Review Article

Indian Journal of Dental Education 67
Volume 13 Number 2, April–June 2020
DOI: https://dx.doi.org/10.21088/ijde.0974.6099.13220.4

Lasers in Dentistry: In Advancing Front; A Review

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How to cite this article:

Neelam Mittal, Vijay Parashar, Sakshi Gupta, Lasers in dentistry: In Advancing Front; A Review. Indian J Dent Educ. 2020;13(2):67–74.

Abstract

LASER is an acronym of Light Amplification by the Stimulated Emission of Radiation. Since 1960s, When Maiman used it for the first time in dentistry, laser have evolved their way in the field, where they are been used for several procedures like caries removal, cavity preparations, dental hypersensitivity treatment, etching, composite polymerization, bleaching, canal sterilization, soft tissue and apical surgeries. With these applications, lasers also presents certain advantages like, minimized bleeding yielding good visibility, decreased swelling and postoperative pain, accelerated healing, controlled collateral damage, reduced need for anesthesia. In recent years, with improved understanding of laser-tissue interactions and advancements in technology, laser have spread their applications from diagnosis to preventive procedures, making them an efficient and valuable tool for dental surgeon in near future.

Keywords: LASER Basics; Laser-Tissue Interactions; Applications in Dentistry; Endodontics; Laser.

Introduction

Since 1960s, with invention of lasers, it had attracted many dental clinician and researchers in recent times. Lasers present with a ton of advantages like reduced patient's anxiety, minimized bleeding yielding good visibility, decreased swelling and postoperative pain, accelerated healing, controlled collateral damage, reduced need for anaesthesia and many more. It has opened new doors towards technology where a small beam can work from detection of incipient caries to surgeries, with all efficiency and precision.

Lasers have allowed easy caries removal, cavity preparations, dental hypersensitivity treatment, etching, composite polymerisation, bleaching, canal sterilisation, soft tissue and apical surgeries, and many more. With the developing technology and use of thinner, more flexible fibres, the applications of lasers have enhanced in dentistry. This article will highlight about lasers history, tissue interactions, types, and uses of lasers that lay foundation of lasers in dentistry.

History

In 1917, Albert Einstein put forth "The Theory of Stimulated Emission", which formed basis for development of laser.[1] In 1960, Theodore Maiman, a scientist with the Hughes Aircraft Corporation, first developed the working laser device, which emitted a deep red-coloured beam, called as "Ruby Laser", with 0.694 um wavelength. But in 1964, Stern and Sognnaes, reported that it can vaporize enamel and have deleterious thermal effects on dental tissues.[2] Then in 1964, Patel developed CO_2 laser, which had better interactions with dental tissues.[3] In 1964, Guesic developed Nd: YAG. Weichman and Johnson, in 1971, first used lasers in endodontics, by utilizing high power infrared CO_2 laser to seal the apical foramenin vitro.[4] In late 1990s, semiconductors-based diode lasers also emerged. FDA gave clearance to dental hard tissue Er: YAG laser and Er, Cr: YSGG in 1997. Since then, the uses and technology are pacing rapidly.

Mechanism of Action

An action medium is required for production of laser, which can be solid, gas or semiconductor. This active medium when stimulated by electricity or light, produces photons of a specific wavelength. Lasers are characteristically monochromatic, coherent, unidirectional, and emitted from stimulated active medium. In solid state, e.g. Er: YAG lasers, the erbium is stimulated by light from a flash lamp with a process known as optical pumping.[5] As an erbium atom absorbs a photon, its electrons are excited to a higher energy level. When electron return to a lower energy state, two identical photons are emitted which can further stimulate more atoms in a chain, resulting in amplification of photons. The mirrors as resonators increases this light intensity. Light leaks from the output couplers and thesephotonsform the laser beam.[6] It is carried to the target tissue by various types of beam and transfer through hardware like mirrors in articulated arms and optical fibres.

Classification of Lasers

A. Based on Light Active Medium

GAS lasers: Argon and CO_2

LIQUID Lasers: Dyes

SOLID lasers: Nd: YAG, Erbium: Yttrium aluminium garnet (Er: YAG), Er: YSGG, Diode

Semiconductors Lasers: Hybrid silicon laser

B. Based on Light Spectrum

1) U/V laser	400–800 nm	Not used in Dentistry
2) Visible Light	400–750 nm	Sometimes used in Dentistry
3) Infrared Light	750–1000 nm	Most Commonly used in Dentistry

Laser-Tissue Interactions

There are 4 types of interactions occurring with target tissue, depending on their optical properties-

Absorption- It is the first and most desired interaction with tissue. The amount of energy absorbed depends on various characteristics of the tissues, such as chromophores, water content, laser wavelength and emission mode.[7] e.g. Hemoglobin, the molecule that transports oxygen to tissues, reflects red wavelengths, imparting colour to arterial blood, strongly absorbs blue and green wavelength. Melanin, the pigment which imparts colour to skin, strongly absorbs short wavelength lasers. Water, the universally present molecule also

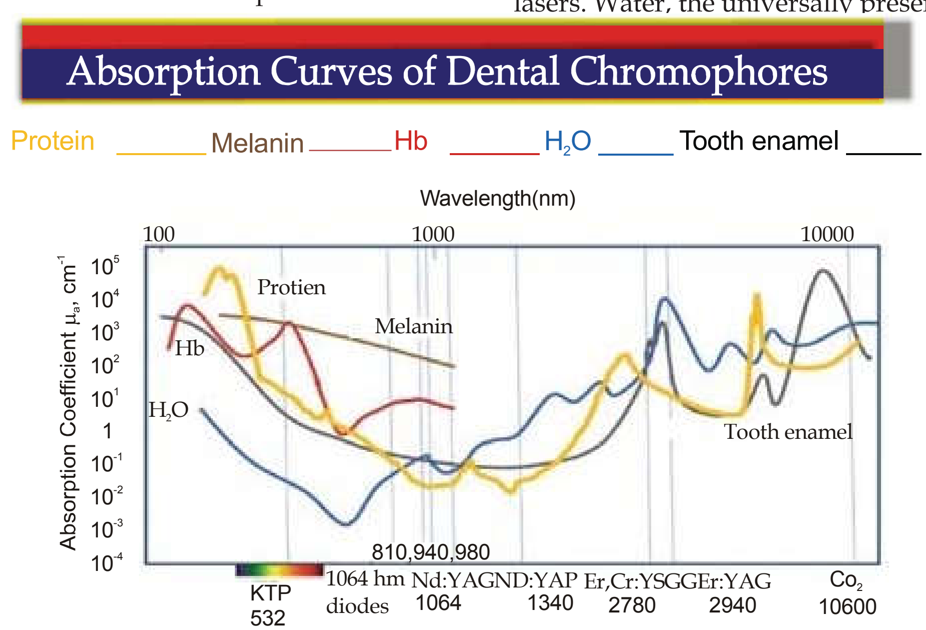

Fig 1. Absorption curves of different dental compounds by various Wavelengths of lasers.

exhibits varying degree of absorption by different wavelengths.

Dental structures contain different amount of water with enamel being the least 4%, then dentine, bone, calculus, caries, and soft tissue (about 70%). Erbium and CO_2 lasers are predominantly absorbed by water.[8] Another compound most abundantly present in dental hard tissues is hydroxyapatite. Generally, shorter wavelengths (500-1000nm) are readily absorbed in pigmented tissue and blood elements. Argon is attenuated by haemoglobin while diode and Nd: YAG have higher affinity for melanin than haemoglobin. Longer wavelengths are more interactive with water and hydroxyapatite. CO_2 laser is well absorbed in water and greatest affinity for tooth structure.

2. *Transmission*–Energy passes through the tissues without any effect on the target tissues, which is just opposite of absorption. This property is dependent on wavelength of laser. Water, for e.g. is relatively transparent for shorter wavelength of lasers like diode, argon, Nd: YAG, whereas tissue fluids readily absorbs erbium family and CO_2. A classic example to explain the property is diode and Nd: YAG are transmitted through the lens, cornea and iris of the eye and are absorbed on the retina.
3. *Reflection*–It is the property where beam redirects itself off the surface, having no effect on the target tissue. The reflected light could maintain its collimation in a narrow beam or become diffuse. A caries detecting laser device uses this property to measure degree of sound structure. This property can be dangerous as the energy can be redirected to an unintentional target e.g. eyes, which is a major safety concern for lasers.
4. *Scattering*–This property means weakening of intended energy, thereby producing no useful biological effect. Scattering of laser beam could transfer heat to the adjacent tissues of surgical site causing unwanted collateral damage. However, this scattering property may facilitate polymerisation of composites, covering a wider area.

Laser wavelengths used in Dentistry

Several wavelengths are used in dentistry, we would briefly discuss them in this section. These lasers are named according to their active medium, wavelength, delivery system, emission mode, tissue absorption and clinical applications.

Lasers used in dentistry are listed below, according to their wavelengths with shortest being first-

Argon Laser

The laser has argon gas as active medium, which is energized using high-current electrical discharge. It is fiberoptically delivered in continuous wave and gated pulse mode. There are two emission wavelengths used in dentistry: 488 nm, blue in colour and 514 nm, blue green in colour.

The 488 nm emission is the wavelength needed to activate camphorquinone, most commonly used photo initiator used for polymerisation of resin in composite restorations. The divergent beam is used in non-contactmode, to provide curing energy. Some studies showed, increase in strength of the resin cured using argon laser as compared with conventional blue light.[9] These lasers are also being used in laboratory and chair side for procedures like, light activated bleaching and impression materials.

The 514 nm wavelength is well absorbed in tissues containing hemoglobin, hemosiderin, melanin. Popularized as excellent haemostatic agent and used for treatment of Acute inflammatory periodontal disease and highly vascularised lesions, such as hemangioma.[10]

Neither of these wavelengths are absorbed in dental hard tissues or in water. This property of poor absorption into enamel and dentin is advantageous when cutting and sculpting gingival tissues, posing no damage to the tooth structure during the procedure. Both wavelengths can be used in caries detection. When one illuminates the tooth with argon laser, carious areas appear dark orange red and are easily distinguishable from healthy tissues.

Diode

Diode (fig 2) is a solid active medium laser, manufactured from semiconductor crystals, aluminium or indium, gallium and arsenic. The wavelengths available for dental use depends on active medium, 800 nm for aluminium being active medium and 980 nm for indium. Each system deliversenergy in continuous wave and gated pulse mode.

All the diode lasers are well absorbed by pigmented tissues and are deep penetrating, controls haemostasis to some extent.

Continuous wave emission of diode laser causes rapid rise in temperature in target tissues. The clinician should use air and water to cool the surgical site. It is an excellent soft tissue laser indicated for cutting and coagulating gingiva and mucosa for sulcular debridement.[11,12] Another big advantage is the laser is of smaller size and portable.

In additionto surgical lasers, these are used for manufacturing of devices like Diagnodent, which uses visible red diode at 655 nm wavelength and 1mW power. This red energy excites fluorescence from carious tooth structure, which when reflected to detector in the device, analyses and quantifies the degree of caries.[13]

Fig. 2: SIROLaser Blue, FDS, BHU

Neodymium: YAG

Nd: YAG has solid active medium, containing garnet crystal combined with rare earth metals yttrium and aluminium, doped with neodymium ions. The wavelength delivered is of 1064 nm. These instruments in free running pulsed mode, with short pulse durations in microseconds, and features a small flexible tissue contact optic fibres. These lasers are highly absorbed in melanin but less in haemoglobin. Used for cutting and coagulating dental soft tissues and sulcular debridement.[14,15]

Nd:YAG laser energy is slightly absorbed by dental hard tissue, with little interaction with sound tooth structure, allowing soft tissue surgery without adjacent tooth structure damage. Carious lesions can be easily removed without removing sound tooth structure.

In non-contact mode also, the laser energy penetrates several millimetres, and can be used for haemostasis, treatment of aphthous ulcers, or pulpal analgesia.

The Erbium Family

There are two different laser wavelengths that uses erbium, that is Erbium, Chromium: YSGG (2790 nm) has an active medium as solid crystal of yttrium scandium gallium garnet that is doped with erbium and chromium.

Er: YAG (2940 nm) (fig 3) has an active medium of solid crystal of yttrium aluminium garnet doped with erbium. Both wavelengths are invisible, mid-infrared and non-ionizing electromagnetic waves.

Both wavelengths are emitted in pulsed mode, where the device contains hollow wave guide or a fibre optic bundle. The fibre diameter is much larger and require air coolant for proper operation. These wavelengths have a high affinity for hydroxyapatite and water.[16-18] The laser gets absorbed into hydroxyl radical of the crystal and into the water bound to the crystalline structures of the tooth. The vaporisation of water in mineral structure causes massive volume explosion, which causes surrounding minerals to explode away.[19]

Caries removal and tooth preparation can be done easily using this laser,[20] while protecting the sound tooth structure;[21] increased water content in decayed part allows laser to interact only with diseased tissue.[22,23]

Fig. 3: Fotona sky walker, IMS, BHU (funded by DST, New Delhi)

Co_2 Laser

The CO_2 laser is a gas active medium laser that contains gaseous constituents of CO_2 molecules pumped via electrical current, producing wavelength of 10600 nm, delivered through a hollow tube in continuous or gated pulse mode.

This wavelength is well absorbed by water, so can easily cut and coagulate the soft tissue. It has shallow depth penetration thus can be utilised for treating mucosal lesions and can vaporize dense fibrous tissues. This laser can be used in both contact and non-contact modes. After surgery, it may be used in defocused mode to place biological bandage called eschar on wound surface.

This laser has highest absorption in hydroxyapatite, 1000 times greater than erbium. Therefore, tooth adjacent to surgical site must be protected using a metal instrument.

Uses of Lasers in Restorative Dentistry

Hard Tissue Applications

Photochemical Effects –

The argon Laser (488nm) which produces blue light, is extremely effective in curing light-activated composite and similar materials.[24] Vargas et al suggested, that argon laser can adequately polymerize composite more rapidly, when compared with conventional visible lights.[25]

Moreover, Argon laser can also alter the surface chemistry of enamel and dentine, which reduces probability of recurrent caries.[26]

Argon and Potassium Titanyl Phosphate ($KTiOPO_4$, KTP) lasers can achieve positive results that are completely unresponsive to conventional photothermal bleaching. This bleaching effect relies on specific absorption of a narrow spectral range of green light (510-540 nm) into the chelate compounds formed between the apatites, porphyrins and tetracycline compounds.[27]

Cavity preparation, caries and Restorations removal

Er: YAG is being used for removing caries in the enamel and dentine by ablation, without any detrimental temperature changes on the pulp 28, same as that with air-rotor devices, except for slight smoothness. The laser can also easily remove cement, composites and glass ionomer. Laser can be used at 1-8 mJ energy (depending on tissue type) and frequency 2-20Hz for cavity preparation, while at 8-13 mJ/cm2 for caries prevention.

Etching

Laser (Er, Cr: YSGG) has been evaluated as an alternative to the conventional etching system, producing micro irregularities and no smear layer.[29] But many studies show, adhesion to hard tissues after laser etching to be inferior that obtained by conventional etching.[30]

Treatment of dentinal Hypersensitivity

Desensitisation of dentinal sensitivity is commontreatment, for which most dental patient seeks for. While comparing Er: YAG laser to conventional treatment plans, laser had shown positive results, that to for prolonged duration 31.one can use, Nd or Er: YAG at 30 mJ and 10 Hz with water spray for 2 min.

Diagnostic Aid

Argon and diode laser are popularly used for detection and quantifying of dental caries using diagnodent. Further, diode lasers are used for detection of subgingival calculus, fissure lesions, and testing pulpal blood flow via Laser Doppler Flowmetry. Helium-neon lasers also find their use for scanning phosphor plates of digital radiographs. Nd, Er: YAGare also utilised in spectroscopic analysis and confocal cytometric imaging of soft and hard tissues.

3-D Laser scanner for e-model preparation

The laser scanners can be used as soft tissue scanners, at 250-300 m W/cm 2 for 10s, creating 3D images of oral and dental structures.[32,33] With an advantage of reduced cost for impressions making, cast preparation and record keeping.

Endodontics

Pini et al used XeCl excimer laser (308nm) with suitable fibreoptic delivery, at 0.5-1.5 J/cm2 gave effective and fast cleaning of canals34.Many studies show, Lasers also provide canal wall glazing, apical plug fusion, microbial control, pulpal tissue debridement, and repair of incomplete vertical root fractures.[35]

Soft tissue applications

Gingival re-contouring and crown lengthening

Diode laser had emerged as a rescue from painful conventional gingival surgeries, where laser is associated with less pain, discomfort and bleeding. Moreover, healing is rapid and without healing marks.[36,37]

Wound Healing

At low doses, laser application stimulates proliferation of fibroblasts maturation and locomotion, also contributes to the better tensile strength of healed wounds. Low-level laser Therapy (LLLT) (e.g. 2J/cm2) is observed to transform fibroblasts into myoblasts as early as 24 hrs 38. LLLT has shown positive results for promoting healing and dentinogenesis, following pulp capping and pulpotomy.[39]

Post herpetic neuralgia and aphthous ulcer

Many studies have shown that, photo modulation of aphthous ulcers and recurrent herpetic lesions, with LLLT of laser energy (He-Ne) provides pain relief and accelerated healing 40,41. LLLT in case of herpes labialis in prodromal stage (tingling), is believed to accelerate healing and reduce frequency of occurrence of lesion.[42]

Photoactivated Dye Disinfection using lasers

Low level laser energy is very useful in activating oxygen releasing dyes, causing bacterial killing by damaging their membrane and DNA. This PAD (Photo Activated Dye) Technique is done using low power with diode laser and tolonium chloride dye. This helps one to effectively kill bacteria in complex biofilms like subgingival pockets, deep carious lesions and sites of peri-implantitis.[43,44] PAD technique is effective in killing even resistant bacteria like MRSA, fungi, viruses.[45]

This technique is also crawling its way towards diagnosis and treatment of malignancies. It generates reactive oxygen species, which damages cells and blood vessels, promoting both necrosis and apoptosis of tumour cells.[46]

Removal of inflamed and hypertrophic tissue

Diode lasers can effectively excise and remove the isolated and hypertrophied growths without compromising patient's compliance, with reduced requirement of anaesthesia, haemostatic agent during the procedure.

Frenectomy

High frenum attachment and ankyloglossia, creates several problems in dental health, like diastema, malocclusion and difficulties in deglutition and speech. Laser has permitted excision of Frenum painlessly, with less bleeding, and reduced requirement of surgical packing and postoperative care

Miscellaneous Applications

Laser Analgesia

Many studies have proved analgesic effect of LLLT wavelengths (632-904nm) on nerves by decreasing firing frequency and increasing threshold of receptors.[47] Local CO_2 irradiation is believed to reduce orthodontic pain without interfering with the tooth movement.[48]

Nerve repair and Regeneration

LLLT, 4.5 J for 10 days is believed to reduce production of inflammatory mediators, promote neuronal maturation and regeneration after injury.[49] The direct application of laser has promoted repair and regeneration of inferior alveolar nerve tissue, which was damaged while surgical procedures.

Laser Safety

Despite of being easy to use, lasers bring certain precautions to be taken to ensure safe and effective operation. First and foremost being, wearing protective eyewear, that to of specific wavelength. This protection should be done by anyone in the vicinity of the laser, i.e. operator, patient, assistant and any family member, if near.[50]

Any accidental exposures may be prevented by putting warning signs on the doors, minimizing the reflective surfaces, limiting access to surgical environment, and ensuring good working condition of laser.

The room should be well ventilated for escape of vapours while tissue ablation which may be poisonous to people present in surgical room.

Acknowledgements- Authors are grateful to Department of Science And Technology under the programme DST Purse 5050 for procuring laser.

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