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Lasers: A Double Edged Sword

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Abstract: ***Laser is an acronym, which stands for light amplification by stimulated emission of radiation. Several decades ago, the laser was a death ray, the ultimate weapon of destruction, something you would only find in a science fiction story. Then lasers were developed and actually used, among other places, in light shows. However as the every coin have two sides there are various complications and safety measures which are required to be kept in mind, while using lasers. The following review has be made keeping in mind the initial points which includes the history, physics of lasers, types of lasers, complications in lasers and safety measures in lasers.***

Keywords: Lasers, Types, Physics, Complications, Safety Measures

1. Introduction

Laser is an acronym, which stands for light amplification by stimulated emission of radiation. Several decades ago, the laser was a death ray, the ultimate weapon of destruction, something you would only find in a science fiction story. Then lasers were developed and actually used, among other places, in light shows. The beam sparkled, it showed pure, vibrant and intense colors.[1] Today the laser is used in the scanners at the grocery store, in compact disc players, and as a pointer for lecturer and above all in medical and dental field. The image of the laser has changed significantly over the past several years.

2. History of Lasers[2]

Approximately, the history of lasers begins similarly to much of modern physics, with Einstein. In 1917, his paper in Physikialische Zeil, "Zur Quantern Theorie der Strahlung", was the first discussion of stimulated emission. In 1954 Townes and Gordon built the first microwave laser or better known as 'MASER' which is the acronym for 'Microwave Amplification by stimulated Emission of Radiation'. The first gas laser was developed by Javan et al in 1961. This was the first continuous laser and used helium – neon. The Nobel Prize for the development of the laser was awarded to Townes, Basor and Prokhovov in 1964. The neodymium – doped (Nd): glass laser was developed in 1961 by Snitzer. In 1964 Nd: YAG was developed by Geusic. The CO_2 laser was invented by Patel et al in 1965. In 1990 Ball suggested opthalmologic application of ruby laser.

3. Laser Physics[3]

Laser is a device that converts electrical or chemical energy into light energy. In contrast to ordinary light that is emitted spontaneously by excited atoms or molecules, the light emitted by laser occurs when an atom or molecule retains excess energy until it is stimulated to emit it. The radiation emitted by lasers including both visible and invisible light is more generally termed as electromagnetic radiation. The concept of stimulated emission of light was first proposed in 1917 by Albert Einstein.[4]

He described three processes:

1. Absorption
2. Spontaneous emission
3. Stimulated emission.

Einstein considered the model of a basic atom to describe the production of laser. An atom consists of centrally placed nucleus which contains +vely charged particles known as protons, around which the negatively charged particles. i.e. electrons are revolving.

When an atom is struck by a photon, there is an energy transfer causing increase in energy of the atom. This process is termed as *absorption*. The photon then ceases to exist, and an electron within the atom pumps to a higher energy level. This atom is thus pumped up to an excited state from the ground state.

In the excited state, the atom is unstable and will soon spontaneously decay back to the ground state, releasing the stored energy in the form of an emitted photon. This process is called *spontaneous emission.*

If an atom in the excited state is struck by a photon of identical energy as the photon to be emitted, the emission could be stimulated to occur earlier than would occur spontaneously. This stimulated interaction causes two photons that are identical in frequency and wavelength to leave the atom. This is a process of *stimulated emission.*

If a collection of atoms includes, more that are pumped into the excited state that remain in the resting state, a population inversion exists. This is necessary condition for lasing. Now, the spontaneous emission of a photon by one atom will stimulate the release of a second photon in a second atom, and these two photon will trigger the release of two more photons. These four than yield eight, eight yield sixteen and so on. In a small space at the speed of light, this photon chain reaction produces a brief intense flash of monochromatic and coherent light which is termed as 'laser'.

4. Properties of Laser[5]

1. **Coherent:** Coherence of light means that all waves are in certain phase relationship to each other both in space and time
2. **Mono- chromatic:** Characterized by radiation in which all waves are of same frequency and wavelength.
3. **Collimated**: That means all the emitted waves are parallel and the beam divergence is very low. This property is important for good transmission through delivery systems.
4. **Excellent concentration of energy:** When a calcified tissue for eg. dentin is exposed to the laser of high energy density, the beam is concentrated at a particular point without damaging the adjacent tissues even though a lot of temperature is produced ie 800-900^{o}C.
5. Zero entropy.

5. Laser Design[6]

The laser consist of following components.

1. **A laser medium or active medium:** This can be a solid, liquid or gas. This lasing medium determines the wavelength of the light emitted from the laser and the laser is named after the medium.
2. **Housing tube or optical cavity:** Made up of metal, ceramic or both. This structure encapsulates the laser medium. Consists of two mirrors, one fully reflective and the other partially transmittive, which are located at either end of the optical cavity.
3. **Some form of an external power source:** This external power source excites or "pumps" the atom in the laser medium to their higher energy levels. A population inversion happens when there are more atoms in the excited state rather than a non-excited state. Atoms in the excited state spontaneously emit photons of light which bounce back and forth between the two mirrors in the laser tube; they strike other atoms, stimulating more spontaneous emission. Photons of energy of the same wavelength and frequency escape through the transmittive mirror as the laser beam. An extremely small intense beam of energy that has the ability to vaporize, coagulate, and cut can be obtained if a lens is placed in front of the beam. This lens concentrates the emitted energy and allows for focussing to a small spot size.

6. Laser Light Delivery[7]

Light can be delivered by a numbered of different mechanisms. Several years ago a hand held laser meant holding a larger, several hundred pound laser usually the size of desk above a patient. Although the idea was comical at the time, it is becoming more feasible as laser technology is producing smaller and lighter weight lasers. A devise that emits an intense coherent directional beam of radiant energy by stimulated electronic or molecular transitions to lower energy level. Einstein's atomic theories on controlled radiation can be credited as the foundation for lasers technology in 1917.

1. **Articulated arms :-** Laser light can be delivered by articulated arms, which are very simple but elegant. Mirrors are placed at 45^{o} angles to tubes carrying the laser light. The tubes can rotate about the normal axis of the mirrors. This results in a tremendous amount of flexibility in the arm and in delivery of the laser light. This is typically used with CO_2 laser. The arm does have some disadvantages that include the arm counter weight and the limited ability to move in straight line.
2. **Optical Fiber :-** Laser light can be delivered by an optical fiber, which is frequently used with near infrared and visible lasers. The light is trapped in the glass and propagates down through the fiber in a process called total internal reflection. Optical fibers can be very small. They can be either tenths of micros or greater than hundreds of microns in diameter. Advantages of optical fiber is that they provide easy access and transmit high intensities of light with almost no loss but have two disadvantages, one the beam is no longer collimated and coherent when emitted from the fiber which limits the focal spot size and second disadvantage is that the light is no longer coherent.

7. Patient to laser[8]

Another method of delivering laser light to the patient is actually to bring the patient up to the laser. Eg: Slit lamp used in the ophthalmologist gist has been doing this for quite some time. The ophthalmic laser microscope is simply a slit lamp with a laser built into it. The doctor simply images what he wants on the cornea or retina and then pushes the foot pedal to deliver laser beam to the target.

8. Laser Types[9]

a) Based on wavelength.

1. Soft lasers
2. Hard lasers

b) Based on the type of active / lasing medium used :- ArF excimer, KrF excimer, XeCl excimer, Argon ion, KTP, Ruby, Nd: YAG, HO: YAG, YSGG, Er: YAG, CO_2

Soft Lasers: With a wave length around 632mm Soft lasers are lower power lasers. Eg: He Ne, Gallium arsenide laser. These are employed to relieve pain and promote healing eg. In Apthous ulcers.

Hard lasers: Lasers with well known laser systems for possible surgical application are called as hard lasers. Eg: CO_2, Nd: YAG, Argon, Er:YAG etc.

Nd: YAG Laser: Here a crystal of Yttrium – aluminum – garnet is doped with neodymium. Nd: YAG laser, has wavelength of 1,064 nm (0.106 □) placing it in the near infrared range of the magnetic spectrum.

Argon Lasers :- Argon lasers are those lasers in the blue-green visible spectrum. They operate at 488nm or 514.5nm, are gas like CO_2 lasers and are easily delivered fiber optically like Nd:YAG.

Er: YAG laser:- **Have a wavelength of 2.94 □ m.** A number of researchers have demonstrated the Er: YAG lasers ability to cut, or ablate, dental hard tissue effectively and efficiently. The Er: YAG laser is absorbed by water and hydroxyapatite, which particularly accounts for its efficiency in cutting enamel and dentin.

1) Ho: YAG laser [Holmium YAG lasers]:- **Has a wavelength of 2,100 nm and is a crystal. Delivered through a fiber optic carrier. A He-Ne laser is used as an aiming light. Dragability is less compared to Nd: YAG and argon lasers**

2) Light can interact with tissues in four different mechanisms[10]
   - **Reflection:** Reflected light bounces off the tissue surface and is directed outward. Energy dissipates after reflection, so that there is little danger of damage to other parts of mouth and it limits the amount of energy that enters the tissue.
   - **Scattering:** occurs when the light energy bounces from molecule to molecule within the tissue. It distributes the energy over a larger volume of tissue, dissipating the thermal effects.
   - **Absorption:** occurs after a characteristic amount of scattering and is responsible for the thermal effects within the tissue. It converts light energy to heat energy The absorption properties of tissue and cells depends on the type and amount of absorbing pigments or chromophores. Eg. Hemoglobin, water, Melanin, Cytochromes etc.
   - **Transmission:** Light can also travel beyond a given tissue boundary. This is called transmission. Transmission irradiates the surrounding tissue and must be quantified. Its effects should be considered before laser treatment can be justified.

3) Bio-stimulation and Photodynamic Therapy[11]: Photodynamic therapy is an experimental cancer treatment that is based on a cytotoxic photochemical reaction. This reaction requires molecular oxygen, the photoactive drug dihematoporphyrin ether, a hematophorphyrin derivative and intense light, which is typically delivered by a laser. Dihematoporphyrin which is relatively retained in malignant tissue after several days, is given intravenously to a patient. Laser light at a wavelength corresponding to the absorption peak of the drug is used to activate the drug to an excited state. The drug then reacts with molecular oxygen to produce singlet oxygen, a highly reactive free radical which ultimately leads to tissue necrosis.

4) **Laser Hazards12 and Laser Safety[13]**: The subject of dental laser safety is broad in scope, including not only an awareness of the potential risks and hazards related to how lasers are used, but also recognition of existing standards of care and a thorough understanding of safety control measures.

5) Laser Hazard Class for according to ANSI and OSHA Standards:
   - **Class I** - Low powered lasers that are safe to view
   - **Class IIa** - Low powered visible lasers that are hazards only when viewed directly for longer than 1000 sec.
   - **Class II** - Low powered visible lasers that are hazardous when viewed for longer than 0.25 sec.
   - **Class IIIa** - Medium powered lasers or systems that are normally not hazardous if viewed for less than 0.25 sec without magnifying optics.
   - **Class IIIb** - Medium powered lasers (0.5w max) that can be hazardous if viewed directly.
   - **Class IV** - High powered lasers (>0.5W) that produce ocular, skin and fire hazards.

The types of hazards can be grouped as follows:

1. **Ocular Injury:** Potential injury to the eye can occur either by direct emission from the laser or by reflection from a specular (mirror like) surface or high polished, convex curvatured instruments. Damage can manifested as injury to sclera, cornea, retina and aqueous humor and also as cataract formation. The use of carbonized and non-reflective instruments has been recommended.
2. **Tissue Hazards:** Laser induced damage to skin and others non target tissues can result from the thermal interaction of radiant energy with tissue proteins. Temperature elevation of 21°C above normal body temp (37°C) can produce cell destruction by denaturation of cellular enzymes and structural proteins. Tissue damage can also occur due to cumulative effects of radiant exposure. Although there have been no reports of laser induced caroinogenesis to date, the potential for mutagenic changes, possibly by the direct alteration of cellular DNA through breathing of molecular bonds, has been questioned. The terms photodisruption and photoplasmolysis have been applied to describe these type of tissue damage.
3. **Respiratory:** Another class of hazards involves the potential inhalation of airborne biohazardous materials that may be released as a result of the surgical application of lasers. Toxic gases and chemical used in lasers are also responsible to some extent. During ablation or incision of oral soft tissue, cellular products are vaporized due to the rapid heating of the liquid component in the tissue. In the process, extremely small fragments of carbonized, partially carbonized, and relatively intact tissue elements are violently projected into the area, creating airborne contaminants that are observed clinically as smoke or what is commonly called the 'laser plume'. Standard surgical masks are able to filter out particles down to 5□ m in size. Particle from laser plume however may be as small as 0.3□ m in diameters. Therefore, evacuation of laser plume is always indicated.
4. **Fire and Explosion:** Flammable solids, liquids and gases used within the clinical setting can be easily ignited if exposed to the laser beam. The use of flame-resistant materials and other precautions therefore is recommended.
5. **Electrical Hazards:** These can be: Electrical shock hazards**,** Electrical fire or explosion hazards

Summary of laser safely control measures recommended by ANSI[13]

a) Engineering controls
   - Protective housing
   - Interlocks

- Beam enclosures
- Shutters
- Service panels
- Equipment tables
- Warning systems
- Key switch

b) Administrative controls

- Laser safety officer
- Standard operating procedures
- Output limitations
- Training and education
- Medical surveillance

c) Personal protective equipment

- Eye wear
- Clothing
- Screens and curtains

d) Special controls

- Fire and explosion
- Repair and maintenance

9. Conclusion

Laser has become a ray of hope in medical field. When used efficaciously and ethically, lasers are an exceptional modality of treatment for many clinical conditions that dentists treat on daily basis. But laser has never been the “magic wand” that many people have hoped for. It has got its own limitations. However, the futures of laser is bright with some of the newest ongoing researches.

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