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REVIEW ARTICLE

Lasers in Prosthodontics - An Overview Part 1: Fundamentals of Dental Lasers

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The introduction of lasers in the field of prosthodontics has replaced many conventional surgical and technical procedures and is beginning to replace the dental handpiece. Although lasers were introduced in dentistry as early as the 1960s it has gained widespread popularity mainly in the developed countries only from the early 90s. Today, prosthodontists can select from a variety of laser wavelengths available in dentistry. This has led to great confusion regarding laser operation and selection of the most appropriate laser wavelength for a given procedure. 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 prosthodontics. Peer reviewed literature published in English language between 1991 and 2007 obtained using Medline, and hand searches is reviewed in a series of three articles: Part 1 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 and also understand the biologic rationale for its use. Part 2 will deal in brief with the applications of lasers in the various branches of prosthodontics and their advantages over conventional techniques. Part 3 will deal with lasers in prosthodontics from an Indian perspective.

Keywords: Dental lasers, Electromagnetic spectrum, Laser tissue interactions, Laser safety

Introduction

The field of prosthodontics has come a long way from just replacing missing teeth by simple mechanics to the boundless era of modern technology. One such technological advancement is the introduction of lasers in the field of prosthodontics that has replaced many conventional surgical and technical procedures and is beginning to replace the dental handpiece.

The dental lasers of today have their basis in the quantum theory of mechanics initially formulated during the early 1900s by Danish physicist Bohr. However, Einstein's article on the stimulated emission of radiant energy, published in 1917, is acknowledged as the conceptual basis for amplified light. Nearly 40 years later, American physicist Townes amplified microwave frequencies by the stimulated emission process and the acronym MASER (microwave amplification by stimulated emission of radiation) came into use.

In 1958, Schawlow and Townes discussed extending the MASER principle to the optical portion of the electromagnetic field. This led to the invention of the first LASER (light amplification by the stimulated emission of radiation) device by Theodre Maiman, at the Hughes Aircraft Company USA, in 1960. Maiman's laser used a solid ruby as an active medium, which was energized or 'pumped' by an electrical source. During the next few years, dental researchers studied possible applications of this visible laser energy. Dr Leon Goldman, a dermatologist who had been experimenting with tattoo removal using the

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ruby laser, focused two pulses of that red light on a tooth of his dentist brother in 1965. The result was painless surface crazing of the enamel.

Studies in the 1970s and 1980s turned to other devices such as CO_2 and Nd: YAG (Neodymium Yttrium Aluminium Garnet), which was thought to have better interaction with dental hard tissues. CO_2 lasers were the first to be marketed for intraoral use. In May 1990, the Food and Drug Administration (FDA) cleared a pulsed Nd: YAG laser developed by Myers and Myers [1] for intraoral soft tissue surgery. In time other laser wavelengths such as Argon, Ho:YAG and Er:YAG was investigated and numerous instruments have been made available for use in dental practice and more are being developed [2, 3].

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.

Basic Laser Science

The word LASER is an acronym for light amplification by the stimulated emission of radiation

Laser light: The light wave produced by a laser is a specific form of electromagnetic energy that behaves as a particle and a wave.

The basic unit of energy is called a photon. The wave of photons produced by a laser can be defined by 3 measurements, namely,

- Velocity i.e speed of light
- Amplitude (intensity in the wave) - this is the total height of the wave oscillation from the top of the peak to the bottom of the vertical axis. Larger the amplitude greater is the performable work
- Wavelength - this is the distance between any two corresponding points on the wave on the horizontal axis

Laser light occurs through the amplification of stimulated emission [2, 3].

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.

The component parts of a typical laser are (Fig. 1) [2–4]:

Active medium

A material, either naturally occurring or man-made that when stimulated, emits laser light. This material may be a gas e.g. Argon, CO_2), a crystal (YSGG crystal doped with Er and Cr, YAG crystal doped with Er or Nd) or a solid-state semiconductor (AlGaAs, InGaAs diode).

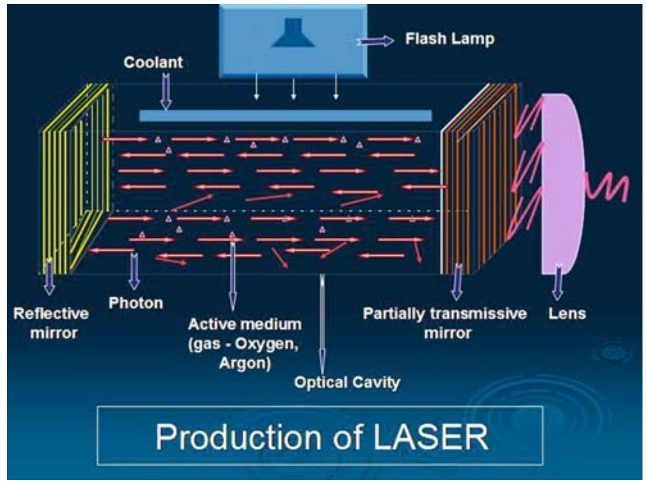

Fig. 1 The basic components of a typical laser cavity

The active medium is positioned within the laser cavity, an internally-polished tube, with mirrors co-axially positioned at each end and surrounded by the external energising input, or pumping mechanism.

Pumping Mechanism

This represents a man-made source of primary energy that excites the active medium. This is usually a light source, either a flashlight or arc-light or an electromagnetic coil. Energy from this primary source is absorbed by the active medium, resulting in the production of laser light by the process of *stimulated emission*.

The term 'stimulated emission' has its basis in the quantum theory of physics, introduced in 1900 by the German physicist Max Planck and further conceptualized as relating to atomic architecture by the Danish physicist Neils Bohr.

Incident light energy, absorbed by a target atom, will result in an electron moving to a higher energy shell. This unstable state will result in the emission of photonic energy relative to the stable energy state of the target, with excess energy being produced as heat. This process is called *'spontaneous emission'*.

Albert Einstein theorized further that if an already energized atom is bombarded with a second photon, this will result in the emission of two coherent photons of identical wavelength, a phenomenon he termed *'stimulated emission'*.

This energy is emitted or radiated as two identical photons, traveling as a coherent wave (Fig. 2).

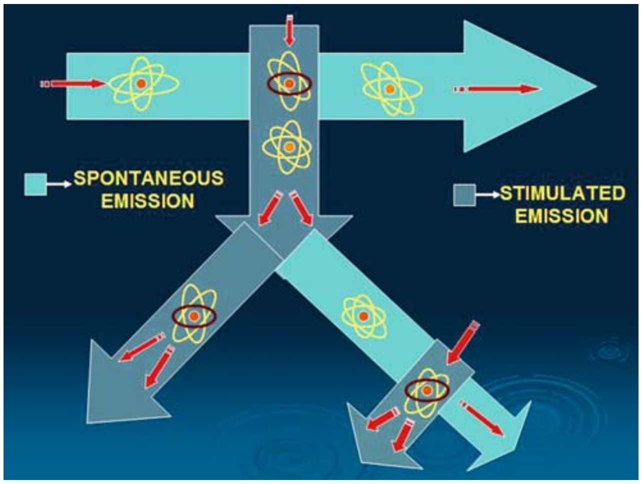

Fig. 2 Depiction of spontaneous and stimulated emissions

These photons are then able to energize more atoms, which emit additional identical photons stimulating more surrounding atoms. There must be a constant supply of energy, to maintain excitation.

This process is very inefficient, with only some 3–10% of incident energy resulting in laser light, the rest being converted to heat energy.

Optical Resonator

Laser light produced by the stimulated active medium is bounced back and forth through the axis of the laser cavity, using two mirrors placed parallel to each other at either end, thus *amplifying* the power. The distal mirror is totally reflective and the proximal mirror is selectively transmissive, allowing light of sufficient energy to exit the optical cavity. The parallelism of the mirrors insures that the light is collimated.

Delivery Systems

Currently, two delivery systems are used (for surgical lasers):

- A flexible hollow waveguide/tube attached to a handpiece (non-contact mode) or an accesory tip of saphire or hollow metal (contact mode) connected to the end of the waveguide.
- A glass fiberoptic cable attached to a handpiece (non contact mode) or a sapphire or quartz tip (contact mode). Most of the times it is used in contact mode.

Cooling System

Heat production is a by-product of laser light propagation. It increases with the power output of the laser and hence, with heavy-duty tissue cutting lasers, the cooling system represents the bulkiest component. Co-axial coolant systems may be air- or water-assisted.

Control Panel

This allows variation in power output with time, above that defined by the pumping mechanism frequency. Other facilities may allow wavelength change multilaser instruments) and printout of delivered laser energy during clinical use.

Focusing Lens

Radiation - refers to the light waves produced by the laser as a specific form of electromagnetic energy.

Characteristics of Laser Light

- *Monochromacity* - laser light is one specific color/ single wavelength unlike ordinary white light which is a sum of many colors of the visible spectrum.
- *Collimation* - refers to the beam having specific spatial boundaries which ensures a constant size and shape of the beam emitted from the laser cavity.
- *Coherency* - means that the light waves produced in the instrument are all in phase with one another and have identical wave shapes, i.e. all the peaks and valleys are equivalent.
- *Efficiency* - at very low average power levels lasers can produce the required energy to perform their specific function, e.g. 2 watts of Nd: YAG laser light provides the thermal energy to precisely incise a gingival papilla.

Laser - Tissue Interaction

Depending on the optical properties of the tissue, laser light can have four different interactions with the target tissue, i.e. *absorption, transmission, reflection and scattering* (Fig. 3) [2, 3, 5].

Absorption

The absorption of the laser energy by the intended tissue is the first and most desired interaction.

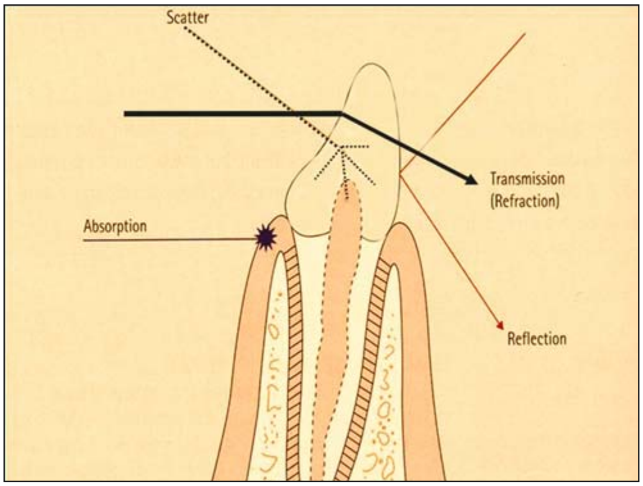

Fig. 3 Laser light target tissue interactions

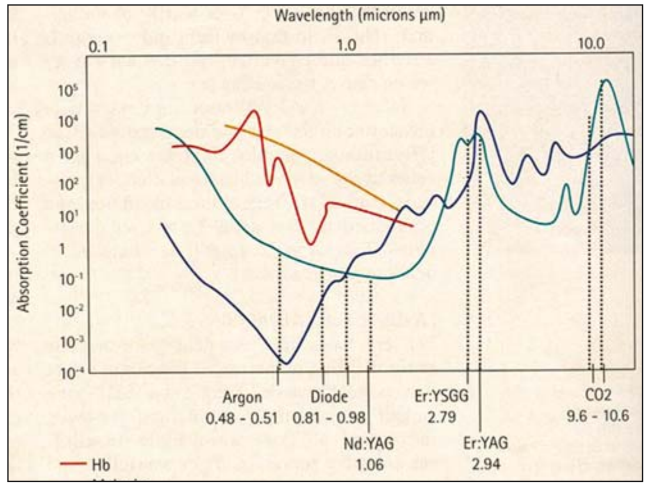

Fig. 4 Approximate absorption co-efficients of hemoglobin, melanin, hydroxyapatite and water relative to dental laser wavelengths

The amount of energy absorbed by the tissue depends on following factors

Tissue Characteristics

- Pigmentation - The pigment melanin which imparts color to skin is strongly absorbed by short wavelengths. Hemoglobin reflects red wavelengths imparting color to arterial blood. It is therefore strongly absorbed by blue and green wavelengths whereas venous blood containing less oxygen absorbs more red light and appears darker.
- Water content - Water has varying degrees of absorption of different wavelengths.

Laser Wavelength

The shorter wavelengths (500–1,000 nm) are readily absorbed in pigmented tissue and blood elements.

Argon is highly attenuated by hemoglobin. Diode and Nd:YAG has a high affinity for melanin and less interaction with hemoglobin.

The longer wavelengths (2,000–10,600 nm) are more interactive with water and hydroxyapatite. The largest absorption peak for water is at the Er:YAG wavelength (just below 3,000 nm. Erbium is also well absorbed by hydroxyapatite. CO_2 (at 10,600 nm) is well absorbed by water and has the greatest affinity for tooth structure (Fig. 4).

Emission Mode

The principle behind any laser emission mode is that the light energy strikes the tissue for a certain length of time producing a thermal interaction.

The dental laser device can emit light energy in three different modalities, namely:

- *Continuous wave mode* – the beam is emitted at only one power level for as long as the operator depresses the foot switch. Here the operator must cease the laser emission manually so that thermal relaxation of the tissue may occur.
- *Gated pulse mode* – there are periodic alternations of the laser energy. This mode is achieved by the opening and closing of a mechanical shutter in front of the beam path of a continuous wave emission.
- *Free-running pulsed mode* – (“true-pulsed”) This emission is unique in that large peak energies of laser light are emitted for a short time span (microseconds) followed by a relatively long time in which the laser is off.

Contact vs non-contact modes

Laser light will undergo some divergence on exit from a quartz fiber delivery system and most non-fiber sustems (hollow waveguide and articulated arm) use a focusing lens. Consequently, the ‘spot size’ of the beam, relative to the target tissue, will determine the concentration of laser energy – fluence and power density – being delivered over an area.

It follows therefore, that during any laser tissue interaction the concentration of energy being delivered to a target site can be modified and controlled by moving the handpiece back and forth (Fig. 5).

Transmission

Is the inverse of absorption i.e. the laser energy passes directly through the tissue with no effect on the target tissue. This effect is highly dependent on the wavelength of laser light. For example, water is relatively transparent to

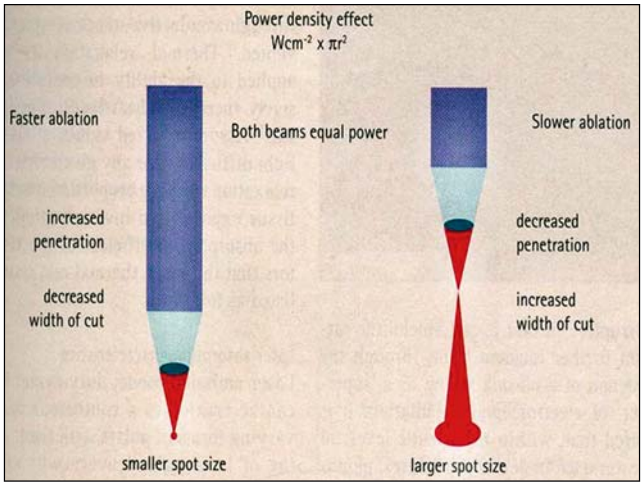

Fig. 5 Effect of contact vs non-contact modes on the 'spot size' of the laser beam

the shorter wavelengths (argon, diode and Nd:YAG lasers) whereas tissue fluids readily absorb the longer wavelengths (erbium family and CO_2) at the outer surface so that there is little energy transmitted to adjacent tissues.

Relative depth of penetration in millimeters of different wavelengths in water is depicted in Figure 4. The erbium family acts mainly on the surface with an absorption depth of approximately 0.01 mm whereas the 800 nm diodes are transmitted through the tissue to depths up to 100 nm.

Reflection

Refers to the beam redirecting itself off of the surface, having no effect on the target tissue. For example, a caries detecting device used the reflected light to measure the degree of sound tooth structure. Reflection can be dangerous because the energy is directed to an unintentional target such as eyes. This is a major safety concern for laser operation.

Scattering

Refers to the laser beam in different directions. This phenomenon is useful in facilitating the curing of composite resin or in covering a broad area. However, scattering results in weakening the intended energy and also unwanted thermal damage due to heat transfer to the tissue adjacent to the surgical site.

Thermal relaxation is the term applied to the ability to control a progressively increasing heat loading of the target tissue.

Rate of thermal relaxation is:

Directly proportional to – the area of the tissue exposed; and

Inversely proportional to – the absorption coefficient of the tissue.

i.e. RTR (rate of thermal relaxation)

$$\alpha \quad \frac{\text{Area of tissue exposed}}{\text{Absorption coefficient of the tissue}}$$

Factors that influence thermal relaxation are:

- Laser emission mode
- Laser incident power (J/sec)
- Laser power density (W/cm^2)
- Laser beam movement (relative to tissue site) - rapid laser beam movement will reduce heat build up and aid in thermal relaxation
- Endogenous coolant (blood flow)
- Exogenous coolant (water, air, precooling of tissue).

Photobiologic Effects of Laser

- Photothermal effect
- Photochemical effect
- Photoacoustic effect [3].

Photothermal Effect

The principle effect of laser energy is photothermal, i.e. the conversion of light energy into heat. The rate of temperature rise plays an important role in this effect and is dependent on several factors such as

- Cooling of the surgical site
- Ability of the surrounding tissues to dissipate heat
- Various laser parameters such as emission mode, power density and the time of exposure.

With regard to surgical laser-tissue interaction with soft tissue [6] (Fig. 6):

- Absorption of incident energy leads to generation of heat
- Ascending heat levels leads to dissociation of covalent bonds (in tissue proteins), phase transfer from liquid to vapor (in intra and intercellular water), onto phase transfer to hydrocarbon gases and production of residual carbon
- Heat generation can lead to secondary effects through conduction.

Assuming a correct incident wavelength, using correct delivery parameters, a central zone of tissue ablation is surrounded by an area of irreversible protein denaturation (coagulation, eschar). Surrounding this, along a thermal gradient, a reversible, reactionary zone of edema will develop. The depth and extent of this tissue change will differ with laser wavelength, being more superficial in nature with longer wavelengths, with less edema, and deeper with greater edema with shorter wavelengths (Fig. 7).

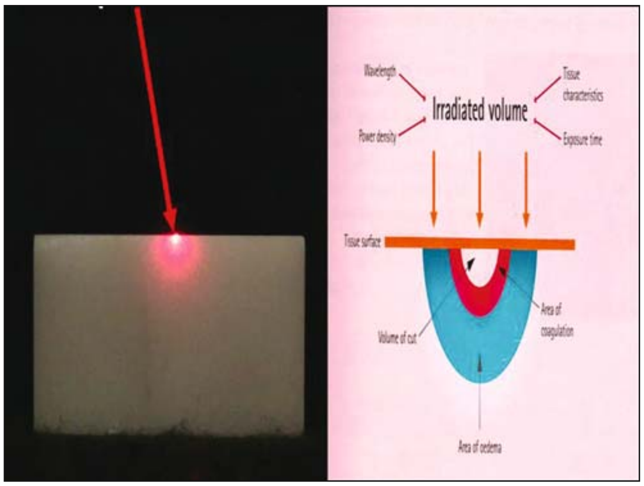

Fig. 6 Schematic representation of an ideal surgical laser interaction with soft tissue

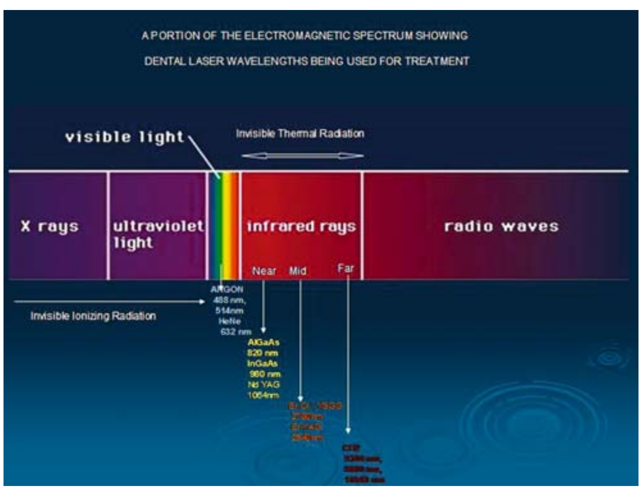

Fig. 7 A portion of the electromagnetic spectrum showing the available dental laser wavelengths

The physical change in target tissue achieved through heat transfer is termed photothermolysis. This is further subdivided, subject to temperature change, phase transfer and incident energy levels, into *photopyrolysis, photovaporolysis and photoplasmolysis*.

Photopyrolysis: consistent with ascending temperature change from 60°C to 90°C, target tissue proteins undergo morphologic change, which is predominately permanent.

Photovaporolysis: at 100°C, inter and intracellular water in soft tissue and interstitial water in hard tissue is vaporized. This destructive phase transfer results in expansive volume change, which can aid the ablative effect of the laser by dissociating large tissue elements, especially seen in laser use in hard dental tissue cutting.

Photoplasmolysis: characterized by high temperatures and explosive expansion at microtissue and molecular levels, this is observed in ultra-short pulsed lasers, e.g. Nd:YAG, Er:YAG, with pulse widths of <100s. This phenomenon is adjunctive to photothermolysis, whereby a plasma is formed by the ionizing effects of the strong electric fields of light waves, and power densities $>10^{10}$ W/cm^2 are attained. Photoplasmolysis is achieved photonically in soft tissue and thermionically in hard tissue and is characterized by flashes and popping sounds during laser use. Plasma formation can be beneficial, in that extremely high ablative energies can be produced, but also disruptive in that it can 'shield' the target from further incident light, through the phenomenon of a plasma acting as a 'super-absorber' of electromagnetic radiation. It is considered that, within therapeutic levels of laser power used in dental procedures, photoplasmolysis is a rare occurrence.

The photothermal effects of laser energy on the target tissue are shown in Table 1.

Photochemical Effect

The laser light can stimulate chemical reactions (e.g. curing of composite resin) and breaking of chemical bonds (e.g. using photosensitized drugs exposed to laser light to destroy tumor cells, a process called photodynamic therapy).

Photoacoustic effect

The pulse of laser energy on a crystalline structure (e.g. dental hard tissues) can produce an audible shock wave, which could explode or pulverize the tissue with mechanical energy creating an abraded crater. This phenomenon is called the photoacoustic effect of laser light.

Benefits of Laser Tissue Interaction

The benefits of laser use in the treatment of soft and hard tissue can be listed as follows:

Soft tissue:

- Ability to cut, coagulate, ablate or vaporize target tissue elements

Table 1 Photothermal effects of laser energy on the target tissues

Tissue temperature	Observed effect	Applications
37–50°C	*Hyperthermia* i.e. tissue temperature is elevated above normal temperature but is not destroyed.	Photobiostimulation
60–70°C	*Coagulation* (irreversible damage to tissue, congealing liquid into a semi-solid mass)	*Coagulation* produces hemostasis by contraction of the vessel wall
	Photopyrolysis- Protein denaturation without any vaporization of the underlying tissue. The tissue whitens or blanches	*Protein denaturation* is useful in surgically removing diseased granulomatous tissue leaving the underlying healthy tissue intact
70–80°C	*Welding of tissue* i.e. adherence or stickiness of layers of soft tissue due to the helical unfolding of the collagen molecules and their intertwining with adjacent segments	Approximation of soft tissue edges
100–150°C	*Photovaporolysis* - *Vaporization/ablation* (vaporization of water within the target tissue)	Ablative effect of lasers - excision of soft tissue commences at this temperature because of the high content of water in the soft tissues
	Spallation - refers to the microexplosion of the apatite crystals due to the vaporization of water from within the hard tissue resulting in a jet of steam that expands and then explodes the surrounding matter into small particles.	Hard tissue cutting
>200°C	*Carbonization - i.e dehydration* and burning of tissue in the presence of air resulting in carbon as the end-product. *Heat sink, collateral thermal trauma* - on continuous laser application above 200°C the surface carbonized layer prevents normal tissue ablation by absorbing the incident beam causing heat conduction collaterally to a wide area.	

- Sealing of small blood vessels (dry field of surgery)
- Sealing of small lymphatic vessels (reduced post-operative edema)
- Sterilizing of tissue (due to heat build-up and production of eschar layer and destruction of bacterial forms)
- Decreased postoperative tissue shrinkage (decreased amount of scarring).

Hard tissue:

- Ability to selectively ablate carious dental tissue (faster ablation due to higher water content)
- Reduced perioperative cracking compared to rotary instrumentation
- Scope for minimally-invasive restorative treatment of early caries
- Reduced pulpal temperature rise
- Cavity sterilization.

Laser Wavelengths used in Dentistry

A brief description of laser wavelengths used in dentistry is given in Table 2. The laser is named according to its active medium, wavelength, delivery system, emission modes, tissue absorption and clinical applications [2, 3].

All available dental laser devices have emission wavelengths of approximately 500 nm (0.5 μ) to 10,600 nm (10.6 μ) (Table 2). These wavelengths are in the visible or the invisible non-ionizing portion of the electromagnetic spectrum (Figs. 7 and 8) and emit ‘thermal radiation’.

Table 2 Laser wavelengths used in dentistry

LASER	Argon	Diode	Nd:YAG	Ho:YAG	CO_2	Erbium family (Er Cr :YSGG, Er:YAG)
Active medium	Argon gas	Solid semiconductor crystals/wafer composed of aluminium/indium, gallium and arsenic (GaAlAs, InGaAs)	A solid garnet crystal combined with rare earth elements yttrium and aluminium doped with neodymium ions	A solid crystal of YAG (yttrium aluminium garnet) sensitized with chromium (Cr) and doped with holmium and thulium ions	A mixture of CO_2, helium (He) and nitrogen (N_2) gases in proportions 8:7:1	1. ErCr:YSGG (erbium chromium: yttrium scandium gallium garnet): A solid crystal of YSGG doped with Er Cr 2. Er:YAG (erbium: yttrium aluminium garnet): A solid crystal of YAG doped with Er
Wavelength	There are 2 emission wavelengths used in dentistry (both are visible to the human eye): (i) 488 nm (blue) (ii) 514 nm (blue-green)	Available wavelengths for dental use (placed at the near infrared portion of the invisible non-ionizing spectrum): (i) 655 nm (a visible red diode) (ii) 800–830 nm (AlGaAs) (iii) 980 nm (InGaAs, GaAlAs)	1,064 nm (placed in the invisible near-infrared portion of the electromagnetic spectrum)	2,100 nm (placed in the near infrared portion of the invisible non-ionizing radiation spectrum)	Three emission wavelengths exist (placed at the end of mid-infrared invisible non-ionizing portion of the spectrum): 9,300 nm 9,600 nm and 10,600 nm	Two emission wavelengths exist(Both the wavelengths are placed at the beginning of the mid-infrared, invisible and non-ionizing portion of the spectrum): (i) 2780 nm (Er Cr:YSGG) (ii) 2,940 nm (Er:YAG)
Delivery system	Fiberoptic cable Non-contact mode Contact mode	Fiberoptic cable used in contact mode (for soft tissue surgery) and non-contact mode (for deeper coagulation)	Fiberoptic cable Contact mode non-contact mode	Fiberoptic system	Hollow waveguide with a hand piece in contact/ non-contact modes	Fiberoptic cable (for Er Cr:YSGG) Hollow waveguide/ fiberoptic bundle (for Er:YAG)
Emission mode	Continuous wave and gated pulsed modes	Continuous wave and gated pulsed modes	Free running pulsed mode	Free running pulsed mode	Continuous/gated pulsed mode	Free running pulsed mode

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Table 2 Laser wavelengths used in dentistry *(Cont'd)*

Tissue absorption	Both wavelengths have poor absorption in dental hard tissues and in water The 488 nm blue light activates camphorquinone, the most commonly used photoinitiator in light cure composites, and light activated impression pastes and bleaching gels The 514 nm blue-green light has its peak absorption in hemoglobin, hemosiderin and melanin	Highly absorbed by pigmented tissue. Relatively poorly absorbed by tooth structure	Highly absorbed by melanin but is less absorbed by hemoglobin than the argon laser. Approximately 90% transmitted through water	Absorbed by water 100 times greater than Nd:YAG Ablates hard calcified tissue at high peak powers Does not react with hemoglobin or other tissue pigments	Highest absorption in hydroxyapatite than any other dental laser, about 1,000 times greater than erbium and is well absorbed by water, second only to the erbium family. It has shallow depth of penetration into tissue (100–300 micrometer deep)	Both the wavelengths have the highest absorption in water in comparison with other dental laser wavelengths and have a high affinity for hydroxyapatite (Affinity of Er is 20% higher than Er, Cr)
Clinical applications	Both wavelengths can be used as an aid in caries detection. When the argon laser light illuminates the tooth, the carious area appears as a dark orange-red color and is easily discernible from the surrounding healthy structures Polymerization of light activated composite resins, dentin bonding agents, sealants, bleaching gels and light-activated impression materials The 514 nm green light argon is used to perform soft tissue procedures: gingivoplasty, gingivectomy, crown lengthening and troughing. Treatment of highly vascularized lesions such as hemangiomas, coagulation and hemostasis	The 655 nm visible red diode is used to analyze and quantify the degree of caries Soft tissue surgeries like cutting and coagulating gingiva and oral mucosa Sulcular debridement	Cutting and coagulating dental soft tissues. Sulcular debridement removal of pigmented surface carious lesions hemostasis. Treatment of aphthous ulcers pulpal analgesia	Frequently used in oral surgery for arthroscopic surgery on the TMJ. Also, has many medical applications	Primary dental applications are soft tissue procedures such as: Gingivectomy, gingivoplasty, frenectomy, biopsy, treating, mucosal lesions, vaporization of dense fibrous tissue, debulking substantial soft tissue masses (because of a shallow thermal necrosis zone) and coagulation after completion of surgery (a defocused beam is used to place a biologic bandage called 'eschar' on the wound surface)	Decontamination of cavity sites Caries removal and cavity preparation Removal of dentin and pulpal tissue(RCT) Bone removal Tissue retraction for uncovering implants

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Table 2 Laser wavelengths used in dentistry *(Cont'd)*

Advantages	Enhanced physical properties, improved adhesion, reduced microleakage and less curing time (10 secs) compared to conventional curing light Excellent hemostatic capabilities No damage to the tooth structure during soft tissue procedures because of poor absorption into enamel and dentin	Small, portable and compact unit Excellent soft tissue surgical laser. However, hemostasis is not as rapid as with argon laser Soft tissue surgeries can be performed in close proximity to enamel, dentin and cementum as these lasers are poorly absorbed by the tooth structure Lowest priced lasers currently available The 655 nm visible red diode excites fluorescence from a carious tooth which is reflected back into a detector in the unit that analyzes and quantifies the degree of caries	The free running pulsed mode allows the clinician to treat thin or fragile tissue with a greater safety margin of preventing heat build-up in the surrounding area Allows for safe and precise soft tissue surgery adjacent to sound tooth structure as there is little interaction with the tooth structure Pigmented surface carious lesions can be vaporized without removing the healthy sound enamel Can penetrate several millimeters when used in a non-contact defocused mode, which can be used for procedures such as hemostasis, treatment of aphthous ulcers or pulpal analgesia	Efficient tissue ablation at the surgical site because of good absorption by water in the soft tissues. Optic fiber affords good access, precision and tactile feedback. Collateral thermal damage can be avoided because it is produced in a pulsed mode. The lasers absorbency by tooth structure is low, which allows tissue surgery in close proximity to enamel, dentin or cementum to proceed safely	Precise and quick soft tissue vaporization in a non-contact mode without a need to touch the tissue is especially advantageous when treating movable oral structures such as tongue and floor of the mouth Large lesions can be treated with a simple back and forth motion	Painless procedure. Absence of vibration or high pitched noise experienced during the procedure Provides the tissue interaction characteristics to perform effective RCT and bone removal Can readily ablate soft tissues because of its high water content and the lasers affinity for water A carious lesion in close proximity to the gingiva can be treated and the soft tissue recontoured with the same instrumentation The non-interaction with precious metal and fused porcelain allows the practitioner to remove caries surrounding the restorations without any damage Tissue retraction for uncovering implants is safe with these wavelengths because there is minimal heat transferred during the procedure

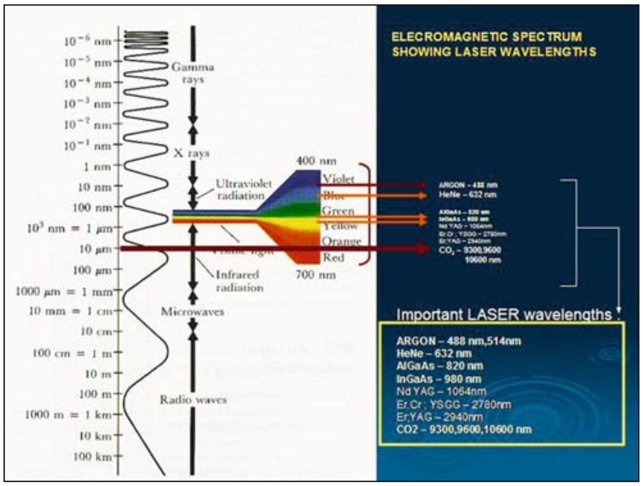

Fig. 8 Electromagnetic spectrum and dental laser wavelengths

Laser Types used in Tissue Therapy

Anecdotally, there has evolved two groups of lasers, 'hard' and 'soft', in distinguishing their effect on tissue [6, 7].

'Hard', or surgical lasers are essentially high power lasers which achieve desired tissue effect through a direct interaction. This effect is primarily *photothermal*, in that incident light energy is absorbed and converted into thermal energy which causes tissue change.

'Soft', or 'low-level' lasers are essentially low power lasers which achieve desired tissue effect through an indirect interaction, known collectively as *photobiostimulation*, e.g. tissue warming, increase of local blood flow and production of 'feel-good' factors, e.g endorphins.

Examples for Soft Lasers

Helium-neon laser (633 nm), gallium-arsenide laser (820 nm), diode lasers (GaAs 904 nm, GaAlAs 780–890 nm, InGaAlP 630–700 nm).

Laser Units

In comparison to surgical lasers, low-level laser units are much smaller, often self-contained, hand-held devices, which are either battery-driven or charged via a pod in a bench-top master unit. There is no need for any integral cooling system and their power output levels often warrant no specific safety rules that apply to surgical laser units.

The amount of laser energy delivered to a target tissue is termed *fluence*, or energy density and is measured in J/cm^2. In clinical practice, low-level laser therapy delivers fluence of 2–10 J/cm^2, depending on the target tissue as follows:

- Oral epithelium and gingival tissue - 2–3 J/cm^2
- Transosseous irradiation (target - periapical area) - 2–4 J/cm^2
- Extraoral muscle groups/TMJ - 6–10 J/cm^2

Laser Safety

Classes of Laser

Class I: Examples are found in CD players and laser caries detectors. Viewing with the naked eye poses no implicit risk, but caution should be observed if wearing spectacles or using optical devices (Class IM – 'magnifying'). The maximum power output of these lasers is 40 µW (blue light) and 400 µW for red light emissions [8, 9].

Class II: Examples are laser pointers. There exist specific risks to viewing light emissions, both to the naked eye and when using magnification. The maximum output is 1 mW.

Class III: The 'old' class IIIA is replaced by classes IM and IIM. Class IIIB represents maximal power output of 0.5 W. Examples include 'soft' medical lasers (LLLT), laser light show equipment and laser measuring devices. Environmental controls, protective eyewear, appointment of assigned safety personnel (laser safety officer [LSO], laser protection advisor [LPA]) and training in laser safety are required by personnel using these lasers.

A new classification is the class IIIR, which may also include some low level medical devices and targeting lasers, but generally lasers of lower power outputs than IIIA. For emission in the visual range of wavelengths (400–700 nm), the maximum power output is 5 mW and with invisible wavelengths 2 mW. The same safety measures are required as with class IIIB lasers.

Class IV: This class includes all high-powered, surgical and other cutting lasers. There is no upper limit of power output. All surgical lasers used in dentistry and oral and maxillofacial surgery are included. The protective measu beam exposure and skin (non-occular) exposure.

Risks Associated with Laser use

Laser Beam Risks

These risks are those that are posed by exposure of non-target tissues to laser beams. Because of the intensity of the output beam and the ability of lasers to produce very high concentrations of optical power at considerable distances, these lasers can cause serious injuries to the eyes and can also burn the skin.

Optical Risks

The majority of laser-induced ocular injuries are considered due to operator error. In general and with specific reference to lasers used in dentistry, there exist two groups of wavelengths that can adversely affect the eye.

- Wavelengths from 400–1,400 nm (visible and near-infrared) can pass through the transparent structures in front of the eye and impact on the retina.
- Longer wavelengths (2,780–10,600 nm, mid-to-farinfrared), will interact with the cornea.

In terms of the scope for repair, retinal injuries are more serious. Due to the focusing ability of the lens, a 1 mW (0.001 W) laser beam, passing to the back of the eye, results in a retinal irradiance more than 300 W/cm^2, well above the ablation threshold. Visible wavelengths may selectively destroy red or green cones, resulting in some color blindness, although the majority of retinal laser burns affect complete areas of tissue due to the predominance of invisible wavelengths in dental lasers. Retinal injury may initially pass unnoticed, due to the lack of pain receptors.

Longer wavelengths will interact with structures at the front of the eye, causing ablation, scarring and distortion of vision

Non-pigmented structures towards the front of the eye will be most at risk from longer wavelengths.

Skin Risks

Whilst ultraviolet lasers (<400 nm) are not commercially used in dentistry, there is a combined risk of ablative damage to skin structure and possible ionizing effects that may be precancerous. All other laser wavelengths can cause 'skin burns' due to ablative interaction with target chromophores.

Non-beam Risks

These risks are associated with possible physical damage arising from:

- Moveable components of a laser, electrical shock and mains supplies (pressurized air, water).
- Fire risks, through the ignition of tubing, some anesthetic gases or chemicals (e.g. alcoholic disinfectants), should be identified and avoided.
- The products of tissue ablation, collectively termed a 'laser plume' represent a considerable hazard that can affect the clinician, auxiliary personnel and the patient.

Whenever non-calcified tissue is ablated, such as in caries removal and all soft tissue surgery, a complex chemical mixture is emitted. This may include water vapor, hydrocarbon gases, carbon monoxide and dioxide and particulate organic material (including bacteria and viral bodies). The effect of plume inhalation can be serious and cause nausea, breathing difficulties and distant inoculation of bacteria. The plume arising from mid-infrared wavelength ablation of dental hard tissue is comparatively less potentially dangerous and can be considered similar to the debris that is produced with an air turbine.

Suitable fine mesh face masks specific to surgical laser use, gloves and high-speed suction aspiration must be used to control the spread of all laser tissue ablation product.

Laser Safety Measures

Safety measures applicable to laser use in dental practice meeting the worldwide standards can be listed as follows:

- Environment
- Laser protection advisor/Laser safety officer (LPA/LSO)
- Access
- Laser safety features
- Eye protection
- Test firing
- Training.

Environment

The concept of laser beam collimation is only true for transmission in a vacuum, or at its immediate exit from the laser cavity. In air, and certainly through a delivery system with or without focusing devices, some divergence will occur. Accepting the power output, amount of divergence and beam diameter and configuration, a nominal ocular hazard distance (NOHD) can be assessed. This is a distance from the laser emission, beyond which the tissue (eye) risk is below the maximum permissible exposure levels (MPE). This is a complex calculation that can be done by a medical physicist, but for a class IV dental laser, this distance is approximately 3 meters.

Consequently, as with ionizing radiation, the concept of a controlled area can be adopted, within which only those personnel directly involved in laser delivery can enter and with specified protection. The controlled area must be delineated with warning signs that specify the risk, windows, doors and all surfaces should be non-reflective and access throughways either supervised or operated by remote interlocks during laser emission. A secure locked designated place for the laser key, if applicable, should be assigned, together with a designated place for all laser accessories. In addition, a suitable fire extinguisher should be sited for easy access.

Safety Officers

Dental practices offering class IIIB and IV laser treatment, must appoint a laser safety officer (LSO) and a (LSA). The Laser protection advisor (LPA) is usually a medical physicist who will advise on the protective devices required, maximum permissible exposure level and nominal ocular hazard distance (NOHD) for any given laser wavelength being used. The laser safety officer is appointed to ensure that all safety aspects of laser use are identified and enforced. Ideally, this could be a suitably trained and qualified dental surgery assistant. Duties of the laser safety officer include the following:

- Confirm classification of the laser
- Read manufacturers' instructions concerning installation, use and maintenance of the laser equipment
- Make sure that laser equipment is properly assembled for use
- Train workers in safe use of lasers
- Oversee controlled area and limit access
- Oversee maintenance protocols for laser equipment
- Postappropriate warning signs
- Recommend appropriate personal protective equipment such as eye wear and protective clothing
- Maintain a log of all laser procedures carried out, relative to each patient, the procedure and laser operating parameters
- Maintain an adverse effects reporting system
- Assume overall control for laser use and interrupt treatment if any safety measure is infringed.

Access

During laser treatment, only the clinician, assistant and patient should be allowed within the controlled area. Door locks and warning lights can be activated during laser emission. Those dental clinics that operate a multi-chair, open-plan environment would need to address the requirement in greater detail.

Laser Safety Features

All lasers have in-built safety features that must be cross-matched to allow laser emission. These include:

- Emergency 'Stop' button
- Emission port shutters to prevent laser emission until the correct delivery system is attached
- Covered foot-switch, to prevent accidental operation
- Control panel to ensure correct emission parameters
- Audible or visual signs of laser emission
- Locked unit panels to prevent unauthorized access to internal machinery
- Key or password protection
- Remote inter-locks.

Eye Protection

All persons within the controlled area must wear appropriate eye protection during laser emission. It is considered advisable to cover the patient's eyes with damp gauze for long wavelength perioral procedures. The laser safety officer should select the correct eyewear for the laser wavelength being used, these should be free of any scratches or damage and be constructed with side protection/shields to protect the eyes from reflective laser energy. The information about lens protection must be imprinted on the frames of the glasses or goggles.

Generally, protective glasses must have an optical density (OD) of at least 4 for the particular laser emission and device.

Test Firing

Prior to any laser procedure and before admitting the patient, either the clinician or laser safety officer should test-fire the laser. This is to establish that the laser has been assembled correctly, is working correctly and that laser emission is occurring through the delivery system. Protective eyewear is worn and all other safety measures met. The laser is directed towards a suitable absorbent material, e.g. water for long wavelengths and dark colored paper for short wavelengths, and operated at the lowest power setting for the laser being used. Following this, the laser is inactivated and the patient admitted.

Training

All staff members should receive objective and recognized training in the safety aspects of laser use within dentistry, as with other specialties. However, there is no legal obligation for this.

Summary and Conclusion

The basics of laser science, tissue effects of dental lasers,various dental laser wavelengths, laser parameters and safety measures have been discussed. Each wavelength and each device has specific advantages and disadvantages. It is therefore important for the clinician to understand these principles to take full advantage of the features of lasers and provide safe and effective treatment.

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