LASER Review course for residents
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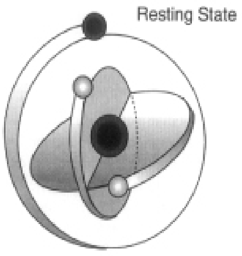
L.A.S.E.R. stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. The basic physical principles by which lasers function was first described by A. Einstein. Subsequently, laser technology has advanced rapidly with many medical applications have been described for a variety of specialties. This manuscript explains the basic principles of quantum mechanics which respect to the function of medically important lasers and briefly reviews some clinical with respect to the use of lasers in gynecology.

Basic Principles

Atoms consist of a nucleus surrounded by electrons in defined orbits. In a resting or ground state, the electrons occupy the lowest potential energy. If energy from an external source is applied to the atom, the energy may be absorbed, boosting the electron to an orbit with a higher potential energy.



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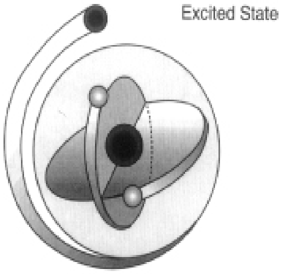

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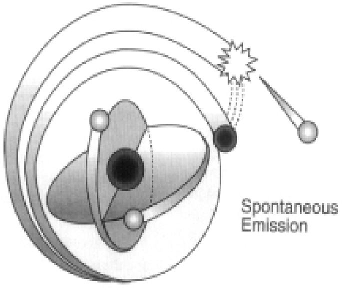

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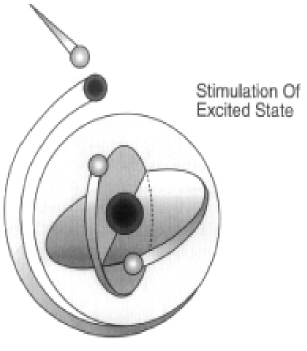

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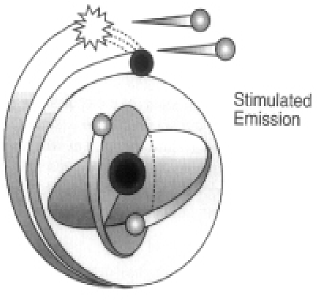

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The excited state is unstable and the electron promptly seeks the lower energy state of the closer obit. This results in the spontaneous emission of electromagnetic radiation. An example of this process is the emission of visible radiation (light) from a tungsten filament that has electricity passed through it. This light is of a variety of wavelengths and is propagated in infinite directions. If an atom in the excited state is stuck by a photon of a given wave length, the electron returns to the ground state and two photons of identical wavelength are released. This is called ***stimulated emission*** and is an essential event in the generation of laser energy.

The radiation produced by stimulated emission is in phase and the two waves are travelling in parallel. Since spontaneous emission occurs rapidly in most substances, not all compounds are suitable to produce laser energy. A gas, liquid, or solid that can be pumped with an external energy source such that most of the atoms will maintain an excited state is called a laser medium. The condition where most of the atoms are excited is called a population inversion.

The basic structure of a laser is a tube filled with a laser medium connected to an energy source (electricity). One end of the tube is covered with a totally reflecting mirror while the other end has a partially reflecting mirror. As stimulated emission proceeds in the laser medium, the identical parallel waves of radiation are reflected back and forth between the two mirrors. The waves traverse the laser medium and further stimulated emission occurs. Thus, the light energy is ***amplified*** before exiting the laser tube through the partially reflecting mirror. At this point the radiation can be focused through a lens selected to produce the desired focal length.

The light generated from such a laser tube has very unique properties. First it is ***monochromatic*** meaning that all light generated is of the same wavelength and energy. Second, the light is ***coherent***, meaning that all of the waves are in phase with each other in both space and time. Third, the radiation is ***collimated***. This means that the light waves are parallel to each other and that the beam does not diverge over long distances. These properties allow the laser light to be finely focused; account for the great deal of energy the radiation contains, and is the explanation for the consistent physical characteristics that are the hallmark of each specific laser.

Laser effect on tissue

Several factors are involved in the specific effect on tissue that results from the ***laser-tissue interaction***.:

- One of these factors is the ***power density*** of the laser energy at the impact site. The laser can be focused to a spot that covers a measurable area (mm^2). The amount of energy contained in the beam (watts) divided by the spot size is therefore a measure of the concentration of laser energy. Thus, the higher the energy for a given spot size the higher the power density. Conversely, the larger the spot size for a given amount of energy the lower the power density.

Effect of CO_2 Laser on tissue according to power density

\> 25,000 watts/cm^2 => Very rapid vaporization

4000 to 25,000 watts/cm^2 => Slow vaporization and less hemostasis

400 to 1,200 watts/cm^2 => Slow vaporization and increased hemostasis

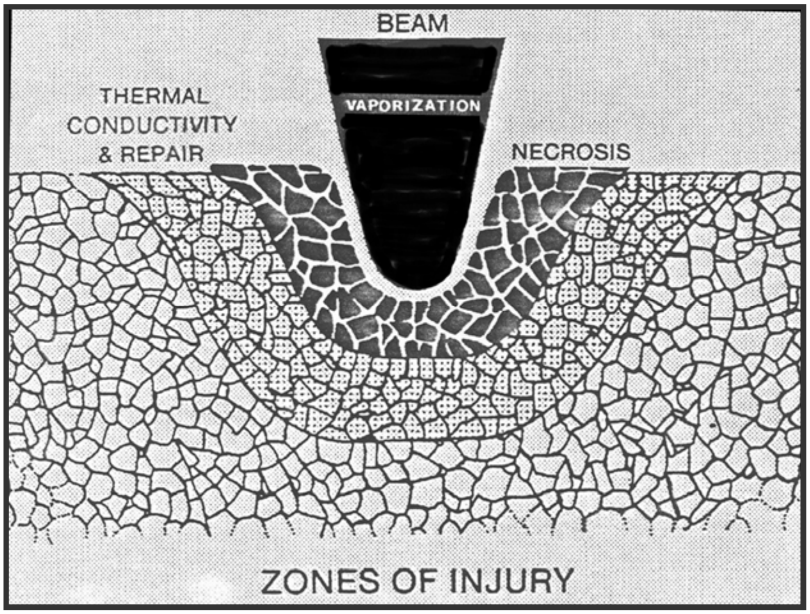
10 to 100 watts/cm^2 => Surface heating and coagulation

- Another important factor which determines the effect of the laser on tissue is the ***duration*** of the laser-tissue interaction. As the length of time that the laser is impacting on tissue increases, the primary effect (vaporization or coagulation) destroys an increasing volume of tissue. In addition, the longer duration allows the increased heat generated to dissipate further into the tissue creating a larger surrounding zone of thermal damage. When precise vaporization is required increased duration can be detrimental. If hemostasis, however is particularly important then the expanded zone of thermal effect can be beneficial.

- The ***characteristics of the tissue*** are also important in determining what the final effect will be. As will be descried below, the color of the tissue, as well as the water content and density may alter the effect of certain laser wavelengths.

- Finally the most important determinant of the effect of the laser on tissue is the specific ***wavelength of radiation***. When light strikes tissue it can be reflected. transmitted or absorbed. It is the portion of electromagnetic energy that is absorbed which ultimately affects the tissue. To compare the tissue effects of different lasers, a useful concept is the ***extinction length***. The extinction length is the distance within the tissue that the laser energy travels before 90% of the initial energy is absorbed. This almost directly corresponds to the depth of tissue damage and is a unique property of each wavelength.

Properties of the CO_2 laser



The CO_2 laser energy is highly absorbed by water. Since biologic tissue is largely water, the extinction length of this laser in tissue is very short (0.03 mm). At the impact site the CO_2 laser is absorbed by the intracellular water that rapidly reaches the boiling point as the radiation is converted to heat. The tissue is therefore vaporized with the generation of laser plume. Because the adsorption of the energy is so rapid and without scatter into the surrounding tissue the vaporization is very precise. Normal cells can be found within 100 microns of the impact site. However, the lack of thermal effects on the surrounding tissue correlates with relatively poor hemostasis. This can be overcome to a certain extent by decreasing the power density and increasing the duration of laser-tissue interaction (defocusing the laser beam). The effect of the CO_2 laser is largely independent of the color of the tissue.

Since the extinction length of this laser in a liquid is so short, it can only be delivered through a gaseous environment. To bring the CO_2 laser energy to the surgical field requires an articulating arm which contains mirrors at each joint. The beam exits the laser tube in to the articulating arm and is reflected along the aligned mirrors until it enters the instrument of delivery. Delivery to the target can be accomplished by a hand piece, a microscope equipped with a micromanipulator (microman), a laparoscope, or a waveguide. The waveguide is used during laparoscopic procedures either through a second puncture or though the operating channel of the scope. Since the CO_2 radiation is in the infrared range it is invisible and requires a helium-neon (Hee Nee) aiming beam regardless of the mode of delivery.

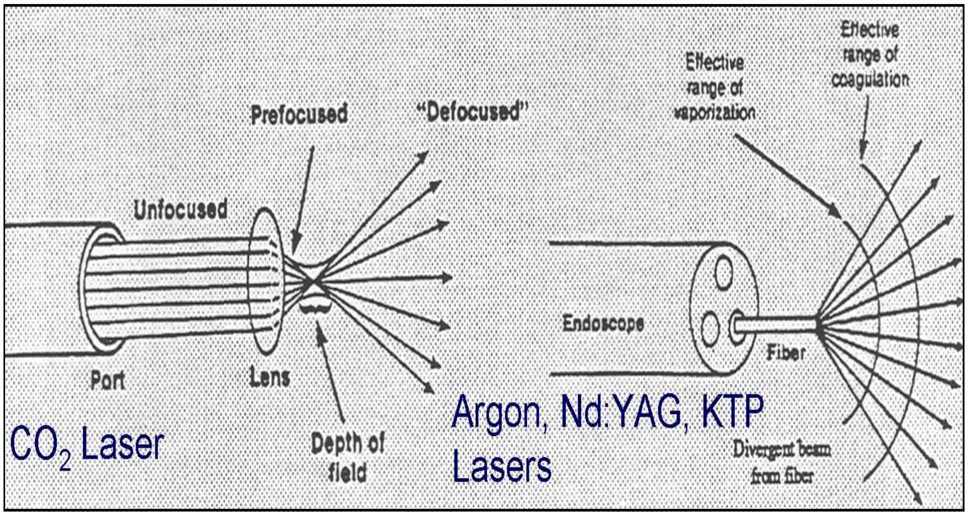
The advantages of the CO_2 laser are the ability to precisely vaporize tissue while leaving the surrounding tissue unscathed and the ease with which the beam is delivered under microscopic guidance. The disadvantages include: cumbersome delivery to the surgical field, plume generation, inability to work in a moist field, a relative lack of hemostasis, and a lack of tactile sense of the laser time interaction.

Argon /KTP Laser

The wavelengths of these two similar lasers are in the blue-green region of the visible spectrum. Delivery to the surgical field is through a flexible fiber which is usually 400-600 microns in diameter. The extinction length is highly color dependent with dramatic absorption by dark or red tissue and reflection by white or pale tissue. Thus 1-2 mm of vaporization or coagulation occurs when the laser energy is directed at implants of endometriosis with little absorption by the adjacent pale normal peritoneum. The color dependency of these effects can be overcome by increasing the power of the laser. Most of the literature documenting the efficacy of this laser in gynecology involves the laparoscopic treatment of endometriosis.

Nd:YAG Laser

The ND:YAG laser produces light in the near infra-red region of the electromagnetic spectrum with a wavelength of 1064 nm. This light is invisible and therefore like the CO_2 laser requires an aiming beam for safe application to tissue.



However, unlike the CO_2 laser, the Argon and ND:YAG lasers can be effectively transmitted through a flexible quartz fiber. This greatly increases the ease with which the laser energy is brought to the surgical field. Two basic modes of delivery are available for the ND:YAG laser, the bare quartz fiber and a quartz fiber adapted for use with an artificial sapphire contact tip. As with all lasers the tissue effect is dependent upon the power level and the duration of application of the laser energy. With the ND:YAG laser, however, further modification of the laser-tissue interaction can be achieved by varying the mode of delivery.

The role of laser for benign genital warts and VIN

Laser therapy, most commonly CO_2 laser, has a limited role in the management of benign genital warts given the availability of other economical and effective modalities such as electrocautery or surgical excision. The use laser vaporization for VIN has been found to result in a higher recurrence frequency.[1] In comparing laser vaporization and laser excision, cure was better for laser excision 33/38 (87%) compared to laser vaporization 11/14 (79%). Advantages to standard surgical excision or laser excision over laser vaporization include the ability to submit pathology from an excision. An advantage to laser vaporization, on the other hand, is evident for the clitoris involved with VIN, where precisely controlled ablation minimizes deformity and sexual dysfunction. Recurrence of VIN with laser vaporization may be particularly problematic in hair-bearing parts of the vulva and standard surgical excision is preferable. In hair-bearing regions of the vulva, dysplastic cells may be found in the deeper epithelial surfaces of hair follicles (mean depth 1.90 ± 0.84 mm) compared to the depth of dysplastic cells in glabrous skin of vestibular mucosa (mean depth 0.52 ± 0.23 mm).[2] If laser destruction is carried to adequate levels for destruction of VIN in the hair bearing areas, the patient may risk excessive scarring and deformity.

Reference List

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