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Lasers in Dentistry:

From Fundamentals to Clinical Procedures

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An Overview of Lasers in Dentistry

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Fundamentals of Lasers

The word LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. A brief description of each of those five words will begin to explain the unique qualities of a laser instrument, and, in turn, will become the foundation for further elaboration of the uses of lasers in dentistry.

Light

Light is a form of electromagnetic energy that exists as a particle, and travels in waves, at a constant velocity. The basic unit of this radiant energy is called a photon; the wave of photons travels at the speed of light can be defined by two basic properties, as shown in figure 1. The first is amplitude, which is defined the vertical height of the wave oscillation from the zero axis to its peak. This correlates to the amount of energy in the wave: the larger the amplitude, the greater the amount of energy that can do useful work. A joule is a unit of energy; a useful quantity for dentistry is a milijoule, which is one-one thousandth of a joule. The second property of a wave is wavelength, which is the horizontal distance between any two corresponding points on the wave. This measurement is very important both in respect to how the laser light is delivered to the surgical site and to how it reacts with tissue. Wavelength is measured in meters; and dental lasers have wavelengths on the order of much smaller units using terminology of either nanometers (10^{-9} meters) or microns (10^{-6} meters.) As waves travel, they oscillate several times per second, termed frequency. Frequency is inversely proportional to wavelength: the shorter the wavelength, the higher the frequency and vice versa.

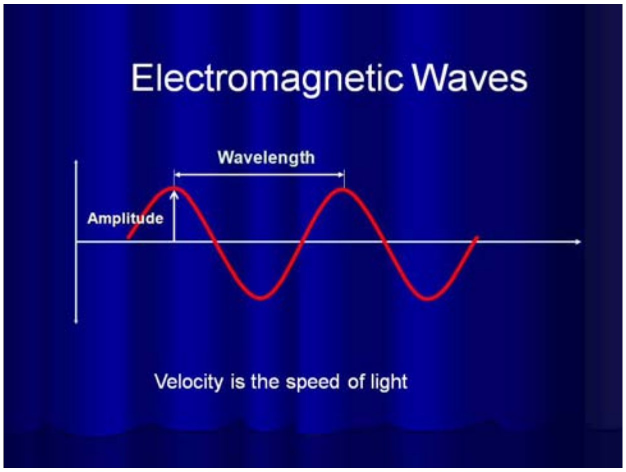


Figure 1. Properties of electromagnetic waves

Ordinary light produced by a table lamp, as an example, is usually a warm white glow. The white color seen by the human eye is really a sum of the many colors of the visible spectrum-- red, yellow, green, blue, and violet. The light is usually diffuse, not focused.

Laser light is distinguished from ordinary light by two properties. Laser light is *monochromatic* because it only generates a laser beam of a single color, which is sometimes invisible. In addition, each wave of laser light is *coherent*, or identical in physical size and shape, and produce a specific form of electromagnetic energy. The laser beams emitted from some instruments are collimated over a long distance, but beams produced from optical fibers usually diverge at the fiber tip. All can be precisely focussed, and this monochromatic, coherent beam of light energy that can do the work of accomplishing the treatment objective.

Using a household fixture as an example, a 100-watt lamp will produce a moderate amount of light for a room area, with some heat. On the other hand, two watts of laser light can be used for a precise excision of a fibroma, and providing adequate hemostasis on the surgical site, without disturbing the surrounding tissue.

Amplification by Stimulated Emission

Amplification is part of a process that occurs inside the laser. Identifying the components of a laser instrument is useful in understanding how light is produced. An optical cavity is at the center of the device. The core of the cavity is comprised of chemical elements, molecules, or compounds and is called the active medium. Lasers are generically named for the material of the active medium, which can be a container of gas, a crystal, or a solid-state semiconductor. Surrounding this core is an excitation source, either a flash lamp strobe device, an electrical circuit, or an electrical coil, which pumps the energy into the active medium. There are two mirrors one at each end of the optical cavity, placed parallel to each other; or in the case of a semiconductor, two polished surfaces at each end. These mirrors act as resonators and help to collimate and amplify the developing beam. A cooling system, focusing lenses, and other controls complete the mechanical components. Figure 2 shows a graphic of a solid state laser such as an Nd:YAG and figure 3 depicts a schematic of a semiconductor device.

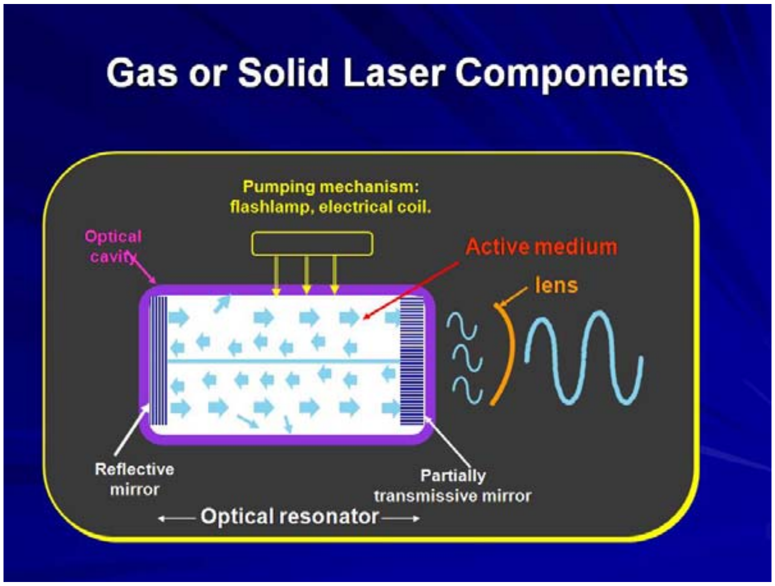


Figure 2 Schematic of a solid state laser, for example Nd:YAG

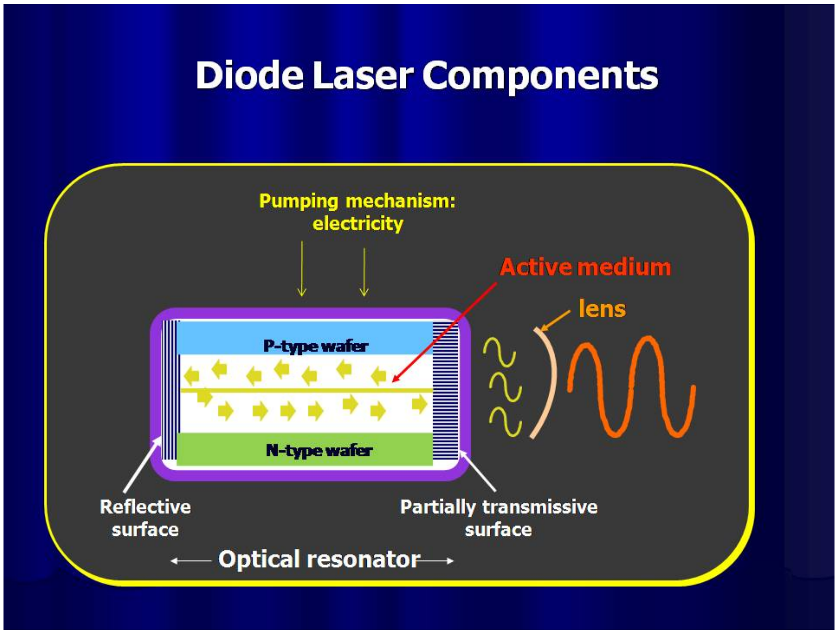


Figure 3 Schematic of a diode laser

Stimulated emission is the process taking place within the active medium due to the pumping mechanism, and was postulated by Albert Einstein in 1916. He based his work on some earlier proposals by physicists from Germany and Denmark, Max Planck and Neils Bohr respectively who theorized a model of the atom as well as the quantum theory of physics, which described a quantum as the smallest unit of energy emitted from an atom. Einstein used that concept and further theorized that an addition quantum of energy may be absorbed by the already energized atom and that would result in a release of two quanta. This energy is emitted, or radiated, as identical photons, travelling as a coherent wave. These photons are then in turn able to energize more atoms in a geometric, which further emit additional identical photons, resulting in an amplification of the light energy, thus producing a laser.

Radiation

The light waves produced by the laser are a specific form of radiation, or electromagnetic energy. The electromagnetic spectrum is the entire collection of wave energy ranging from gamma rays, whose wavelength are about 10^{-12}meters, to radio waves, whose wavelength can be thousands of meters. All available dental laser devices have emission wavelengths of approximately 0.5 microns, or 500 nanometers to 10.6 microns or 10,600 nanometers. That places them in either the visible or the invisible portion non-ionizing portion of the electromagnetic spectrum, as shown in figure 4. It is important to note that the dividing line between the ionizing, cellular DNA mutagenic, portion of the spectrum and the non-ionizing portion is on the junction of ultraviolet and visible violet light. Thus all dental lasers emit either a visible light wavelength or an invisible infrared light wavelength in the portion of that non-ionizing spectrum called thermal radiation.

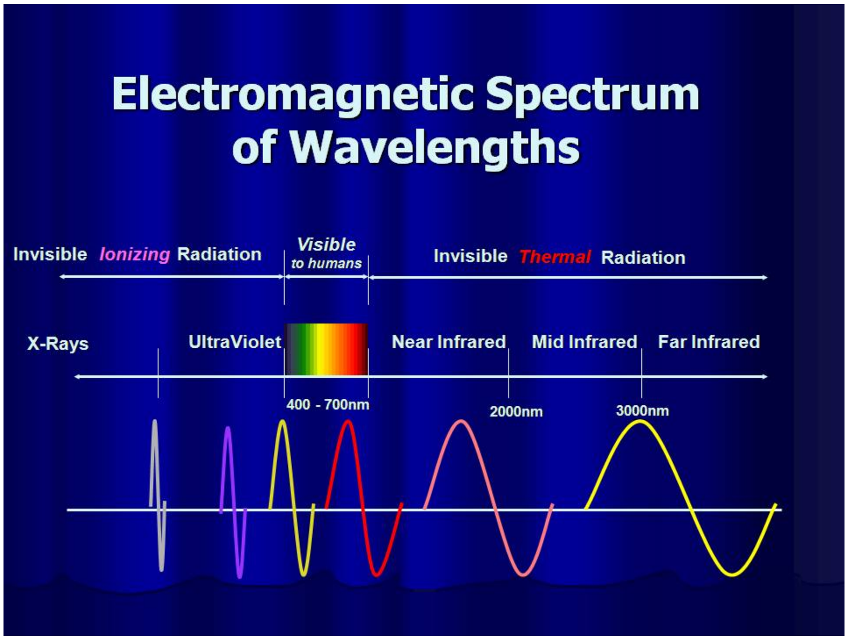
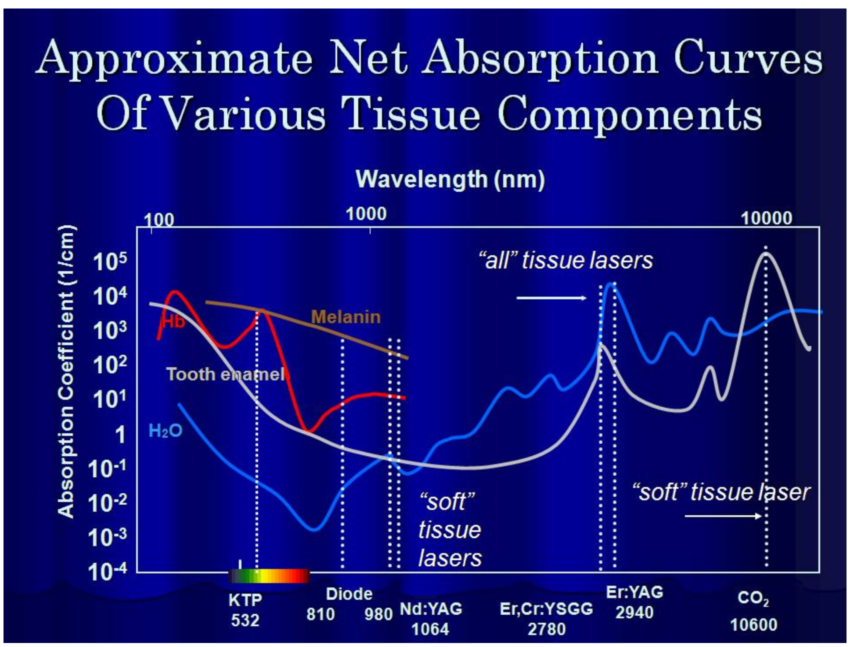


Figure 4. A portion of the Electromagnetic Spectrum showing the division of the ionizing, visible and non-ionizing portions.



The currently used dental lasers are depicted on the Electromagnetic spectrum, figure 5.

There are four instruments that emit visible light:

- Argon laser: Blue wavelength of 488 nm
- Argon laser: Blue-green wavelength of 514 nm
- Neodymium-doped yttrium aluminum garnet (Nd:YAG) and potassium

titanyl phosphate (KTP) lasers: Green wavelength of 532 nm
• Low-level lasers: Red nonsurgical wavelengths of 635 nm (for therapy) and 655 nm (for caries detection)

(It should be noted that Argon lasers are no longer manufactured as dental surgical instruments, although they are still used for medical procedures.)

Other dental lasers emit invisible laser light in the near, middle, and far infrared portion of the electromagnetic spectrum. These include low-level, nonsurgical devices between approximately 800 and 900 nm, as well as surgical instruments:

- Diode laser-- wavelengths between 800 and 830 nm and a semiconductor active medium of aluminum, gallium, and arsenide
- Diode laser--904 nm, with an active medium of gallium and arsenide
- Diode laser-- 940 and 980 nm and a similar active medium of indium, gallium, and arsenide
- Neodymium doped yttrium aluminum garnet (Nd:YAG) laser-- 1,064 nm
- Erbium- chromium–doped yttrium scandium gallium garnet (Er,Cr:YSGG) laser--2,780 nm.
- Erbium doped yttrium aluminum garnet (Er:YAG) laser—2940nm
- Carbon Dioxide (CO_2) laser—10600nm.

Laser Delivery Systems, Emission Modes

Laser energy should be delivered to the surgical site by various means that should be ergonomic and precise. Shorter wavelength instruments, such as KTP, diode, and Nd:YAG lasers, have small, flexible fiber-optic systems with bare glass fibers that deliver the laser energy to the target tissue. Erbium and CO2 devices are constructed with more rigid glass fibers, semi-flexible hollow waveguides, or articulated arms. Some of these systems employ small quartz or sapphire tips that attach to the laser device for contact with target tissue, while others do not directly contact the tissue. In addition, the Erbium lasers employ a water spray for cooling hard tissues.

All conventional dental instrumentation, either hand or rotary, must physically touch the tissue being treated, giving the operator instant feedback. As mentioned, dental lasers can be used either in contact or out of contact. Clinically, a laser used in contact can provide easy access to otherwise difficult to reach areas of tissue. The fiber tip can easily be inserted into a periodontal pocket to remove small amounts of granulation tissue, for example. In non-contact, the beam is aimed at the target at some distance away from it. This modality is useful for following various tissue contours, but the loss of tactile sensation demands that the surgeon pays close attention to the tissue interaction with the laser energy. All the invisible dental lasers are equipped with a separate aiming beam, which can either be laser or conventional light. The aiming beam is delivered co-axially along the fiber or waveguide and shows the operator the exact spot where the laser energy will be focused.

The active beam is focused by lenses .With the hollow waveguide or articulated arm, there will be a precise spot at the focal point where the energy is the greatest, and that spot should be used for incisional and excisional surgery. For the optic fiber, the focal point is at or near the tip of the fiber, which again has the greatest energy. When the handpiece is moved away from the tissue and away from the focal point, the beam is defocused, and becomes more divergent. At a small divergent distance, the beam can cover a wider area, which would be useful in achieving hemostasis. At a greater distance away, the beam will loose its effectiveness because the energy will dissipate.

There are two basic modes of wavelength emission for dental lasers, based on the excitation source.

- Continuous wave emission means that laser energy is emitted continuously—as long as the laser is activated—and produces constant tissue interaction. CO_2 and diode lasers operate in this manner. These lasers are sometimes equipped with a mechanical shutter with a time circuit or a digital mechanism to produce gated or super-pulsed energy. Pulse durations can range from tenths of a second to several hundred microseconds.
- Free-running pulse emission occurs with very short bursts of laser energy due to a flashlamp pumping mechanism. The usual pulse durations are in the low hundreds of microseconds, and there is a relatively long interval between pulses. Nd:YAG, Er:YAG, and Er,Cr:YSGG devices operate as free-running pulsed lasers.

Laser Effects on Tissue

The light energy from a laser can have four different interactions with the target tissue, and these interactions will depend on the optical properties of that tissue.

The first is reflection, which is simply the beam redirecting itself off of the surface, having no effect on the target tissue. The reflected light could maintain its collimation in a narrow beam, or become more diffuse. As stated previously, the laser beam will generally become more divergent as the distance from the handpiece increases. However, the beam from some lasers can still have adequate energy at distances over 3 meters. In any event, this reflection can be dangerous because the energy would be directed to an unintentional target, such as the eyes; and this is a major safety concern for laser operation.

The second effect is transmission of the laser energy directly through the tissue, with no effect on the target tissue. This effect is also highly dependent on the wavelength of laser light. Water, for example, is relatively transparent to the diode and Nd:YAG wavelengths, whereas tissue fluids readily absorb Erbium and Carbon Dioxide at the outer surface, so there is very little energy transmitted to adjacent tissues. As another example, the diode and Nd:YAG lasers can be transmitted through the lens, iris, and cornea of the eye and can be absorbed on the retina.

The third effect is a scattering of the laser light, weakening the intended energy and possibly producing no useful biological effect. Scattering of the laser beam could cause heat transfer to the tissue adjacent to the surgical site, and unwanted damage could occur. However a beam deflected in different directions would be useful in facilitating the curing of composite resin.

Absorption of the laser energy by the intended target tissue is the usual desirable effect, and the amount of energy that is absorbed by the tissue depends on the tissue characteristics, such as pigmentation and water content, and on the laser wavelength and emission mode. The primary and beneficial goal of laser energy, therefore, is absorption of the laser light by the intended biological tissue. There are several photobiological effects possible when using a dental laser.

- The principle laser-tissue interaction is photothermal, which means the energy is transformed into heat. Surgical incisions and excisions with accompanying precision and hemostasis are one of the many results of a photothermal event when the operating parameters are correct.
- There are photochemical effects that the laser can stimulate chemical reactions, such as the curing of composite resin; and break chemical bonds, such as using photosensitive compounds that, when exposed to laser energy, can produce an singlet oxygen radical for disinfection of periodontal pockets and endodontic canals..
- Certain biological pigments, when absorbing laser light can fluoresce, which can be used for caries detection within teeth.
- A laser can be used in a non-surgical mode for biostimulation of more rapid wound healing, pain relief, increased collagen growth and a general anti-inflammatory effect.
- The pulse of laser energy on hard dentinal tissues can produce a shock wave, which could then explode or pulverize the tissue, creating an abraded crater. This is an example of the photoacoustic effect of laser light.

Laser Energy and Tissue Temperature

The thermal effect of laser energy on tissue primarily revolves around the water content of tissue and the temperature rise of the tissue. As the following table shows, when the target tissue containing water is elevated to a temperature of 100 degrees C., vaporization of the water within the tissue occurs, a process called ablation. Since soft tissue is composed of a very high percentage of water, excision of soft tissue commences at this temperature. At temperatures below 100 degrees C and above approximately 60 degrees, proteins begin to denature without any vaporization of the underlying tissue. This phenomenon is useful in surgically removing diseased granulomatous tissue, because if the tissue temperature can be controlled, the biologically healthy portion would remain intact. Conversely, if the tissue temperature is raised to about 200 degrees, it is dehydrated and then burned, and carbon is the end product. Carbon, unfortunately, is a high absorber of all wavelengths, so that it can become a heat sink as the lasing continues. The heat conduction will then cause a great deal of collateral thermal trauma to a wide area.

Tissue Temperature (oC)	Observed Effect
37-50	**Hyperthermia, bacterial inactivation**
>60	**Coagulation, Protein Denaturation**
70-90	**Welding**

100-150	**Vaporization**
>200	**Carbonization**

The laser emission mode plays an important part in the rise in tissue temperature. Pulsing ensures that the target tissue has some time to cool before the next amount of laser energy is emitted. In continuous wave mode, the operator must cease the laser emission manually so that thermal relaxation of the tissue may occur.

Very thin or fragile soft tissue, for example, should be treated in a pulsed mode, so that the amount and rate of tissue removal will be slower, but the chance of irreversible thermal damage to the target tissue and the adjacent non-target tissue will be minimal. Longer intervals between pulses can also help to avoid the transfer of heat to the surrounding tissue. In addition, a gentle air stream or an air current from the high volume suction, will greatly aid in keeping the area cooler. Conversely, thick dense fibrous tissue requires more energy for removal and continuous wave emission will provide a more rapid yet safe speed of excision. In either case, if there is too much thermal energy is used, healing can be delayed, and increased postoperative discomfort can occur.

Absorption of laser energy by dental tissues

Different laser wavelengths have different absorption coefficients with the primary dental tissue components of water, pigment, blood contents, and mineral (Fig 5), and laser energy can be transmitted or absorbed based on the composition of target tissue. Those primary components are termed chromophores, which are absorbers of specific laser energy. Water, which is present in all biologic tissue, maximally absorbs the two Er wavelengths, followed by CO2 wavelength. Conversely, water allows the transmission of the shorter wavelength lasers, diode, and Nd:YAG. Tooth enamel is composed of carbonated hydroxyapatite and water. That apatite crystal readily absorbs the CO2 wavelength, and, interacts to a lesser degree with the Erbium wavelengths. It does not interact with the shorter wavelengths lengths. Hemoglobin and other blood components, and pigments such as melanin absorb diode and Nd:YAG in varying amounts.

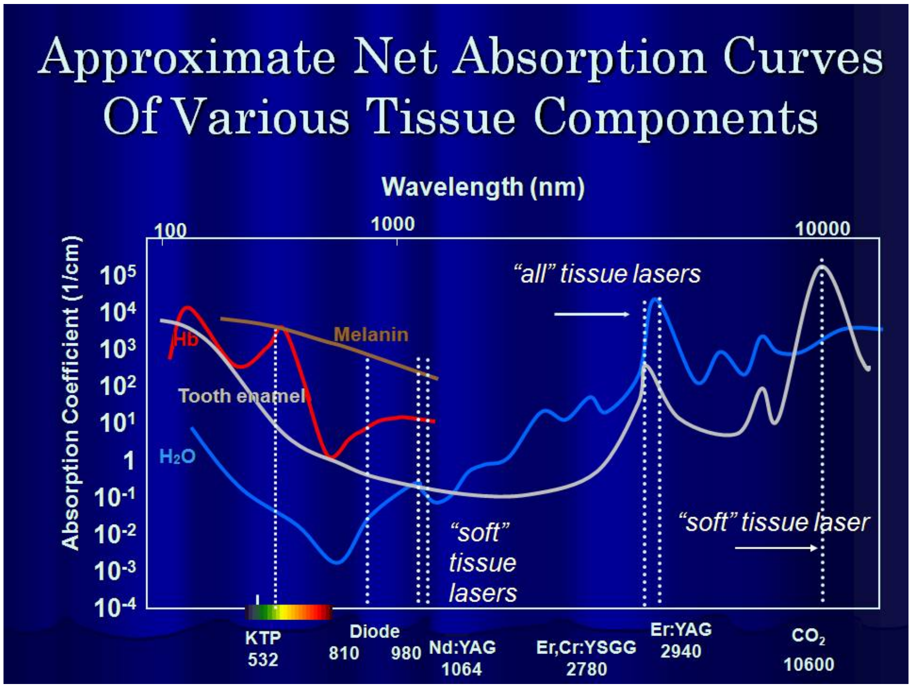


Figure 5. Four absorption curves of the principal dental tissue components. The absorption coefficient in a logarithmic scale is on the vertical axis, and the dental laser wavelengths are on the horizontal axis in ascending order of wavelength.

Three illustrations of different wavelengths' absorption will be depicted. Figure 6 shows the how a short wavelength laser (diode) is absorbed by tissue pigments and hemoglobin and produces a vaporization of the water in the soft tissue, leading to ablation. In figure 7 both Er:YAG and Carbon Dioxide lasers were used in two different cases. Those wavelengths are readily absorbed directly by the soft tissue's water content, producing a surgical result. Figure 8 shows an microscopic view of tooth structure ablation from Erbium laser energy, which occurs by a vaporized water mediated explosion.

Figure 6. Immediate post operative view of an excisional procedure using a diode laser.

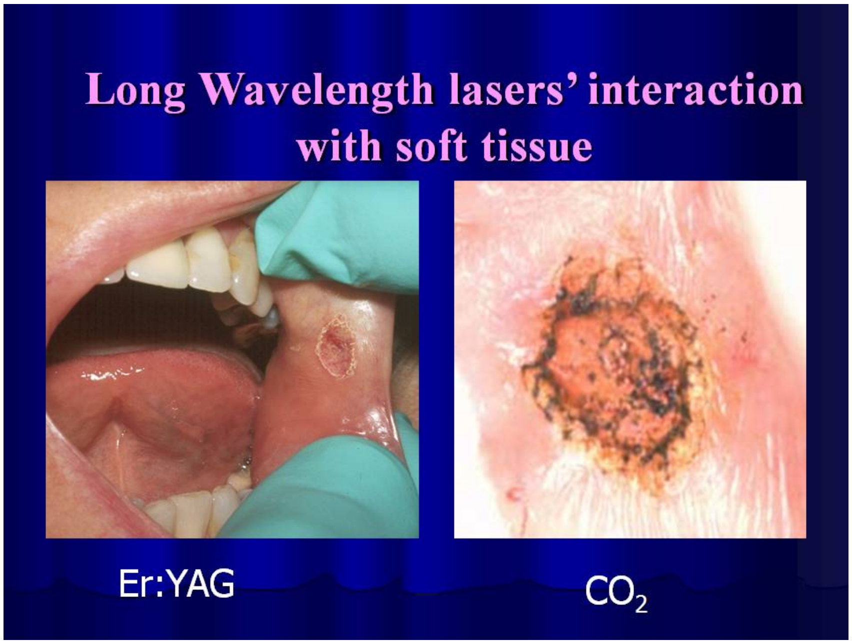


Figure 7. Immediate post operative views of excisional procedures using Erbium and Carbon Dioxide lasers.

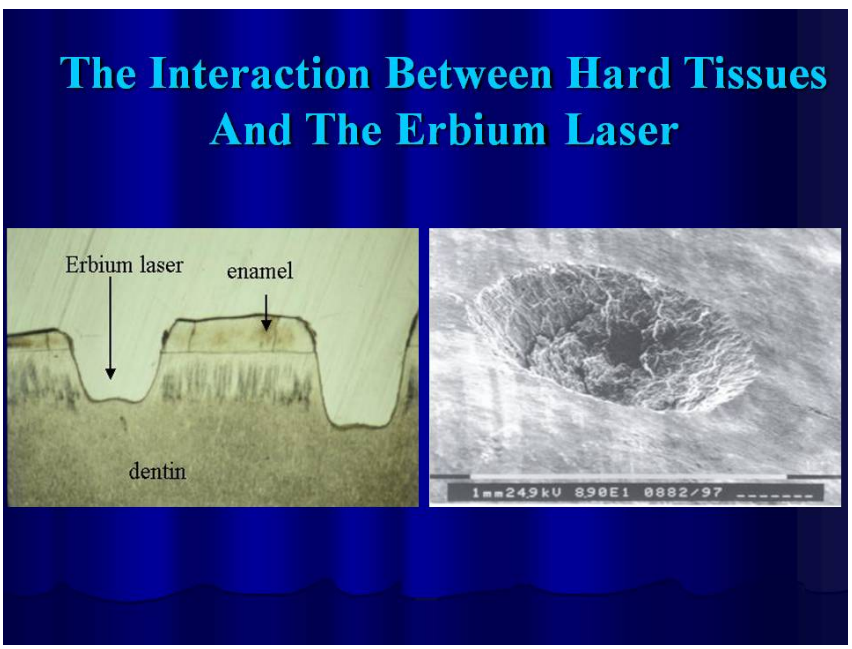


Figure 8. Microscopic views of Erbium laser's interaction with tooth structure. Left photo, sectional side view. Right photo, occlusal view.

Since human dental tissues are composed of a combination of compounds, the clinician must choose the best laser for each treatment. For soft tissue treatments, the practitioner can use any available wavelength, because all dental lasers absorb one or more of the soft tissue components. For hard tissue, however, the Erbium lasers with very short pulse durations easily ablate layers of calcified tissue with minimal thermal effects. It is interesting to note that the short wavelength lasers, like diode and Nd:YAG, are essentially non-reactive with healthy tooth enamel. Recontouring gingival tissue in very close proximity to a tooth can proceed uneventfully utilizing these wavelengths. Conversely, if soft tissue is impinging into the extent of a carious lesion, an Erbium laser can remove it and the decayed tooth structure very efficiently.
In addition to unique absorptive optical properties, all wavelengths have different penetration depths through tissue. The Erbium and Carbon Dioxide lasers are absorbed only in a few to several microns of the target tissue's surface, whereas diode lasers can reach a few millimeters deeper into the tissue.

To summarize the tissue interaction effect of a particular machine, several factors must be considered.

1. Each laser wavelength will affect certain components of the target tissue; the water content, the color of the tissue, and the chemical composition are all inter-related.
2. The diameter of the laser spot size, whether delivered in contact or non-contact with the tissue, will create a certain energy density. The smaller the beam, the greater the energy density. For example a beam diameter of 200 microns compared with a beam diameter of 300 microns at the same output setting will have over twice as much energy density. The result of using the smaller spot will thus greatly increase thermal transfer from the laser to the tissue and a corresponding increase in absorption of heat in that smaller area. If the beam has divergence, moving it away from the tissue will increase its diameter and thus lessen the energy density.
3. The amount of time that the beam is allowed to strike the target tissue will affect the rate of tissue temperature rise. That time can be regulated by the repetition rate of the pulsed laser emission mode as well.
4. The use of a water or air spray can also provide some cooling of the tissue which would affect the rate of vaporization.

Therefore, the laser practitioner must be aware of these factors before beginning treatment. If possible he or she can then choose the appropriate wavelength, beam diameter, focused or defocused distance, pulsing the energy, and providing tissue cooling. The correct combination of all of those parameters should ensure an efficient and beneficial outcome.

Laser Safety

All laser devices have complete instructions on the safe use of the machine. There are certain fundamentals that all laser practitioners should know; however, the primary responsibility for the safe and effective operation of the laser is assigned to the laser safety officer. That person provides all the necessary information, inspects and maintains the laser and its accessories, and insures that all procedures for safety are carried out.

Appropriate protective eyewear for the patient and the entire surgical team must be worn when the laser is operating so that any reflected energy does no damage. The surgical environment has a warning sign and limited access. High volume suction must be used to evacuate the plume formed by tissue ablation, and normal infection protocol must be followed. The laser itself must be in good working order so that the manufactured safeguards prevent accidental laser exposure.

Laser Regulatory Agencies

In various countries, there are a variety of regulatory agencies that control both the laser operator and the laser manufacturer, and these standards are strictly enforced.

In the United States, the American National Standards Institute provides guidance for the safe use of laser systems by specifically defining control measures for lasers. The Occupational Safety and Health Administration is primarily concerned with a safe workplace environment, and there are numerous requirements for laser protocol. The Center for Devices and Radiological Health (CDRH) is a bureau within the Food and Drug Administration (FDA) whose purpose is to standardize the manufacture of laser products and to enforce compliance with the Medical Devices Legislation. All laser manufacturers must obtain permission from the CDRH to make and distribute each device for a specific purpose; this is called marketing clearance, and means that the FDA is satisfied that the laser is both safe and effective to operate for that purpose. The owner's manual then will instruct the operator on how to use the device for the particular procedure that has been scrutinized by the CDRH. At present there are two dozen different indications for use for certain dental lasers. All wavelengths and devices may be used for all aspects of intraoral soft tissue surgery. The Er,Cr:YSGG and Er:YAG lasers may be used for caries removal, tooth preparation, endodontic and osseous procedures. Some instruments have specific clearances for procedures such as sulcular debridement and tooth whitening. The manufacturers continue to develop their technologies and clearance for other clinical applications and other laser wavelengths may be pending.

The dental practitioner may use the laser for techniques other than the cleared indications for use, since the FDA does not regulate dental practice. Hospitals and institutions have their own credentialing programs for the use of lasers in their facilities, and a published curriculum guideline has established standards of dental laser education. The scope of practice as defined by the Dental Practice Act, the training, and clinical experience of the dental laser operator are the primary factors that should determine how the device is used.

Benefits and drawbacks of dental lasers

One of the main benefits of using dental lasers is the ability to selectively and precisely interact with diseased tissues. Lasers also allow the clinician to reduce the amount of bacteria and other pathogens in the surgical field and, in the case of soft-tissue procedures, achieve good hemostasis with the reduced need for sutures. The hard-tissue laser devices can selectively remove diseased tooth structure because a carious lesion has a much higher water content than healthy tissue, and water is the primary absorber of that wavelength of laser energy. These same devices show advantages over conventional high-speed handpiece interaction of the tooth surface; for example, lased dentin has no smear layer and the cavity preparation has been disinfected. Osseous tissue removal and contouring proceed easily with the Erbium family of instruments.

There are some disadvantages to the current dental laser instruments. They are relatively high cost and require training. Because a majority of dental instruments are both side- and end-cutting, a modification of clinical technique will be required. Accessibility to the surgical area can sometimes be a problem with the existing delivery system, and the clinician must prevent overheating the tissue and guard against the possibility of surgically produced air embolisms that could be produced by excessive pressure of the air and water spray used during the procedure. One additional drawback of the erbium family of lasers is the inability to remove metallic restorations. Also, no single wavelength will optimally treat all dental disease.

Summary

This introduction to the use of dental lasers discussed their scientific basis and tissue effects. It is most important for the dental practitioner to become very familiar with those principles, have clinical experience, and receive proper laser training. Then he or she can choose the proper laser(s) for the intended clinical application. Although there is some overlap of the type of tissue interaction, each wavelength has specific qualities that will accomplish a specific treatment objective. Laser energy requires some procedures to be performed much differently than with conventional instrumentation, but the indications for laser use continue to expand and further benefit patient care.

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Biography

Donald J. Coluzzi, DDS, a 1970 graduate of the USC School of Dentistry, is an associate clinical professor in the Department of Preventive and Restorative Dental Sciences at the University of California San Francisco School of Dentistry. He retired from his general dental practice in Redwood City, CA after 35 years. A charter member and past president of the Academy of Laser Dentistry, he has used dental lasers since early 1991.

He has Advanced Proficiency in Nd:YAG and Er:YAG wavelengths. He is the 1999 recipient of the Leon Goldman Award for Clinical Excellence and the 2006 Distinguished Service Award from the Academy of Laser Dentistry, and is a Fellow of the American College of Dentists. He is a Master of the Academy of Laser Dentistry. Dr. Coluzzi has presented about lasers worldwide, co-authored two books, and published several peer-reviewed articles.