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RESEARCH ARTICLE

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AN OVERVIEW OF LASERS IN THE FIELD OF DENTISTRY

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ABSTRACT

Laser is the acronym which means 'Light Amplification by Stimulated Emission of Radiation'. They have showed a very broad way since 1971 (Albert Einstein described the theory of stimulated emission during this year). The advancements and achievements of lasers in the different fields of medicine and dentistry are playing a significant role in the wellbeing of patients. Since the last two decades, there has been an explosion of different research studies in application of lasers. In different fields of dentistry lasers are used in hard tissue application, for prevention of caries, bleaching purposes and restorative purposes i,e both removal and curing, cavity preparation, treatment of dentinal hypersensitivity, growth modulation and for finally for diagnostic purposes, however the soft tissue application includes wound healing, removal of hyperplastic tissue (uncovering of impacted or partially impacted tooth), photodynamic therapy for various malignancies, photo-stimulation of herpetic lesion. Different use of the laser proved to be an effective tool to increase effectivity, efficiency, specificity, ease, cost and comfort of various dental treatments.

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INTRODUCTION

With the introduction of lasers in dentistry (Miaman in 1960s), led to tremendous research in the applications of lasers in different fields of dental practice. There are two particular scenarios, on one hand there are hard lasers (CO2, Nd: YAG and Er:YAG) which offer both hard tissue and soft tissue applications, but have particular limitations due to its high cost and a potential for thermal damage to pulp, whereas, on the other hand there are soft lasers which are based on the semiconductor diode devices which in turn are compact, low-cost devices used particularly for applications and are broadly termed as low-level laser therapy or 'biostimulation'. On the basis of the ease, efficiency, effective, specificity, comfort, and cost over the conventional modalities, lasers are indicated for a tremendous variety of procedures in the fields of dental practice[1]. Lasers associated with dentistry are now being used in different dental disciplines such as oral surgery, restorative dentistry, and Cosmetic dentistry for soft tissue contouring, osseous crown lengthening etc and also in different surgical treatment modalities. Researchers are also looking into the application of lasers in implant dentistry and particularly related to treatment of peri-implantitis[2].This paper outlines some basic laser science and overviews, as well as different types of laser used in different fields of dentistry.

SIMPLIFIED LASER PHYSICS FOR DENTISTS: Spontaneous emission occurs whenever an atom is excited to a higher energy state, there the electrons occupy excited orbits, but then spontaneously drop to a ground state orbit with the release of a packet amount of energy known as photon (Figure 1). Stimulated emission particularly occurs when atoms are energised by light, heat, or electric discharge. In a laser (see Figure 2), the source (pumping source) supplies this energy to an optical cavity which is known as resonator, which in-turn contains excitable atoms i.e the lasing medium.. The optical chamber is lined by a totally reflecting mirror on one end and a partially reflecting mirror at the other end, thus resulting in photons which keep on 'resonating' from one end to the other, while some escaping through the transmissive mirror. As the 'pumping' from the pumping energy source continues, the number of excited atoms in the medium surpases the number of ground state atoms and this is known as population inversion. Some of the excited atoms decay spontaneously to create the free photons. These then interact with other excited atoms without being absorbed and also cause decay of the excited atom and finally releases another photon before returning to the ground state. For lasing to occur, the incident photon should carry on with the same wavelength and be in according to the phase with the emitted photon.

The two free photons then interact with two more excited atoms thus generating four photons. This process continues untill four becomes eight, eight becomes 16 and so on. This results in a photon chain reaction that then generates the laser beam. The laser beam has various characteristics such as monochromatic, collimated and in-phase. The interaction between these photons and high energy state atoms results in stimulated emission of photons and the additive effect of these in-phase photons is known as light amplification - hence the acronym "light amplification by stimulated emission of radiation[3].

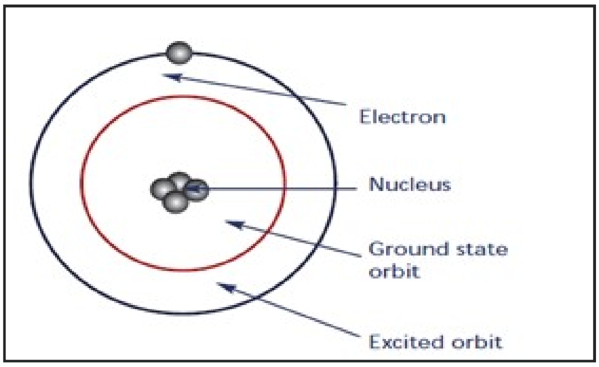

Figure 1.

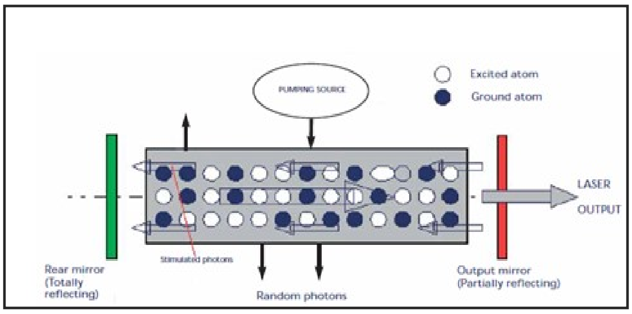

Figure 2.

HISTORICAL REVIEW

Althought Albert Einstein first postulated Stimulated Emission in 1917, the first laser was invented by Theodore Maimam in 1960 a synthetic ruby laser and most of the research in the field of laser was restricted to this laser only. Then in 1964Stern and Sognnaes[4] reported that glass like fusion and catering of enamel when subjected to 500200J/cm2 of laser energy, also observe charring of dentine, following in 1965 by Goldman et al[5] subjected a vital tooth to laser energy, the subject had experienced no pain and had only minor, superficial damage to the crown. Ruby lasers then lost favour soon because it needed too much energy and alsoe was reported that it causes severe thermal injury to the pulp and also collateral damage to adjacent hard and soft tissue because of scattered radiation. Following which the Nd:YAG laser was then developed by Bell Telephone Laboratories in 1964. Although this Lasers where discovered a year after the ruby laser but was largely overshadowed for a long time by the ruby laser and other lasers of that era such as CO_2 laser. Previous studies of this laser were associated with its application for soft tissue procedure as well as inhibition of caries[6]. The carbon dioxide laser was invented by Kumar N Patel in 1964 while working at Bell Telephone Laboratories[7]. CO_2 laser was the first laser that had truly hard tissue and soft tissue application.

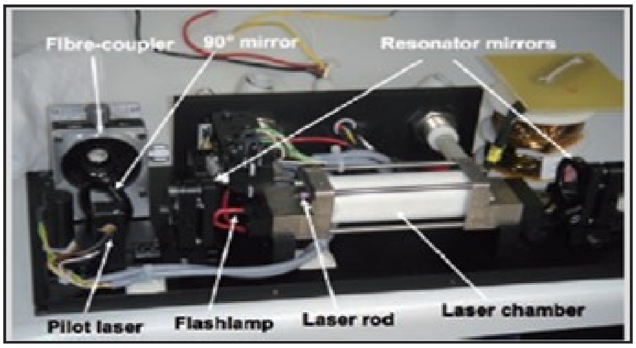

Figure 3

In 1971 Weichman & Johnson[8] were the first to use lasers in Endodontics, they unsuccessfully attempted to seal the apical foramen in vitro by means of a high power infrared carbon dioxide laser. CO_2 lasers are well absorbed by water and also had the ability to be the laser of choice for various dental hard and soft tissue application, however these gas based lasers could not be delivered through optic fiber because it has large wave length which in turnwill not fit into the crystalline moleculesof the conducting glass and has to be conducted either through by a hollow wave guide or by an articulate arm delivery system. Hibst and Paghdiwalain 1988 were the first to describe the Er: YAGlaser on dental hard tissues, however this laser obtained US FDA approval for cavity preparation in 1997. One of the first companies to release Er:YAG lasers onto the market was KaVo (Germany) in 1992. Later the second erbium laser (Er:YSGG, 2.78 mm) was developed and released on market by Biolase (USA). The erbium family of laser has an emission wavelength which in turn coincides exactly with the absorption peak of water thus giving strong absorption in all biological tissues particularly enamel and dentine and hence are the most popular hard and soft tissue lasers. The recent further developments of lasers, with different wavelengths and onboard parameters can further continue to have significant impact on the scope and practice of dentistry[9].

LASER DELIVERY

For a laser to be useful in clinical practice, it must be able to effectively deliver laser energy to the target site. Early delivery systems were too bulky or cumbersome to use in the oral cavity. Fiber optics were introduced into medicine as early as 1954 by Kapany, who developed the endoscope[10]. Early fiber optic systems had high-energy losses, and were incapable of delivering the mid-infrared laser wavelengths efficiently, and thus most early midinfrared lasers used alternate delivery systems. The existing range of laser delivery systems includes: Articulated arms (with mirrors at joints) – for UV, visible and infrared lasers. Hollow waveguides (flexible tube with reflecting internal surfaces) – for middle and far infrared lasers and Fiber optics – for visible and near infrared lasers.Fiber optic delivery systems are presently the delivery system of choice for most lasers as they can deliver laser energy to most parts of the oral cavity and even within the complex root canal system. Fiber optics can deliver laser energy in a forward direction, with minimal divergence from the bare end of a plain tip. This is useful in cases like cavity preparation or certain soft tissue surgery; however the minimal divergence mean that it is difficult to transfer energy laterally and hence may be of limited use for applications such as root canal treatment.

Recently a number of fiber optic modifications have been proposed that may be effective in delivering laser energy laterally[11,12] All the invisible dental lasers are equipped with a separate aiming beam, this coaxial laser beam which can either be either a laser or conventional light. Selecting a delivery system or a fiber optic material that transmits the laser wavelength in use with minimal losses is important for effective delivery of laser energy[13]

MECHANISM OF LASER ACTION

The action of lasers on dental hard and soft tissue as well as bacteria depend on the absorption of laser tissue by chromphore (water, apatite minerals, and various pigmented substances) within the target tissue. Better absorption allows for a more efficient photo-thermal sterilization, ablation of dentine etc. The principle mechanism of action of laser energy on tissue is photothermal[14], other mechanisms may be secondary to this process (rapid heating of water molecules within enamel causes rapid vaporization of the water and build-up of steam which causes an expansion that ultimately over comes the crystal strength of the dental structures, and the material breaks by exploding this process is called ablation) or may be totally independent of this process. The following are the possible mechanisms of laser action:

- Photo-thermal ablation: This occurs with high powered lasers, when used to vaporization or coagulate tissue through absorption in a major tissue component.
- Photo-mechanical ablation: Disruption of tissue due to a range of phenomena, including such as Shock wave formation, Cavitations etc.
- Photo-chemical effects (Using lightsensitive substances to treat conditions such as cancer)

Factors that influence the nature of the effect of lasers on tissue comprise the laser variables of wavelength, pulse energy or power output, exposure time, spot size (and thus energy density), and the tissue variables of physical and chemical composition (e.g. water content, density, thermal conductivity and thermal relaxation)[15-21].

BASIC LASER COMPONENTS[2]

- **ACTIVE MEDIUM:** The active medium can be gas, liquid or solid state where laser light is generated via a process called stimulated emission. The active medium used determines the laser wavelength, power and energy. The active medium typically denotes the name of the different types of lasers. For example: Carbon dioxide laser, Er: YAG laser and Nd: YAG laser.
- **PUMPING MECHANISM:** External power source supplies energy continuously to excite (pump) the active medium so that stimulated emission can occur achieving a population inversion. In the case of semiconductor diode lasers, the power source is electricity. Laser rod of a solid-state laser or dye cell of a liquid laser is pumped with light energy, hence optical pumping. The light sources include flashlamps, arc lamps and other lasers (laser pump).
- **OPTICAl RESONATOR:** The active medium is positioned within an optical subsystem called the laser resonator. The resonator consists of two mirrors separated by the active medium in between. The mirrors are aligned and parallel to each other. On each end of the optical resonator the mirror reflects the excited photons produced by the excited active medium back and forth in a direction perpendicular to the mirror surfaces. This movement of light through the active medium amplifies the power, a 'population inversion' is achieved. One of the mirrors is partially reflective (output coupler). The non-reflective surface on this mirror allows the photons to exit the resonator as a monochromatic and directional beam of energy.
- **COOLING SYSTEM:** Usually not all power put into the active medium is converted into laser energy. Some of the power is converted into heat which raises the temperature of the active medium. A cooling system must be employed to maintain the active medium below its maximum operating temperature.
- **CONTROL PANEL:** Microcomputer or microprocessor installed for the operator to control the parameters for the output of laser energy.
- **DELIVERY SYSTEMS:** Laser energy is delivered to the target site by various delivery systems:

CLASSIFICATION[22]

Lasers are classified into several groups:

- Class I (inherently safe)
- Class II and IIIa (where the eye is protected by the blink reflex)
- Class IIIb (where direct viewing is hazardous)
- Class IV (where the laser power is above 0.5 Watts, and the laser is classed as extremely hazardous).

Most dental and medical lasers are class IV, and thus compliance with safety standards is necessary to protect the dentist, patient and support staff.

USES OF LASERS IN DENTISTRY: The rapid development of laser technology has seen its introduction into various fields of dentistry. Some of the present applications of laser in dentist are as follows:

Diagnosis

- Detection of pulp vitality Doppler flowmetry
- Low level laser therapy (LLLT)
- Laser fluorescence- Detection of caries, bacteria and dysplastic changes in the diagnosis of cancer

Hard tissue applications

- Caries removal and cavity preparation
- Re-contouring of bone (crown lengthening)
- Endodontics (root canal preparation, sterilization and Apicectomy
- Laser etching
- Caries resistance

Soft tissue applications

- Laser-assisted soft tissue curettage and peri-apical surgery
- Bacterial decontamination
- Gingivectomy and GingivoplastyAesthetic contouring, Frenectomy
- Gingival retraction for impressions

- Implant exposure
- Biopsy incision and excision
- Treatment of aphthous ulcers and Oral lesion therapy
- Coagulation / Hemostasis
- Tissue fusion - replacing sutures
- Laser-assisted flap surgery
- Removal of granulation tissue
- Pulp capping, Pulpotomy and pulpectomy
- Operculectomy and Vestibuloplasty
- Incisions and draining of abscesses
- Removal of hyperplastic tissues and Fibroma

Laser-induced analgesia

Laser activation

- Restorations (composite resin)
- Bleaching agents

Other

- Removal of root canal filling material and fractured instrument
- Softening gutta-percha
- Removal of moisture/drying of canal

COMMONLY USED LASERS

- **Carbon dioxide laser:** The CO2 laser wavelength has a very high affinity for water, resulting in rapid soft tissue removal and hemostasis with a very shallow depth of penetration. Although it possesses the highest absorbance of any laser, disadvantages of the CO2 laser are its relative large size and high cost and hard tissue destructive interactions[23].
- **Neodymium yttrium aluminum garnet laser:** The Nd: YAG wavelength is highly absorbed by the pigmented tissue, making it a very effective surgical laser for cutting and coagulating dental soft tissues, with good hemostasis. In addition to its surgical applications, there has been research on using the Nd: YAG laser for nonsurgical sulcular debridement in periodontal disease control and the Laser Assisted New Attachment Procedure (LANAP)[24-26].
- **Erbiumlaser:** The erbium 'family' of lasers has two distinct wavelengths, Er, Cr: YSGG (yttrium scandium gallium garnet) lasers and Er: YAG (yttrium aluminum garnet) lasers. The erbium wavelengths have a high affinity for hydroxylapetite and the highest absorption of water in any dental laser wavelengths. Consequently, it is the laser of choice for treatment of dental hard tissues. In addition to hard tissue procedures, erbium lasers can also be used for soft tissue ablation, because the dental soft tissue also contains a high percentage of water[27,28].
- **Diode laser:** The active medium of the diode laser is a solid state semiconductor made of aluminum, gallium, arsenide, and occasionally indium, which produces laser wavelengths, ranging from approximately 810 nm to 980 nm. All diode wavelengths are absorbed primarily by tissue pigment (melanin) and hemoglobin. Conversely, they are poorly absorbed by the hydroxyapatite and water present in the enamel. Specific procedures include aesthetic gingival re-contouring, soft tissue crown lengthening, exposure of soft tissue impacted teeth, removal of inflamed and hypertrophic tissue, frenectomies, and photo stimulation of the apthous and herpetic lesions[29].

SOFT TISSUE APPLICATION

- **Wound healing:** It affects fibroblast maturation and locomotion, and this in turn may contribute to the higher tensile strengths reported for healed wounds. Low-level laser treatment (LLLT) of gingival fibroblasts in the culture has been shown to induce transformation in myofibroblasts (useful in wound contraction) as early as 24 hours after laser treatment[30].
- **Post herpetic neuralgia and apthousulcer:**It has been demonstrated that photostimulation of aphthous ulcers and recurrent herpetic lesions, with low levels of laser energy (HeNe) can provide pain relief and accelerate healing[31].
- **Photoactivated dye disinfection using lasers:**Low power laser energy is useful for photochemical activation of oxygen-releasing dyes, causing membrane and DNA damage to the microorganisms[32]
- **Photodynamic therapy for malignancies:** Photodynamic therapy (PDT), which has been employed in the treatment of malignancies of the oral mucosa, particularly multi-focal squamous cell carcinoma, acts on the same principle of PAD, and generates reactive oxygen species, which in turn, directly damages the cells and the associated blood vascular network, triggering both necrosis and apoptosis; this activates the host immune response, and promotes anti-tumor immunity through the activation of macrophages and T lymphocytes[33].
- **Aesthetic gingival re-contouring and crownlengthening**: With the advent of the diode laser, many clinicians are choosing to include optimization of gingival aesthetics as part of the comprehensive orthodontic treatment[34].
- **Removal of inflamed, hypertrophic tissue, and miscellaneous tissue removal**: Isolated areas of transient tissue hypertrophy can easily be excised with the diode laser without specialist referral. The diode laser is also very useful for a number of isolated applications, such as, removing tissue that has overgrown mini-screws, springs and appliances, as well as for replacing a tissue punch if needed, when placing mini-screws in the unattached gingiva[35].
- **Frenectomies:** A high or prominent labial frenum, when indicated, laser assisted frenectomy is a simple procedure that is best performed after the diastema is closed as much as possible[36]
- **Exposure of unerupted and partially erupted teeth**: An impacted or partially erupted tooth can be exposed for bonding by conservative tissue removal, allowing for reasonable positioning of a bracket or button[36]

HARD TISSUE APPLICATION

- **Photochemical effects:** The argon laser produces high intensity visible blue light (488nm), which is able to initiate photopolymerizationof light-cured dental restorative materials, which use camphoroquinone as the photo initiator. Argon laser radiation is also able to alter the surface chemistry of both enamel and root surface dentine, which reduces the probability of recurrent caries[37].
- **Laser fluorescence:** Enamel demineralization with white spot formation on the buccal surfaces of the teeth is a

relatively common side effect from orthodontic treatment with fixed appliances. There is evidence, however, which suggests that such small areas of superficial enamel demineralization may re-mineralize[38].

- **Cavity preparation, caries,and restorative removal**: Various studies depict the use of Er: YAG, since 1988, for removing caries in the enamel and dentine by ablation, without the detrimental effect of rise in temperature on the pulp, even without water-cooling, with low 'fluences' laser (LLLT), similar to air-rotor devices, except that the floor of the cavity is not as smooth[39].
- **Etching:** Laser etching has been evaluated as an alternative to acid etching of enamel and dentine. Enamel and dentine surfaces etched with (Er, Cr: YSGG) lasers show micro-irregularities and no smear layer. Adhesion to dental hard tissues after Er: YAG laser etching is inferior to that obtained after conventional acid etching[40].
- **Treatment of dentinal hypersensitivity**: Dentinal hypersensitivity is one of the most common complaints in clinical dental practice. Comparison of the desensitizing effects of an Er: YAG laser with those of a conventional desensitizing system on cervically exposed hypersensitive dentine showed that desensitizing of hypersensitive dentine with an Er: YAG laser is effective, and maintenance of a positive result is more prolonged than with other agents[41].
- **Diagnostic application**: the laser is being used for diagnostic purposes in clinical dental practice as well as in research purposes.
- **3-D Laser scanner for e-model preparation**: Our understanding of the growth of craniofacial structures is improving with the development of accurate, low-cost, 3-dimensional (3D) imaging systems. The laser scanner can be usedas a soft tissue scanner and is a valuable tool for its ease of application and creation of 3D images of oral dental structures[42].

CONCLUSION

Laser technology for hard tissue application and soft tissue surgery is at a high state of refinement, having had several decades of development, up to the present time, and further improvements can occur. The field of laser-based photochemical reactions holds great promise for additional applications, particularly for targeting specific cells, pathogens, or molecules.The emergence of lasers with variable wavelength and the ability to be used for various applications in dentistry may influence the treatment and treatment planning of dental patients. A further area of future growth is expected to be a combination of diagnostic and therapeutic laser techniques.

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