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LASERS IN DENTISTRY: PAST AND PRESENT

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Abstract- Lasers were introduced into the field of clinical dentistry with the hope of overcoming some of the drawbacks posed by the conventional methods of dental procedures. Since its first experiment for dental application in the 1960s, the use of laser has increased rapidly in the last couple of decades. At present, wide varieties of procedures are carried out using lasers. This article reviews literature on lasers with the aim of providing a complete understanding of the fundamentals of lasers and their applications in the various disciplines of dentistry. It will describe the fundamentals of laser science, laser tissue interaction, laser wavelengths available in dentistry, laser parameters and safety measures in brief to enable the clinician to select the best laser for a certain procedure.

Keywords- Dental lasers, Electromagnetic spectrum, Laser science, Laser tissue interactions, Laser safety

Introduction

Lasers are devices that amplify or increase the intensity of light to produce a highly directional, high-intensity beam that typically has a very pure frequency or wavelength [1].

Lasers are a primary component of some of our most modern communication systems and are the probes that generate the audio signals from our compact disk players. They are used for cutting, heat treating, cleaning, and removing materials in both the industrial and medical worlds [2]. They are the targeting element of laser-guided bombs and are the optical source in both supermarket checkout scanners and tools (steppers) that print our microchips [3].

When used efficaciously and ethically, lasers are an exceptional modality of treatment for many clinical conditions that dentists or dental specialists treat on a daily basis. Dental procedures performed today with the laser are so effective that they should set a new standard of care.

This article describes the fundamentals of laser science, laser tissue interaction, laser wavelengths available in dentistry, laser parameters and safety measures in brief to enable the clinician to select the best laser for a certain procedure and also understand the biologic rationale for its use.

Historical Development

The dental lasers of today have benefited from decades of laser research and have their basis in certain theories from the field of quantum mechanics, initially formulated during the early 1900s by Danish physicist *Bohr*, among others.

Einstein's atomic theory on controlled radiation can be credited as the foundation for laser technology. Einstein's article on the stimulated emission of radiant energy, published in 1917, is acknowledged as the conceptual basis for amplified light. Forty years later, American physicist Townes first amplified microwave frequencies by the stimulated emission process, and the acronym MASER came into use. In 1958, Schawlow and Townes discussed extending the maser principle to the optical portion of the electromagnetic field, hence, LASER (light amplification by the stimulated emission of radiation). In 1960, the first working laser, a pulsed ruby instrument, was build by Maiman of Hughes Research Laboratories. One year after Maiman's achievement, Goldman established the first laser medical laboratory at the University of Cincinatti; he is recognized as the first physician to use laser technology, initially working with the ruby laser [4]. Over the years, Goldman and Other researchers documented the ability of various types of lasers to cut, coagulate, ablate and vaporize biologic tissues. L'Esperance was the first to report clinical use of an argon laser in 1968 in ophthalmology. In 1972, Strong and Jako reported the first clinical use of a CO_2 laser in otalaryngolgy. Keifhaber et al documented the first clinical use of Nd: YAG laser in 1977 in gastro intestinal surgery. Historically, the first lasers to be marketed for intra oral use generally were CO_2 lasers with otorhinolaryngologic clearance authorized by FDA. In May 1990, the FDA cleared for intraoral soft tissue surgery a pulsed Nd: YAG laser developed by Myers and Myers, recognized as the first laser designed specifically for general dentistry [5].

Other lasers and researches followed, and today lasers are used routinely across a broad spectrum of medical disciplines, including dentistry.

Basic Laser Science

The word laser originally was the upper-case LASER, the acronym from *Light Amplification by Stimulated Emission of Radiation*, wherein *light* broadly denotes electromagnetic radiation of any frequency, not only the visible spectrum; hence infrared laser, ultraviolet laser, X-ray laser, etc.

Laser Physics

Light is a form of electromagnetic energy that travels in waves, at a constant velocity (186,000 miles/Sec). The basic unit of this radiant energy is called a photon or a particle of light.

A wave of photons can be defined by 3 basic properties

Amplitude- This is defined as the total height of the wave oscillation from the top of the peak to the bottom. A measurement of the amount of energy in the wave: larger the amplitude, greater the amount of energy that can do useful work.

Wave length- Distance between any two corresponding points in the wave. A measurement of physical size, which is important with respect to how the laser light is delivered to the surgical site and to how it reacts with tissue. Wavelength is measured in meters; microns (10^{-6}m) and nanometers (10^{-9}m).

Velocity- i.e. speed of light.

Properties of Laser Light

- A property of waves that is related to wavelength is frequency, which is the measurement of the number of wave oscillations per second. Frequency is inversely proportional to wavelength. Laser light has one specific color; a property called *monochromatic*; and is finely focused. The precision of the monochromatic beam is due to two additional characteristics: collimation & coherency [6].
- *Collimation* refers to the beam having specific spatial boundaries. These boundaries ensure that there is a constant beam size and shape that is emitted from the laser unit which is similar to x-ray beam.
- *Coherency* is a property unique to lasers. The light waves produced by a laser are a specific form of electromagnetic energy. A laser produces light waves that are physically identical. They are all in phase with one another; that is, they have identical amplitude and identical frequency. A laser produces a monochromatic, collimated and coherent beam of light energy that can do the work of accomplishing the treatment objective [7].
- *Brightness* is another property of laser light that distinguishes it from conventional light sources. This property arises from the parallelism or collimation of the laser light as it moves through space maintaining its concentration and thus, the characteristic brightness.

Laser Design

The laser consist of following components

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 [8].

Housing Tube or Optical Cavity- Made up of metal, ceramic or both. It consists of two mirrors, one fully reflective and the other partially transmittive, which are located at either end of the optical cavity [9].

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. Atoms in the excited state spontaneously emit photons of light which bounce back and forth between the two mirrors in the laser tube [10].

Classification of Lasers

Based as Application

- Soft tissue laser, e.g.: Argon, CO_2, diode; Nd: YAG.
- Hard tissue laser, e.g.: Er: YAG.
- Resin curing laser, e.g.: Argon.

Mode of Action

- Contact mode (focused or defocused), e.g.: Ho: YAG; Nd: YAG.
- Non-contact mode (focused or defocused), e.g.: CO_2.

Based on Source and Wavelength

TYPE	SOURCE	WAVELENGTH
INFRARED	CO_2	10,600
	Er:YAG	2780
	Ho:YAG	2940
	Nd:YAG	1064
	Diode Laser	812
VISIBLE	HeNe	633
	Argon	514
ULTRAVIOLET	XeF	351
	XeCL	308

Based on Level of Energy Emission

- **Soft Lasers (Low Level Energy):** A thermal low energy lasers emitted at wave length, which are supposed to stimulate cellular activity. Example: He-Neon; Ga-Arsenide.
- **Hard Lasers (High Level Energy):** Thermal lasers emitted at wavelength in the visible infra red and U.V range. Example: Er: YAG laser; Nd: YAG laser.

Based on Radiant Energy Generation

- Continuous wave or continuous form (CW)
- Discreet or single pulses

Laser Delivery Systems

The coherent, collimated beam of laser light must be able to be delivered to the target tissue in a manner that is ergonomic and precise [11].

Two delivery systems are used in dental lasers:

- One is a flexible hollow wave-guide or tube that has an interior mirror finish. The laser energy is reflected along this tube and exits through a hand piece at the surgical end, with the beam striking the tissue in a non contact fashion (i.e., without directly touching the tissue).
- Second delivery system is a glass fiberoptic cable. The cable is pliant and comes in various diameters, with sizes ranging from 200 to 1000μ.

The glass fiber, although encased in a resilient sheath, can be fragile and cannot be bent into sharp angle. It fits snugly into a hand piece with the bare end protruding or, in some cases, with an attached glasslike tip. This fiber system can be used in contact or non -contact mode, mostly contact mode [12].

Laser Energy and Tissue Temperature

The thermal effect of laser energy on soft tissue primarily revolves around the water content of the tissue and the temperature rise of the tissue. When the tissue temperature reaches approximately 60°C, proteins begin to denature without any vaporization of the underlying tissues. This phenomenon is useful in surgically removing diseased granulomatous tissue [13].

When the target tissue is elevated to a temperature of 100°C, vaporization of the water within the tissues occurs. Excision of soft tissue begins at this temperature. When the tissue temperature is raised to about 200°C, it is dehydrated, and then burned, and carbonization is the result [14].

Carbon is a high absorber of all wavelengths, so that the carbonized or chassed tissue can become a heat sink as the lasing continues. The heat conduction then causes a great deal of collateral thermal damage to a wide area [15].

Laser Effect on Tissues

Tissue Temp. °C	Observed Effect
37-50	Hyperthermia
> 60	Coagulation, Protein denaturation
70-90	Welding of tissue
100-150	Vaporization
> 200	Carbonization.

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

- *Reflection* which is simply the beam redirecting itself off the tissue surface, having no effect on the targeted tissue. This reflection can be dangerous because the energy would be directed to an unintentional target, such as the eyes; major safety concern for laser operation.
- *Absorption* of the laser energy by the intended target tissue. Desirable effect and the amount of energy that is absorbed by the tissue depend on the tissue characteristics, such as pigmentation and water content, and on the laser wavelength and emission mode.
- *Transmission* of laser energy directly through the tissue, with no effect on the target tissue. This interaction also is highly dependent on the wavelength of the laser light.
- *Scattering* of the laser light, weaking the energy and possibly producing no useful biologic effect scattering could cause heat transfer to the tissues adjacent to the surgical site, and unwanted thermal damage could occur [13].

Uses

Lasers range in size from microscopic diode lasers (top) with numerous applications, to football field sized neodymium glass lasers (bottom) used for inertial confinement fusion, nuclear weapons research and other high energy density physics experiments.

When lasers were invented in 1960, they were called "a solution looking for a problem" [14]. Since then, they have become ubiquitous, finding utility in thousands of highly varied applications in every section of modern society, including consumer electronics, information technology, science, medicine, industry, law enforcement, entertainment, and the military.

The first use of lasers in the daily lives of the general population was the supermarket barcode scanner, introduced in 1974. The laserdisc player, introduced in 1978, was the first successful consumer product to include a laser but the compact disc player was the first laser-equipped device to become common, beginning in 1982 followed shortly by laser printers [15].

Some other uses are:

- Medicine: Bloodless surgery, laser healing, surgical treatment, kidney stone treatment, eye treatment, dentistry.
- Industry: Cutting, welding, material heat treatment, marking parts, non-contact measurement of parts
- Military: Marking targets, guiding munitions, missile defence, electro-optical countermeasures (EOCM), alternative to radar, blinding troops.
- Law enforcement: used for latent fingerprint detection in the forensic identification field [16,17].
- Research: Spectroscopy, laser ablation, laser annealing, laser scattering, laser interferometry, LIDAR, laser capture microdissection, fluorescence microscopy
- Product development/commercial: laser printers, optical discs (e.g. CDs and the like), barcode scanners, thermometers, laser pointers, holograms, bubblegrams [18]
- Laser lighting displays: Laser light shows
- Cosmetic skin treatments: acne treatment, cellulite and striae reduction, and hair removal.

In 2004, excluding diode lasers, approximately 131,000 lasers were sold with a value of US$2.19 billion. In the same year, approximately 733 million diode lasers, valued at $3.20 billion, were sold.

The continuous or average power required for some uses:

- less than 1 mW-laser pointers
- 5 mW-CD-ROM drive
- 5-10 mW-DVD player or DVD-ROM drive
- 100 mW-High-speed CD-RW burner
- 250 mW-Consumer DVD-R burner
- 1 W-green laser in current Holographic Versatile Disc prototype development
- 1-20 W-output of the majority of commercially available solid-state lasers used for micro machining
- 30-100 W-typical sealed CO_2 surgical lasers
- 100-3000 W (peak output 1.5 kW)-typical sealed CO_2 lasers used in industrial laser cutting
- 1 kW-Output power expected to be achieved by a prototype 1 cm diode laser bar

Examples of pulsed systems with high peak power:

- 700 TW (700×10^{12} W)-National Ignition Facility, a 192-beam, 1.8-megajoule laser system adjoining a 10-meter-diameter target chamber.
- 1.3 PW (1.3×10^{15} W)-world's most powerful laser as of 1998, located at the Lawrence Livermore Laboratory

Disadvantages

- Retinal burn if no protection.
- Prolonged exposure to pulp causes irreversible pulp damage.
- High cost.
- Specially trained personnel required.
- Chances of explosion.
- Aerosol contamination- respiratory hazards

Laser Safety

Even the first laser was recognized as being potentially dangerous. Theodore Maiman characterized the first laser as having a power of one "Gillette" as it could burn through one Gillette razor blade. Today, it is accepted that even low-power lasers with only a few milliwatts of output power can be hazardous to human eyesight, when the beam from such a laser hits the eye directly or after reflection from a shiny surface [19].

At wavelengths which the cornea and the lens can focus well, the coherence and low divergence of laser light means that it can be focused by the eye into an extremely small spot on the retina, resulting in localized burning and permanent damage in seconds or even less time.Lasers are usually labeled with a safety class number, which identifies how dangerous the laser is:

- Class I/1 is inherently safe, usually because the light is contained in an enclosure, for example in CD players.
- Class II/2 is safe during normal use; the blink reflex of the eye will prevent damage. Usually up to 1 mW power, for example laser pointers.
- Class IIIa/3R lasers are usually up to 5 mW and involve a small risk of eye damage within the time of the blink reflex. Staring into such a beam for several seconds is likely to cause (minor) eye damage.
- Class IIIb/3B can cause immediate severe eye damage upon exposure. Usually lasers up to 500 mW, such as those in CD and DVD writers.
- Class IV/4 lasers can burn skin, and in some cases, even scattered light can cause eye and/or skin damage. Many industrial and scientific lasers are in this class.

The indicated powers are for visible-light, continuous-wave lasers. For pulsed lasers and invisible wavelengths, other power limits apply. People working with class 3B and class 4 lasers can protect their eyes with safety goggles which are designed to absorb light of a particular wavelength [20,21].

Certain infrared lasers with wavelengths beyond about 1.4 micrometres are often referred to as being "eye-safe". This is because the intrinsic molecular vibrations of water molecules very strongly absorb light in this part of the spectrum, and thus a laser beam at these wavelengths is attenuated as completely as it passes through the eye's cornea that no light remains to be focused by the lens onto the retina. The label "eye-safe" can be misleading, however, as it only applies to relatively low power continuous wave beams and any high power or Q-switched laser at these wavelengths can burn the cornea, causing severe eye damage [22,23].

According to the CDRH and ANSI system of classification, class IV lasers are defined as those devices that pose a biologic hazard from either direct or diffuse reflection. Generally any laser capable of emitting power greater than 500 mW continuous wave output belongs in this class [24,25].

The types of hazards that may be encountered within the clinical practice of dentistry may be grouped as follows [26].

- Ocular injury
- Tissue damage
- Respiratory hazard
- Fire and explosion
- Electric shock.

Conclusion

Laser has become a ray of hope in dentistry. 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 future of dental laser is bright with some of the newest ongoing researches. Once, our knowledge about optimal laser parameters for each treatment modality is complete, lasers can be developed that will provide dentists with the ability to care for patients with improved techniques.

Conflicts of Interest: None declared.

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