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Review Article

Laser Essentials for the Dental Practitioner: Foundation Knowledge - Construction, Modes of Operation and Safety

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Abstract

Aim: Understanding laser and light generation by therapeutic optical sources is fundamental to comprehending light and laser-tissue interaction in biological tissues. The aim of this article is to set out the fundamentals of laser technology as it may be applied to clinical application and therapy within General Dental Practice. The elements of construction and modes of operation will be explained, together with an overview of safety aspects of laser use and how they might impact on all personnel involved in the delivery of laser photonic energy in the dental office or treatment room.

Materials: A review of recent and current peer-reviewed publications will provide suitable reference to this article, sufficient to inform the reader who might be a new or early adopter of clinical laser technology.

Conclusion: Understanding the fundamentals of laser photonic energy generation and transmission is essential in order to best guide laser and light applications to achieve optimum clinical gain in a safe and predictable manner. This paper has offered the new user of lasers in clinical dentistry a guide to the types of lasers in common use, together with their desired effects. Of prime importance, the protocols that promote the safe use of lasers are outlined.

Keywords: *Laser, Diode; Laser Types; Laser-Tissue Interaction; Optical Properties of Tissues; Dentistry; Low Level Laser Therapy; High Intensity Laser Therapy; Photobiomodulation; Laser Safety*

Introduction

Human homeostasis in general represents a ground state of endothermic energy balance pursuant to the optimal activity of the individual and controlled turnover of constituent structural elements [1]. A change in energy applied to the individual may cause compensatory measures to re-establish normal cellular and tissue physiology; a simple example of this is the change induced through hot weather with skin vasodilation and perspiration.

External sources of energy may be in the form of electromagnetic energy, of which light is an example, forming a portion of an electromagnetic spectrum. Light may be interpreted as that form of electromagnetic energy capable of stimulating the human retina and allowing an image to be produced by the brain. Additionally, wider forms of electromagnetic energy - either shorter wavelength such as ultra-violet or longer wavelength infra-red radiation may also give rise to the consequences of absorbed energy by the body [2].

Specific light therapy has been prescribed in the past - exposure to sunlight and known as heliotherapy - in the treatment of certain diseases, such as the skin condition lupus vulgaris. The difficulty in delivering a known specific dose was one of several reasons why such therapy may have been difficult to deliver satisfactorily.

The development of early theory and later manufacture of sources of laser photonic energy provided benefit in that a known source of single wavelength irradiation could be delivered within a predetermined therapeutic dose range. Exposure of target tissue or biological structures to this unique form of photonic energy would define the essentials of surgical laser-tissue interaction, in which absorbed incident energy would be predominately converted to thermal energy, leading to consequent heat-mediated change in the ground state of the exposed tissue element [3].

In exploring the delivery of a therapeutic photonic dose, it is necessary to discuss the fundamental physics of photonic energy generation, the capture of such energy within a laser instrument and the effects of both energy wavelength and power might have on target tissue.

Laser fundamentals

The unique properties of laser photonic energy are spatial and temporal coherence of wave propagation together with the emission monochromaticity conferred through a single wavelength value. These fundamental properties render advantage through a predictable level of target absorbance and reduced power loss that is a result of positive wave interference within incoherent light propagation. In consequence, it is possible to deliver selective laser-tissue interaction and to maximise the light dose effectiveness [4].

The creation of laser photonic emission, drawing upon theoretical work of Young, Faraday, Maxwell, Hertz, Bohr and Einstein and the concept of electromagnetic energy, provides a reference point whereby a chosen "host" material may be stimulated with externally-sourced energy; the consequent excitation leads to the emission of a unit of energy, or photon as the host energy state returns to a base level. This process represents a form of stimulated emission, which differs from spontaneous emission that is a characteristic of radioactive substances. The photon stream produced in harmony with the frequency of the applied external energy constitutes a beam of light. Amplification of the stream - oscillating back and forth through the use of mirrored surfaces, allows photon interaction with already-excited atoms of the host material and consequent emission of two photons, identical in energy and phase coherence. The work of Maxwell helped define the strict relationship between photon energy and electromagnetic wavelength, hence the photon energy created through amplification would be unique for the source host atom and define monochromaticity [5].

The acronym LASER - Light Amplification by the Stimulated Emission of Radiation - is an appropriate summation of the process of creation of laser photonic energy. The understanding of the basic process can extend to explain the many different laser machines that may be found in clinical dental practice. With solid host material, a central crystal is grown with component atoms and mounted co-axial to distal and proximal mirrors. When energised - often by use of a flash-lamp - the resultant stream of photons is emitted with the same frequency as the pumping mechanism. It is common to see in these lasers an emission mode of rapid micro-second pulses, termed Free-Running Pulsed. Examples of this form of emission may be seen in lasers where a host crystal such as yttrium aluminium garnet (YAG), suitably "doped" with impurities of near-earth atoms such as neodymium (Nd) and erbium (Er) may provide lasers that are so-called according to the host material. Since each individual laser will have a unique emission wavelength, measured from wave-crest to wave-crest in nanometers (1nm - 1×10^{-9} meters), these examples of lasers in dentistry are referred to as Nd:YAG (1064 nm) and Er:YAG (2940 nm). Other examples of similar solid state lasers derive their emission through similar "doped" crystal host materials, such as erbium, chromium, yttrium scandium gallium garnet (Er,Cr:YSGG 2780 nm) and neodymium yttrium aluminium perovskite (Nd:YAP 1340 nm).

Gas-based lasers commonly found with argon-ion (Ar^{++}) or carbon dioxide (CO_2) as host material formed an historical base to early laser adoption within dentistry in the 1970s and 1980s. These host materials were housed within a tube similar to that found in fluorescent lamps and were energised through the delivery of a continuous wave electric discharge. The emission frequency of these lasers matched that of the energy source, resulting in a basic continuous wave emission. The wavelength of these lasers was 488 nm and 10,600 nm respectively. The use of the argon laser in dentistry has diminished over time and the CO_2 laser technology has grown through the development of atomic carbon isotope employment in the parent molecule, resulting in a generic CO_2 laser but with individual emission wavelengths of 10,600 nm, 9,600 nm and 9,300 nm - each with differing application relative to target absorption phenomena.

The third important group of lasers found in dentistry are referred to by the generic term "diode". Within an electric circuit, the use of a "diode" component - a portmanteau of "di" and "electrode" - serves to rectify an alternating (AC) current to a direct (DC) current. The basis of a diode is the semiconductor chip; although several types of diodes exist, in simple terms atoms of differing valence are grouped within a silicon "sandwich", which when energised, allows the flow of electrons from the higher valence group to the lower valence group.

With a diode laser, the choice of typical Group III and V valence atoms (e.g. gallium or indium and arsenic or phosphorus) give rise, when energised to a flow of electromagnetic units (photons) of approximately 800nm. The silicon "chip" may be no more than a few millimetres in size and through selective polishing of the sides of the chip, internal reflection and amplification of the photon flow can be achieved to accomplish stimulated emission and laser gain.

In general, the technical complexity and capability of the larger laser units (solid state and gas) is greater than the smaller but more portable diode laser units. Additionally, the scope for wavelength emission within the mid-infrared region of the EM spectrum remains solely with the erbium group of lasers. Finally, the potential for very high "peak power" values during laser tissue interaction rests with the larger laser units [6].

With all lasers, the potential for use within the oral cavity may be achieved through either the use of ultra-flexible fibre delivery or a hand-piece construction, not dissimilar to that used with rotary instruments.

Lasers in dentistry - modes of operation

As a source of electromagnetic energy, "light" when applied to a target tissue, may behave in one of four basic ways: there may be transmission of the beam through the tissue without any interaction; there may be reflection of the beam across the tissue surface, again without interaction; a degree of interaction may occur and the beam is scattered as it passes into the sub-surface region of the tissue; or the light may be absorbed by the tissue and photonic energy converted primarily into heat.

From a predictive and dose-related ideal, the possibility of selective absorption of a given incident laser beam by the target tissue offers the greater level of control. To this end, the phenomena of various wavelengths and their corresponding levels of absorption among oral and dental tissue can be highlighted with reference to the molecular and structural components of these tissues. Water, as a component of all living tissue exhibits low absorption of shorter, visible and near infra-red laser wavelengths and much higher absorption with longer mid- and far infra-red wavelengths. Water is seen as a chromophore - a molecule that has a capacity to absorb incident photonic energy; other chromophores that are commonly found within the oral cavity include protein, of which melanin and collagen are examples, hydroxyapatite and carbonated hydroxyapatite - component crystalline structures of bone and mineralised dental tissue respectively and non-structural components such as circulating blood plasma and haemoglobin [7]. Such levels of absorption relative to laser wavelength can be represented graphically in a series of absorption curves.

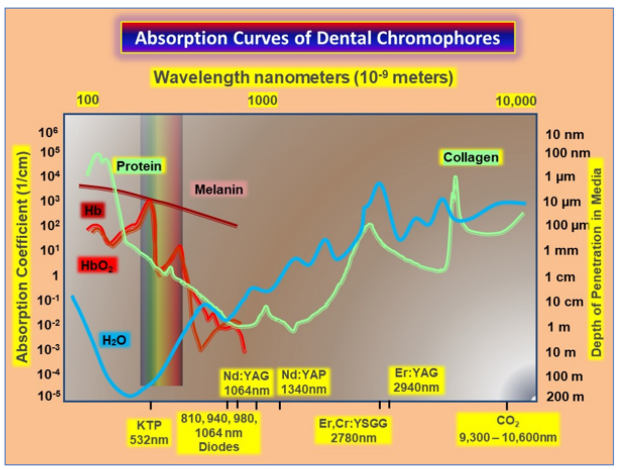

Figure 1: *Absorption curves of major dental/oral chromophores associated with soft tissue management. Absorption is shown relative to wavelength of irradiation. Depth of penetration is shown as 1/absorption. Source: Graphics adapted S. Parker from: Parker S. Laser - Tissue interaction and its application in clinical dentistry. Int. J. Laser Dent. 2011;1(1):1-8.*

Exposure of oral and dental tissue to laser energy will offer a potential mixture of interaction, owing to the complex and anisotropic nature of the tissue. Notwithstanding, such potential for any absorption will result in energy conversion to heat and some thermal rise. The greater the incident laser power, the higher the temperature rise and, considering the level of thermal rise above which some permanent disruption of the tissue will occur, such a level can be seen as the ablation threshold for that tissue. In applying incident laser photonic energy that exceeds the ablation threshold, the resulting change may include protein denaturation, water vaporisation and tissue carbonisation - all examples of photothermolysis [8]. At a molecular level this may induce effects including photoelectrical, photomechanical, photofluoresecent, photomagnetic, photochemical and photothermal change. Such action may be utilised as an adjunct to tissue cutting, heat-induced blood coagulation and, with bone and dental hard tissue an explosive dislocation of the crystalline structure due to water vaporisation and consequent bone removal and dental cavity preparation.

Where a laser photonic energy level is of a lower level, the tissue ablation threshold may not be reached; in consequence, a lesser amount of tissue warming may occur and the penetration of photons deep into the soft tissue - a phenomenon readily seen with near infra-red and some visible wavelengths - may stimulate cellular and intracellular structures as well as biochemical and immune pathways associated with tissue repair and healing [9]. Stimulation of these structures by sub-ablative laser photonic energy constitutes a wide-ranging combination of some stimulation (endothelial cellular budding associated with healing), some inhibition (suppression of pain pathways) and overall a promotion of "feel good" factors that collectively is known as photobiomodulation (PBM) [10].

Such is the belief, through detailed clinical trials and animal studies that PBM affords a predictable source of non-surgical therapy, as well as an accompanying support to laser-assisted surgery, that the author is attributed with the maxim of "laser surgery may appear ugly but the healing is beautiful".

Soft tissue laser surgery

Lasers use in soft tissue surgery may be to deliver excision (fibromata, frenae, tissue hyperplasia, haemangiomata), tissue modification (gingival depigmentation, gingivoplasty, gingivectomy) and treatment of oral pathology such as lichen planus, aphthae as well as adjunctive use in post-extraction haemostasis [11].

The extensive group of diode laser wavelengths (455 – 1064 nm) offers opportunity for the clinical dental practitioner to both treat frank soft tissue lesions or to integrate the management of soft tissue as an adjunct to restorative and other hard oral tissue management. Predominately, absorption will be in tissue protein, pigmented structures and blood and the majority of procedures provided within the out-patient clinic will be achievable with power levels of 1.0 - 2.5 Watts average power. Current diode lasers have greater sophistication in power delivery, whereby the beam can be interrupted ("gated") to offer some tissue thermal relaxation.

Longer wavelength lasers, such as the erbium group (Er:YAG and Er,Cr:YSGG) together with the CO_2 lasers are predominately absorbed in tissue water and may be used on all soft tissue structures.

Hard oral/dental tissue laser surgery

This group of procedures includes bone and dental hard tissue, as well as dental calculus and cementum. The erbium group of wavelengths are capable of free-running pulsed delivery emission and each pulse can be as little as 50 micro-seconds in width. As a result, very high peak power values may accompany such delivery and with the predominant absorption in water (free water and intramolecular hydroxyl groups in enamel, dentine and bone), will lead to explosive dislocation of the target hard tissue macrostructure - a process known as spallation. Average ablation powers may be slightly higher than with soft tissue ablation - approximately 3.0 - 6.0 Watts, but the very high peak power values (> 3000 Watts) serves to provide sufficient power to achieve hard tissue ablation [12]. Additionally, a newer configuration of a CO_2 laser, operating at 9,300 nm and with ultra-short gating of the emission, has been shown to also achieve competent dental tissue ablation [13].

Although the predominant chromophore with current laser wavelengths remains as water, there is evidence of high absorption in protein hydroxyapatite (bone / dentine) and carbonated hydroxyapatite (enamel) [14]. In irradiance of the latter, there is some absorbance within the carbonate radical around 7,000 nm and the phosphate radical at 9,300 - 9,600 nm. By far, the limiting factor in defining true crystalline dissociation with current lasers in dentistry, is the ability to develop high enough peak power values through nano- and femto-second pulses, although technology is leading in this direction.

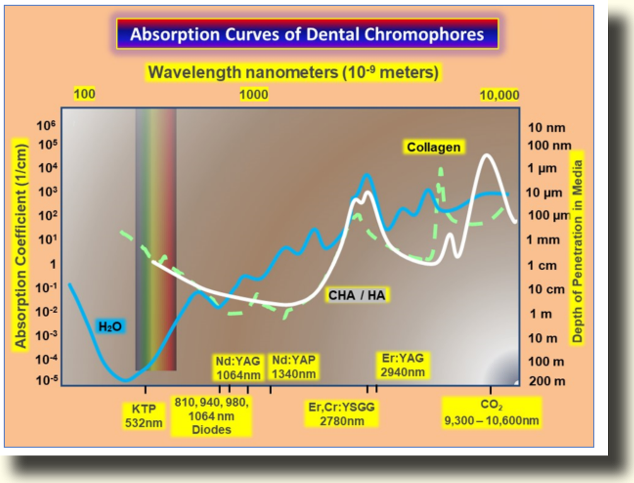

Figure 2: *Absorption curves of major chromophores associated with bone and dental hard tissue management. Absorption is shown relative to wavelength of irradiation. Source: Graphics adapted S. Parker from: Parker S. Surgical lasers and hard dental tissue. Br. Dent J. 2007;202:(8)445-454.*

Aspects of laser safety

The wide range of lasers for useful application in daily dental clinical practice can range from simple devices for use in scanning procedures, slightly more complex devices that are used as adjuncts to aid diagnostic examination and on to those more powerful lasers that may be used to deliver PBM and tissue surgery. Such a wide range serves to illustrate a classification (I - IV) of lasers with a determining grouping related to maximum power output.

In the same way that target oral tissue may be modulated or ablated with a chosen laser wavelength, a substantial risk may present to non-target tissue, intra-orally, with skin and especially the unprotected eye.

In general, those lasers classified within Group III and IV have power output that places them as the greatest risk to non-target and unprotected structures of the patient, operator and any support staff within close proximity to the procedure being performed.

The absolute governance of regulations as they may pertain to the safe use of lasers is the International Electrotechnical Institute (IEC) and A.N.S.I. (American National Standards Institute). From these organisations and their representation, National Regulations may apply - either as specific statutory instruments or more often as part of laws and regulations that might apply within the workplace [15-17].

From such broad regulation, safety and risk assessment when using lasers and light-emitting diode (LED) equipment in clinical dental surgery can be devolved to include [17]:

- Suitability for use, clinical parameters
- Administrative code, record keeping
- Safety features of laser, laser maintenance
- Environment safety, patient safety
- LSO - laser safety officer

The risk posed by coherent light irradiation, etc:

(i) **The laser wavelength:** In clinical dentistry, the range of laser wavelengths falls within 370 nm and 10,600 nm, i.e. from the blue visible limit to the far infra-red, non-ionising spectrum. All laser tissue interaction may be viewed as photothermal in that incident photonic energy is absorbed by chromophore molecules, raising the molecular energy level and leading to disruption.

(ii) **The power intensity of the incident laser irradiation:** This will be related to the amount of energy delivered over time, together with consideration of the area of tissue that is exposed to the beam. In consequence, the power density of the beam may represent a threshold above which irreversible change may occur in tissue exposed to the beam.

(iii) **Optical risks:** The unprotected eye is generally regarded as the organ at greatest risk from accidental laser exposure. Several cases of laser-induced eye injuries have been documented [19-21]. For any given laser beam that exceeds an output value in excess of the maximum permitted exposure (MPE) of ocular tissue, a risk pertains that must be anticipated, and safety protocols of eye protection employed. Laser hazards to the eye depend most predominantly upon wavelength [22-24].

(iv) **Non-target oral tissue:** The oral cavity may present significant challenge in terms of access and non-intentional/function-related movements of structural components in the conscious dental patient. Often the visualisation and access for treatment of individual teeth and areas of supporting tissues, is compromised by restriction in space together with involuntary movement of the cheeks, lips and tongue. Additional risk may be posed to non-target oral tissue through reflection phenomena. Many instruments used in dentistry are metal and in many instances the clinician will operate using a mouth mirror. Direct reflection or specular (diffuse) reflection of the incident laser beam may expose non-target oral tissue to ablative beam fluences and may not be detected at the time of the treatment. Moist oral tissue may lead to specular reflection.

(v) **Non-target skin**.

(vi) **Inhalation and laser plume risks:** A by-product of the surgical ablation of target oral tissue is the production of the "laser plume". This represents a significant hazard from breathing airborne contaminants produced during the vaporization of tissues. Studies of the production of both the chemical toxicity of photothermolysis products and the potential viability of infectious particulates (e.g., viral fragments) have shown cause for concern unless efficient aspiration, local exhaust ventilation and operating staff facial protection measures are employed. Although many associated factors may provide some influence, the amount of plume produced and volume of contaminants will be related to incident laser power, nature of target tissue, laser emission mode (CW, FRP) and co-axial supplies such as water and air spray [25-28].

(vii) **Other associated risks:** Hazards - mechanical, chemical, fire and sterilisation

Laser Safety Officer: The LSO is appointed to ensure that all safety aspects of laser use are identified and enforced. Ideally, the LSO could be a suitably trained and qualified dental surgery assistant.

The LSO standing duties refer to the minimum level of responsibility:

(i) Read the manufacturers' instructions concerning installation and use of the laser equipment. Confirm the Class of the laser.
(ii) Be familiar with and oversee maintenance protocols for laser equipment.
(iii) Train other staff in the safe use of lasers.
(iv) Maintain an adverse effects reporting system.

LSO responsibilities during laser use include:

(i) Define and oversee the controlled area specific to the laser being used and limit unauthorised access.
(ii) Post appropriate warning signs at all points of access to the controlled area.
(iii) Make sure that laser equipment is properly assembled for use, together with all disposables. Carry out or supervise a "test fire" of all laser equipment before the patient enters the controlled area.
(iv) Recommend appropriate personal protective equipment such as eye wear and protective clothing (suitable face masks, gowns etc.).

(v) Maintain a log of all laser procedures carried out, to include the patient details, the procedure carried out and laser operating parameters employed.

(vi) Assume overall control for laser use and interrupt the procedure if any safety measure is infringed.

Conclusion

The use of lasers in dentistry has grown during a period of 30 years and drawing upon early application of lasers in surgery and medicine that spanned from the early 1960s. The many applications of laser photonic energy have been the subject of detailed investigation and has given rise to a far-reaching list of applications where the laser is adjunctive to the provision of both surgical and non-surgical therapy within the scope of practice of general and specialist dentistry.

It is incumbent on the clinician to grasp an understanding of the fundamentals of lasers, their application and perhaps foremost, their safe application that extends to the clinician, support staff and patient.

This paper has provided an overview - a basic explanation of laser use in dentistry. It is hoped that those who are new to this treatment modality will build upon this overview and seek greater detail of adjunctive laser use as it may apply to the range of treatments being carried out in clinical practice.

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