**

In the United States, the Centers for Disease Control and Prevention (CDC) have established infection control guidelines in a 2003 Morbidity and Mortality Weekly Report.38 Lasers in dental practices are to be considered as another dental instrument. Dental practitioners and their team must follow standard precautions. Standard precautions include use of personal protective equipment (PPE) (e.g., gloves, masks, protective eyewear or face shield, and gowns) intended to prevent skin and mucous membrane exposures.39

Specific to lasers, any reusable fibers and tips must be heat-sterilized along with their handpieces, and not wiped with a high-level disinfectant. Any debris on the end of the tip must be removed and/or cleaved off the end of the fiber to ensure effective sterilization. The operator’s manual should contain recommendations about the sterilization process. For example, it is suggested that one does not sterilize the high-speed, lubricated dental handpieces at the same time as the laser fibers so as to
eliminate the possibility of oil from the handpieces leaking through the bag onto the fibers.\(^3\) Disposable tips must be put into sharps containers, along with cleaved pieces of the fiber. Plastic or metal cannulas fitted to the handpiece and used to position the fiber optic should be disposed of in regular trash. Removable or wipeable barriers are recommended to be placed over operational controls on the laser. Care should be shown to the possibility of contamination of all laser hardware; protective sleeves and barriers (e.g., syringe covers, sensor protector sheaths, transparent universal sticky barrier covers) should be utilized where possible. The laser and surfaces within the dental environment should be wiped with high-level disinfectant following the procedure. Any cleaver used on a contaminated fiber should also be heat-sterilized.

**ENGINEERING CONTROLS**

Through successive internationally agreed regulations, laser devices (specifically but not exclusively Class IIIb and IV) have built-in safety features. These regulations are designed to prevent unauthorized use and protect those involved in laser applications. Engineering controls are set in place by the manufacturer and are always preferred, where possible, over administrative controls. Safety features include the following:

- Locked unit panels to prevent unauthorized access to internal machinery
- Covered foot switch, to prevent accidental operation
- Delayed response from the foot switch (to prevent accidental operation, e.g., unintentional stepping on the foot switch)
- Casters, if present, must be lockable
- Remote interlocks. These constitute a connection between a closed door and the laser. Should the door be opened during laser operation, the remote interlock will shut down the laser
- Key or password protection to prevent the laser from being operated when authorized personnel are not present
- Emission port shutters to prevent laser emission until the correct delivery system is attached
- Emergency stop switch or button – visible and easily located so that the laser can be shut down in an instant without the operator having to go through a lengthy process
- Control panel and display to ensure correct emission parameters are set
- Laser software diagnostics and error messages. Internal systems within the laser that shut down operations when any component that is not functioning correctly is detected
- Specific laser standby and laser-emission modes
- Time-lapsed default to standby mode so that if a laser left in “ready” mode is not used within a certain time frame, the laser will revert to “standby” mode. Stepping on the foot switch in “standby” mode will not initiate the laser to operate
- Audible sound that is distinctive to the laser when it is in operation
- Visible signs on the laser, such as lights which warn whether the laser is in standby mode or is being used.

**ADMINISTRATIVE CONTROLS**

In addition to the manufacturer’s engineering controls, additional safety measures are also required in order to minimize the risk of an adverse event. In this context, an adverse event is defined a serious and undesirable experience or outcome (including death, life-threatening injury, disability, hospitalization, and intervention to prevent those outcomes) that results from a dental laser marketed in accordance with the standards\(^3\) set forth by the regulations governing its use within that specific country or region. It is essential that all surgical lasers be used with responsibility and due regard to their potential safety risk. These administrative policies supplement the aforementioned mechanisms in order to facilitate a safe laser environment and require the appointment of a Laser Safety Officer (LSO) to oversee their implementation. Policies include:

- Establishing written Standard Operating Procedures (SOPs) for the dental practice, as required by ANSI Z136.1 – 2007 and other national standards as they may apply
- The appointment of an LSO with specific responsibilities, as follows:
  - Serves as the “keeper of the key” to secure the key in a safe place when the laser is not in operation
  - Authorized to shut down laser operation. This authority is to be recognized and respected in the dental office regardless of the dental employee position held by the LSO
  - Keeps current with safety standards, such as OSHA, ANSI, IEC (or those of the appropriate country) through educational meetings and literature review, and updates this information with the dental practice
  - Supervises the education and training of the dental team
  - Assists with evaluation when a new laser is needed
  - Understands the operational characteristics of the laser(s) in the practice
  - Using the manufacturer’s NHZ, identifies this area within the dental office in accordance with the laser being used
  - Ensures correct warning signs are posted at every entryway into the operatory in which the laser is being used
  - Ensures that the laser signs are taken down after the procedure is completed, and not left up as “wallpaper”
  - Oversees the protective eyewear
  - Ensures the correct wavelength-specific eyewear is being worn within the NOHD
  - Ensures that the policy of patient eyewear “first-on and last-off” is adhered to. The policy for the dental team is “on before the laser is initiated and off after the laser application is finished,” and the laser is turned off or placed in standby mode
  - Ensures the laser is being operated by authorized personnel only
  - Understands the operational characteristics of the laser(s)
  - Knows the output limitations of the device
  - Determines the controlled area and the potential hazard and nonhazard zones
• Ensures laser maintenance, beam alignment, and calibration is familiar with the biological and other potential hazards of the laser
• Supervises medical surveillance and incident reporting
• Keeps a log of recorded laser use and parameters employed
• Ensures proper test-firing of the laser prior to admission of the patient into the operatory.

Laser test-firing is a safety measure designed to establish that the laser is working correctly and that there is patency of the delivery system. Test-firing should be carried out by the clinician or LSO prior to every procedure and before the patient is admitted to the controlled area. Protective eyewear is worn and all other safety measures met. The laser is directed toward a suitable absorbent material (e.g., water for longer wavelengths – 1400-11,000 nm, and dark-colored paper for short wavelengths – 400-1400 nm) and operated at the lowest power setting for the laser being used. Test-firing will demonstrate that the laser is functioning properly, all connections are securely in place, the delivery system is not damaged, and the laser beam is patent.

It is necessary to define a controlled area, within which all safety aspects pertaining to laser use are enforced. The LSO must follow the operator’s manual regarding the dimensions or limits of the controlled area. Dental clinics with multichair, open-plan environments need to address the physical dimensions and administrations of their controlled area in greater detail. Within the controlled area, all surfaces should be nonreflective, and measures should be taken to ensure that all supply cables for the laser along with its delicate delivery system are protected from inadvertent damage. A fire extinguisher should be sited for easy access.

The LSO is required to oversee the training of the entire dental team with regard to lasers, including the nonuser and administrative staff. It is imperative that nonuser team members in the dental office are educated at some level with regard to the laser equipment and have received training on aspects of laser safety as they apply to their dental office. Regulatory agencies recognize the essential nature of appropriate training in laser use and there is an implied necessity that clinicians should receive training as part of their duty of care and dental licensing.

The Standard Operating Procedure is a living, written document that outlines the existence and identity of laser devices within a given practice setting, personnel authorized to use the laser, and safety measures to address the hazards associated with the lasers in that particular dental practice. It contains all the local and national rules, including those set out in the aforementioned administrative controls. In the United States, ANSI Z136.1 – 2007 requires every dental practice with a laser to have such a document and many countries or regions have similar requirements.

The Academy of Laser Dentistry adopted the Curriculum Guidelines and Standards for Dental Laser Education which defines a core of knowledge appropriate to the safe use of lasers in dentistry. All those clinicians passing proficiency examinations with the Academy will satisfy an acceptable level of competence in laser safety, and nonclinicians may take proficiency examinations to be recognized as laser safety officers.

CONCLUSION

Laser use in dentistry is proven to be beneficial in treating a wide range of dental conditions as well as a therapeutic tool in tissue management. The dynamics of laser energy beams pose general risks to non-oral tissues and the immediate environment of such use must be deemed at risk from direct or scattered exposure. Safety measures have been devised to safeguard those personnel – staff and patients – who may be involved in dental treatment using lasers. Most safety measures are the product of official regulatory bodies such as ANSI, OSHA, FDA, and IEC, but additional measures may be the product of individual needs within particular dental offices and consequently recorded in local rules. The reader is encouraged to consult these regulatory bodies as they may apply on a national or regional basis, to ensure a correct and responsible compliance with all laser safety measures in the treatment of dental patients. The analysis of general and specific risk during laser use has been addressed through many statutory instruments and all clinical procedures should be measured against such standards, in order to offer the maximum protection for the patient, clinical staff, and those within the immediate environment.
GLOSSARY

ANSI: American National Standards Institute. A not-for-profit organization, founded in 1918, that oversees the administration and coordination of the United States private sector voluntary standardization system.


FDA: The U.S. Food and Drug Administration, a division of the U.S. Department of Health and Human Services. Founded through consolidation in 1930. The FDA enacts the provisions of the Federal Food, Drug and Cosmetic Act (rev. 2004). The FDA Center for Devices and Radiological Health (CDRH) is responsible for the premarket approval of all medical devices, as well as overseeing the manufacturing, performance and safety of these devices.

IEC: International Electrotechnical Commission. Founded in 1906, the IEC is a not-for-profit, nongovernmental international organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The headquarters are in Geneva, Switzerland.

NHZ: Nominal Hazard Zone. This is the space within which the Maximum Permissible Exposure (MPE) is being exceeded.

MPE: Maximum Permissible Exposure. This represents a value of exposure to laser energy above which a risk of target damage may occur. MPE values are applied to the unprotected eye and skin.

OD: Optical Density. The ability of the glass or polycarbonate shield to attenuate the laser beam. The opacity of the protective filter.

NOHOD: Nominal Ocular Hazard Distance. That distance from the emission port of the laser beyond which any exposure is within MPE values.

DIR: Ability of the glass or polycarbonate to attenuate the beam relative to the emission mode of the laser for which the eyewear is intended, using coding “D” (continuous mode), “P” (pulsed mode), “R” (Q-switched mode).

L6A: Defines the suitability for the eyewear within clinical, industrial, or research conditions.

DIN: Direct Impact Number. A standard for the glass or polycarbonate shield against beam damage, relative to a 10-sec exposure (continuous wave) or 100 pulses (free-running pulsed emission mode).


Critical Instrument: Any instrument that penetrates soft tissue, contacts bone, enters into or contacts the bloodstream, or other normally sterile tissue. Examples include surgical instruments, periodontal scalers, and scalpel blades.

Semi-critical Instrument: Any instrument that does not penetrate soft tissue, contact bone, bloodstream, or sterile tissue but can contact mucous membranes. Although dental handpieces are considered semi-critical, the U.S. Centers for Disease Control and Prevention state that they should be heat-sterilized and not high-level disinfected.

High-Level Disinfection: Process that inactivates vegetative bacteria, mycobacteria, fungi, and viruses but not high numbers of bacterial spores.

Sterilization: Use of a physical or chemical procedure to destroy all microorganisms including substantial numbers of resistant bacterial spores.

FURTHER READING

Further reading is recommended in order to ensure that the clinician is complying with national, federal, or regional regulations:


REFERENCES


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Laser Energy in Oral Soft Tissue Applications

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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:


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.3-6 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, wavelength, 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 millisecondes, and some manufacturers have coined different terms, such as ‘superpulse’ 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 defocused 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 (assuming 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 non-sporulating bacteria are inactivated at 50°C and above.\(^ {20}\) Coagulation occurs and proteins begin to denature at approximately 60°C.\(^ {21}\) 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. 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 which is in contrast to surgical diode lasers in the range of 0.5-3 mm. Underlying periosteum and hard tissue are particularly vulnerable to excessive heat in sites with overlying thin oral mucosa.

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

<table>
<thead>
<tr>
<th>Laser Device</th>
<th>Wavelength(s)</th>
<th>Emission mode(s)</th>
<th>Delivery system(s)</th>
<th>Primary soft tissue chromophore</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTP (Potassium Titanyl Phosphate)</td>
<td>532 nm</td>
<td>Continuous Wave (CW) / gated CW</td>
<td>Optic fiber</td>
<td>Melanin / hemoglobin</td>
</tr>
<tr>
<td>Diode</td>
<td>810, 940, 980, 1064 nm</td>
<td>CW / gated CW</td>
<td>Optic fiber</td>
<td>Melanin / hemoglobin</td>
</tr>
<tr>
<td>Neodymium (Nd):YAG</td>
<td>1064 nm</td>
<td>Free-running pulsed (FRP)</td>
<td>Optic fiber</td>
<td>Melanin / hemoglobin</td>
</tr>
<tr>
<td>Nd:YAP (YAlO₃ Perovskite)</td>
<td>1340 nm</td>
<td>FRP</td>
<td>Optic fiber</td>
<td>Melanin / hemoglobin</td>
</tr>
<tr>
<td>Erbium Chromium (Er,Cr):YSGG</td>
<td>2780 nm</td>
<td>FRP</td>
<td>Optic fiber</td>
<td>Water</td>
</tr>
<tr>
<td>Er:YAG</td>
<td>2940 nm</td>
<td>FRP</td>
<td>Waveguide, Optic fiber, Articulated arm</td>
<td>Water</td>
</tr>
<tr>
<td>CO₂</td>
<td>10,600 nm</td>
<td>CW / gated CW</td>
<td>Waveguide, Articulated arm</td>
<td>Water</td>
</tr>
</tbody>
</table>

**LASER USE OFFERS IMPROVED HEMOSTASIS COMPARED TO SCALPEL**

Improved hemostasis through enhanced coagulation can occur with laser use. (The erbium lasers [Er:YAG and Er,Cr:YSGG] are the exception to this general statement, since they provide limited hemostasis.) 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. The warming of tissue to more than 60°C will result in protein denaturation and coagulation, 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. Care should be exercised to avoid collateral thermal damage from excessive power and pulse repetition rate. The use of a surface coolant (water or saline) to aid in reducing surface temperatures has been described. Surface coolants can be used for temperature control of the surface and to minimize subsurface overheating, thus helping to optimize coagulation.
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. However, bacterial reduction has been found to occur at temperatures as low as 50°C. Furthermore, bacterial reduction has been demonstrated in both in vitro\textsuperscript{45-47} and in vivo\textsuperscript{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.\textsuperscript{53} Studies have shown that combining photo-initiators with specific wavelengths can enhance bactericidal properties.\textsuperscript{54-59} An in vivo study using an Nd:YAG laser has shown bacterial reduction to be effective for up to 3 months.\textsuperscript{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\textsuperscript{61-63} drug sensitivity,\textsuperscript{64} altered taste, and staining of the dentition.\textsuperscript{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 PHOTOBIOMODULATION

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.\textsuperscript{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 defocused mode. At energy levels (measured in mW) incapable of tissue removal, the stimulation of cellular metabolism known as low-level laser therapy (LLLT)\textsuperscript{66-68} or photobiomodulation (PBM) can be observed. The PBM effect has been shown to stimulate mitochondria, enhancing ATP production.\textsuperscript{69-72} This effect can lead to increased wound healing through increased fibroblast proliferation\textsuperscript{73} and collagen formation; thus, low-level biostimulation can promote gingival healing or reduction of gingival inflammation,\textsuperscript{74-75} increased release of growth factors,\textsuperscript{76} and pain relief.\textsuperscript{77} Healing times have been reported to be reduced.\textsuperscript{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.\textsuperscript{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.\textsuperscript{80} Reports of pain relief mechanisms appear to originate in stimulating oxidative phosphorylation in mitochondria and through modulating inflammatory responses.\textsuperscript{81}

Reports of positive patient responses to laser treatment\textsuperscript{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\textsubscript{2} laser and conventional methods; these patients indicated fewer complaints and/or expressed complete freedom from postsurgical afflictions with the laser procedures.\textsuperscript{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.\textsuperscript{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.\textsuperscript{88} The value of using animal studies to evaluate pain relief is that any placebo effect is nullified.\textsuperscript{91}

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\textsuperscript{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.\textsuperscript{90} Immediately postoperatively the laser can offer protection to the surgical site through a coagulum surface\textsuperscript{91} and, as mentioned previously, bacterial reduction.

Studies have shown additional benefits with laser use, such as minimal wound contraction\textsuperscript{91} and minimal scarring when compared to scalpel surgery.\textsuperscript{92} Researchers comparing CO\textsubscript{2} laser vs. scalpel and electrosurgery demonstrated less tissue damage with the laser compared to electrosurgery or conventional instruments\textsuperscript{93} and a higher production and release of growth factors in laser sites compared to scalpel sites.\textsuperscript{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 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. 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 predominately 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:YSGG, Er:YAG, and CO2). 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 shallow to deeper in the tissue, depending on the wavelength.

Anatomical Aspects

Oral epithelium varies in thickness from 0.3 to 6.7 mm. Gingival tissue is associated with underlying 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.
- 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. As healing occurs, regardless of device, physiologically a zone of reversible edema surrounds the surgical site.

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.

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.
REFERENCES


Statement on the Use of Lasers by Licensed Dental Professionals
(January 27, 2003, updated December 6, 2004)

PREFACE

Dentistry continues to evolve, as do all modern medical fields. With that evolution new technologies appear. Lasers have been in dentistry since their first introduction in 1990. Now that literally thousands of dentists around the world utilize laser technology, several questions have been raised about their appropriate use. This presents a challenge to those who regulate the practice of dentistry. These regulatory agencies, charged with protecting the safety of dental consumers, might be considering how to deal with a new technology that was not even conceived of when most dental practice acts were written.

The Academy of Laser Dentistry has been a leading organization in this rapidly developing field since its inception. Academy members are the leaders in laser research, training, education, testing, and manufacturing. Many of our members are involved with organized dentistry in their home countries. The Academy is a primary source of information, training, and certification for laser users and those with any interest in the use of lasers in dentistry.

The Academy does not endorse any restrictions placed on the use of lasers that do not equally apply to other devices and equipment, and therefore makes the following recommendations to the appropriate regulatory agencies or boards regarding laser use:

1. Use of Lasers by Dentists, Dental Hygienists, and Dental Assistants
   - When addressing the issue of which laser procedures should be allowed by providers of dental services, consider first the scope of practice as currently defined in the dental practice act. For example, if a board seeks to determine whether scaling and root planing, the curing of composites, or bleaching of teeth may be performed with a laser by a dental hygienist or dental assistant, one must determine if the dental practice act in your particular state/country allows them to perform those procedures at all.

   • If such procedures are outside of the scope of practice for dental hygienists and/or dental assistants, then they are not permitted by law, irrespective of any device – laser or not.

   • If such procedures are permitted under the existing dental practice act, one must determine if there is any mention of specific instruments to be used to perform those procedures. If not, the provider of dental services (dentist, hygienist, or dental assistant) should be able to choose any device suitable to perform that procedure, laser or otherwise – if that device is safe and effective, and if the use of that device is consistent with the provider's education, training, and experience.

2. Dental Laser Education and Training – The Academy of Laser Dentistry believes all providers of dental laser services (dentists, hygienists, dental assistants) should be properly trained in the use of lasers and recommends that laser practitioners complete, at minimum, a Standard Proficiency level of competency as described in the Curriculum Guidelines and Standards for Dental Laser Education. If a board chooses to implement a prerequisite for laser use, the Academy recommends that Standard Proficiency be used as the educational standard.

STATEMENT

- The Academy of Laser Dentistry (ALD) supports the use of lasers in dentistry when used by a properly trained and licensed dental professional where the procedure is safe, effective, consistent with his/her education and experience, and within the scope of his/her license.

- The ALD supports all international agencies in their duty of insuring the safety and effectiveness of any laser instrument. These agencies regulate the companies that produce and/or sell these instruments so that they adhere to sound manufacturing principles and truthful marketing claims.

- The ALD supports the laws of individual nations that regulate claims made by manufacturers for specific indications for use. The laser devices sold and/or manufactured in various countries may have different operator’s manuals describing techniques of safety and effectiveness on dental tissues.
Lasers in Dentistry and Oral Surgery: A Selected Bibliography and Reference List

EDITOR’S NOTE
Surgical medicine was among the potential uses for lasers cited by American physicist Theodore H. Maiman during the July 7, 1960 press conference in which he announced his development of the world’s first laser, initially demonstrated on May 16, 1960. Some 16 months after the press conference, some of the first journal articles appeared in the peer-reviewed literature that reported on the use of laser beams as biological and clinical tools and alerted users to their hazards. Thus began intensive research and subsequent publication of investigations of laser use in medicine over the years, now numbering in the tens of thousands of journal citations, thousands of books and theses, and untold quantities of meeting abstracts.

Regarding their 1961 account of laser hazards, from a historical standpoint it is instructive to note how Zaret and colleagues characterized the retinal lesions experimentally produced in a rabbit by a pulsed optical maser (laser): “Ophthalmoscopically, the retinal lesions resembled flash burns from an atomic fireball.”

That they should compare the ocular effects of laser light to flash burns “after exposure to atomic bomb explosions” not only underscores their recognition of the high energy density of laser beams, but also provides insight into the socio-political perspective of researchers at the time. This was an era of palpable and growing concerns over the threat of global thermonuclear war. Atmospheric testing of nuclear weapons was the norm. Zaret’s observations were published in 1961, the same year the Berlin Wall was erected and President Kennedy advised Americans to build fallout shelters as part of a campaign to reduce vulnerability to nuclear attack (see Life magazine, September 15, 1961). The Cuban Missile Crisis occurred one year later, and it was not until 1963 that the United States and the Soviet Union signed the Limited Test Ban Treaty, which prohibited atmospheric, underwater, and outer space nuclear tests; other countries continued atmospheric testing into the 1970s and 1980s.

Meanwhile, in spite of Cold War distractions, investigations into possible medical uses of lasers continued. Published accounts of the use of lasers in dentistry and oral surgery specifically began to appear in 1964. Ever since, researchers and clinicians have been able to avail themselves of an ever-expanding reservoir of laser-related resources that focuses on the oral cavity.

REFERENCES

INTRODUCTION
The resource material provided below concentrates mostly on texts, organizations, meeting proceedings, and periodicals that may be of interest to those pursuing surgical and therapeutic laser applications in dentistry and oral surgery. For practical reasons, relevant journal articles (thousands) and theses (hundreds) in these disciplines are intentionally omitted, as are many government publications and individual chapters within books.

While the list of reference material is extensive, there is no claim of comprehensiveness. Readers are encouraged to explore these citations and use them to expand their knowledge of the rich history and expanding reach of historical, experimental, and clinical applications of lasers in dentistry and oral surgery. Any omissions from this list are unintentional, and suggestions for updates and additions are always welcomed by the editors of the Journal of Laser Dentistry.
BIBLIOGRAPHY

DENTISTRY AND ORAL SURGERY TEXTS


47. Matsumoto K. *Shikayō tansan gasu rēzā no rinshō: gijutsu hen [Clinical application of CO\textsubscript{2} laser in dentistry].* Tokyo: Igaku Jōhōsha, 2002.


**PHOTOBIOLOGICAL AND LOW-LEVEL LASER THERAPY TEXTS**


- Lasers in medicine and dentistry with special chapters about anaesthesiology, dermatology, endoscopy, ophthalmology, photodynamic therapy, radiology & angiology, safety & laser nursing. [Vol. 2.]
- Lasers in medicine and dentistry with special chapters about veterinary. Update of basic science, operative technique and clinical application guidelines. [Vol. 3.]
- Lasers in medicine, science and praxis. Trilogy updates with emphasis on LLLT – Photobiostimulation – Photodynamic therapy and laser acupuncture. [Vol. 4.]


**ORGANIZATIONS, MEETING PROCEEDINGS, AND PERIODICALS**

Table 1 on the next page provides a partial listing of professional societies, conferences, and journals pertinent to the use of lasers in dentistry and oral surgery. Many of the named organizations have component societies or country representatives. Contact the individual organizations for information regarding conference schedules, abstracts, and meeting proceedings. All Web citations were accessed September 19, 2012.
<table>
<thead>
<tr>
<th>Table 1: Professional Laser Dentistry and Medicine Organizations</th>
<th>Key Activities</th>
<th>Publications and Journal Affiliations</th>
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<tbody>
<tr>
<td><strong>Academy of Laser Dentistry</strong>&lt;br&gt;www.laserdentistry.org&lt;br&gt;1993</td>
<td>• Organizes annual conferences&lt;br&gt;• Administers student scholarship program&lt;br&gt;• Endorses the Curriculum Guidelines and Standards for Dental Laser Education</td>
<td>• Journal of Laser Dentistry (<a href="http://www.laserdentistry.org">www.laserdentistry.org</a>)&lt;br&gt;• Lightwaves e-newsletter</td>
</tr>
<tr>
<td><strong>American Society for Laser Medicine and Surgery</strong>&lt;br&gt;www.aslms.org&lt;br&gt;1980</td>
<td>• Organizes annual conferences&lt;br&gt;• Administers research grants and student research grants&lt;br&gt;• Establishes practice guidelines and safety standards</td>
<td>• Lasers in Surgery and Medicine (<a href="http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1096-9101">http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1096-9101</a>)&lt;br&gt;• The Light Reader newsletter</td>
</tr>
<tr>
<td><strong>Deutsche Gesellschaft für Laserzahnheilkunde E.V.</strong>&lt;br&gt;www.dgl-online.de&lt;br&gt;1991</td>
<td>• Organizes annual conferences</td>
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</table>
| **International Society for Oral Laser Applications**<br>www.sola-int.org<br>ca. 2000 | • Organizes annual meetings | • Journal of Japanese Society for Laser Dentistry (www.jstage.jst.go.jp/browse/jjpnsoclaserdent/)
| **Laser Institute of America**<br>www.lia.org<br>1968 | • Organizes annual conferences<br>• Administers scholarships and educational outreach grants | • Journal of Biomedical Optics (http://spie.org/x1848.xml)<br>• Optical Engineering (http://spie.org/x867.xml)<br>• Numerous other journals<br>• SPIE Professional magazine |
| **North American Association for Laser Therapy**<br>www.naalt.org | • Organizes annual conferences | • Photomedicine and Laser Surgery (www.liebertpub.com/pho) |
| **SPIE**<br>www.spie.org<br>1955 | • Organizes annual technical forums and education programs. For meeting proceedings of Lasers in Dentistry and SPIE’s other conferences of interest to the dental profession, search the SPIE database (http://spie.org/x1848.xml)<br>• Administers scholarships and educational outreach grants | • Journal of Biomedical Optics (http://spie.org/x1848.xml)<br>• Optical Engineering (http://spie.org/x867.xml)<br>• Numerous other journals<br>• SPIE Professional magazine |
| **World Association for Laser Therapy**<br>www.walt.nu<br>1994 | • Organizes congresses every two years | • Photomedicine and Laser Surgery (www.liebertpub.com/pho)<br>• Laser Therapy (1988-2001)<br>• WALT Review e-newsletter |
| **World Federation for Laser Dentistry**<br>www.wflt-org.info<br>1988 | • Organizes conferences every two years | • Photomedicine and Laser Surgery (www.liebertpub.com/pho) |

Besides the periodicals cited above, another journal that frequently publishes articles on laser dentistry is *Lasers in Medical Science* (http://www.springer.com/medicine/journal/10103).
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