

Laser in dentistry: An innovative tool in modern dental practice

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ABSTRACT

The term LASER is an acronym for 'Light Amplification by the Stimulated Emission of Radiation'. As its first application in dentistry by Miaman, in 1960, the laser has seen various hard and soft tissue applications. In the last two decades, there has been an explosion of research studies in laser application. In hard tissue application, the laser is used for caries prevention, bleaching, restorative removal and curing, cavity preparation, dentinal hypersensitivity, growth modulation and for diagnostic purposes, whereas soft tissue application includes wound healing, removal of hyperplastic tissue to uncovering of impacted or partially erupted tooth, photodynamic therapy for malignancies, photostimulation of herpetic lesion. Use of the laser proved to be an effective tool to increase efficiency, specificity, ease, and cost and comfort of the dental treatment.

Key words: Dental application, lasers, photostimulation

INTRODUCTION

Introduction of laser in dentistry, in the 1960s, by Miaman,^[1] led to a continuous research in the various applications of lasers in dental practice. There are two scenarios, on the one hand there are hard lasers, such as, Carbon dioxide (CO₂), Neodymium Yttrium Aluminum Garnet (Nd: YAG), and Er:YAG, which offer both hard tissue and soft tissue applications, but have limitations^[2,3] due to high costs and a potential for thermal injury to tooth pulp, whereas, on the other hand in cold or soft lasers, based on the semiconductor diode devices, which are compact, low-cost devices used predominantly for applications, are broadly termed as low-level laser therapy (LLLT) or 'biostimulation'.^[4] On account of the ease, efficiency, specificity, comfort, and cost over the conventional modalities, lasers are indicated for a wide variety^[5-8] of

procedures in dental practice. The aim of this review is to focus on the hard as well as soft tissue applications, in dentistry.

HISTORY

In 1917, Albert Einstein^[9] laid the foundation for the invention of the laser and its predecessor, 'the Maser,' by theorizing that photoelectric amplification could emit a single frequency, or stimulated emission. The term LASER is an acronym for 'Light Amplification by the Stimulated Emission of Radiation' and was first introduced to the public in 1959, in an article by a Columbia University graduate student, Gordon Gould.^[10] Theodore Maiman, at the Hughes Research Laboratories in Malibu, CA, built the first functioning laser,^[11] by using a mixture of helium and neon. In 1961, a laser generated from crystals of yttrium-aluminum-garnet treated with 1-3% neodymium (Nd: YAG) was developed.^[10] In 1962, the argon laser was developed, whereas, the ruby laser became the first medical laser to coagulate retinal lesions, when it was used in 1963.^[10] In 1964, Patel at Bell Laboratories developed the CO₂ laser.^[10] Nowadays diode lasers are being extensively used in the field of dentistry.

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TYPES OF LASER

Lasers used in dental practice can be classified by various methods: According to the lasing medium used, such as, gas laser and solid laser; according to tissue applicability, hard tissue and soft tissue lasers; according to the range of wavelength [Figure 1], and of course the risk associated with laser application.

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^[11] absorbance of any laser, disadvantages of the CO₂ laser are its relative large size and high cost and hard tissue destructive interactions.

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,^[12] there has been research on using the Nd: YAG laser for nonsurgical sulcular debridement in periodontal disease control^[13] and the Laser Assisted New Attachment Procedure (LANAP).^[14]

ERBIUM LASER

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

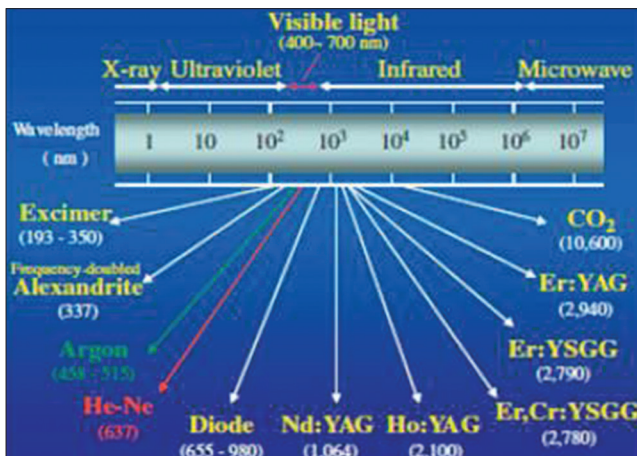


Figure 1: Various types of lasers and their corresponding wavelengths

for hydroxyapatite and the highest absorption of water in any dental laser wavelengths. Consequently, it is the laser of choice for treatment of dental hard tissues.^[15] 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.^[16]

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 photostimulation of the aphthous and herpetic lesions.^[17]

MECHANISM OF LASER ACTION

Laser light is a monochromatic light and consists of a single wavelength of light. It consists of three principal parts: An energy source, an active lasing medium, and two or more mirrors that form an optical cavity or resonator. For amplification to occur, energy is supplied to the laser system by a pumping mechanism, such as, a flash-lamp strobe device, an electrical current, or an electrical coil. This energy is pumped into an active medium contained within an optical resonator, producing a spontaneous emission of photons. Subsequently, amplification by stimulated emission takes place as the photons are reflected back and forth through the medium by the highly reflective surfaces of the optical resonator, prior to their exit from the cavity via the output coupler [Figure 2]. In dental lasers, the laser light is delivered from the laser to the target tissue via a fiberoptic cable, hollow waveguide, or articulated arm [Table 1]. Focusing lenses, a cooling system, and other controls complete the system.

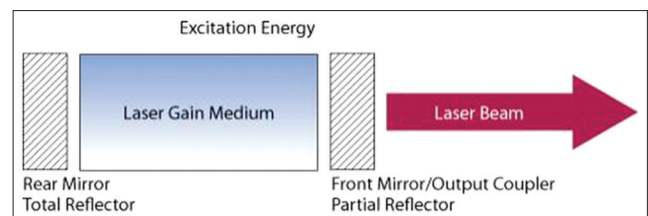


Figure 2: Mechanism of action of the laser

Table 1: Common laser types used in dentistry

Laser type	Construction	Wavelength(s)	Delivery system(s)
Argon	Gas laser	488, 515 nm	Optical fiber
KTP	Solid state	532 nm	Optical fiber
Helium–neon	Gas laser	633 nm	Optical fiber
Diode	Semiconductor	635, 670, 810, 830, 980 nm	Optical fiber
Nd:YAG	Solid state	1064 nm	Optical fiber
Er, Cr:YSGG	Solid state	2780 nm	Optical fiber
Er:YAG	Solid state	2940 nm	Optical fiber, waveguide, articulated arm
CO ₂	Gas laser	9600, 10600 nm	Waveguide, articulated arm

The wavelength and other properties of the laser are determined primarily by the composition of an active medium, which can be a gas, a crystal, or a solid-state semiconductor.

The light energy produced by a laser can have four different interactions with a target tissue:^[18,19] Reflection, Transmission, Scattering, and Absorption [Figure 3]. When a laser is absorbed, it elevates the temperature and produces photochemical effects depending on the water content of the tissues. When a temperature of 100°C is reached, vaporization of the water within the tissue occurs, a process called *ablation*. At temperatures below 100°C, but above approximately 60°C, proteins begin to denature, without vaporization of the underlying tissue. Conversely, at temperatures above 200°C, the tissue is dehydrated and then burned, resulting in an undesirable effect called *carbonization*.

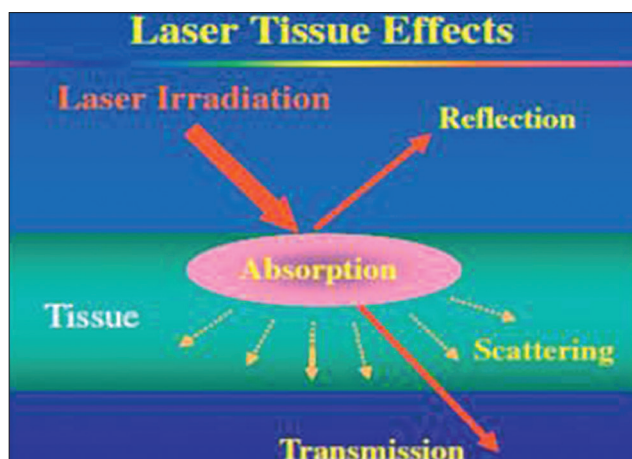
Absorption requires an absorber of light, termed *chromophores*, which have a certain affinity for specific wavelengths of light. The primary chromophores in the intraoral soft tissue are Melanin, Hemoglobin, and Water, and in dental hard tissues, Water and Hydroxyapatite. Different laser wavelengths have different absorption coefficients with respect to these primary tissue components, making the laser selection procedure-dependent.^[20-22]

Depending on application on various tissues, use of laser application in dentistry can be categorized as follows: Soft tissue application and hard tissue application.

SOFT TISSUE APPLICATION

Wound healing

At low doses (e.g., 2 J/cm²), laser application stimulates proliferation, while at high doses (e.g. 16 J/cm²) it is suppressive.^[23,24] It affects fibroblast maturation and locomotion,^[25] and this in turn may contribute to the

**Figure 3:** Interactions of the laser on tissue

higher tensile strengths reported for healed wounds.^[26] 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.^[27] The positive effects of LLLT on the healing of lesions of recurrent aphthous stomatitis in humans have also been recorded.^[28] There are some positive data, which indicate that LLLT promotes healing and dentinogenesis following pulpotomy,^[29] as also the healing of mucositis and oropharyngeal ulcerations in patients undergoing radiotherapy for head and neck cancer.^[30]

Post herpetic neuralgia and aphthous ulcer

It has been demonstrated that photostimulation of aphthous ulcers and recurrent herpetic lesions,^[31] with low levels of laser energy (HeNe) can provide pain relief and accelerate healing.^[32-35] In the case of recurrent herpes simplex labialis lesions, photostimulation during the prodromal (tingling) stage seems to arrest the lesions before painful vesicles form, accelerate the overall healing time, and decrease the frequency of recurrence.^[36]

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. The photoactivated dye (PAD) technique can be undertaken with a system using low power (100 milliwatts) visible red semiconductor diode lasers and toluidine chloride (toluidine blue) dye. The PAD technique has been shown to be effective in killing bacteria in complex biofilms, such as, subgingival plaque, which are typically resistant to the action of antimicrobial agents^[37-39] and can be made species-specific by tagging the dye with monoclonal antibodies.^[40] Photoactivated dye can be applied effectively for killing Gram-positive bacteria (including Methicillin-resistant *Staphylococcus aureus* (MRSA)), Gram-negative

bacteria, fungi, and viruses.^[41-42] The major clinical applications of PAD include disinfection of root canals, periodontal pockets, deep carious lesions, and sites of peri-implantitis.^[43-44] Tolinium chloride is used in high concentrations for screening patients, for malignancies of the oral mucosa and oropharynx.^[45-46]

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;^[47] this activates the host immune response, and promotes anti-tumor immunity through the activation of macrophages and T lymphocytes.^[48] There is direct evidence of the photodynamic activation of production of the tumor necrosis factor, alpha,^[49] a key cytokine in host anti-tumor immune responses. Clinical studies have reported positive results for the PDT treatment of carcinoma *in-situ* and squamous cell carcinoma, in the oral cavity, with response rates approximating 90%.^[50,51]

Aesthetic gingival re-contouring and crown lengthening

With the advent of the diode laser, many clinicians are choosing to include optimization of gingival aesthetics as part of the comprehensive orthodontic treatment,^[52,53] whereas, conventional gingivectomy [Figure 4] is associated with pain, discomfort, and bleeding.

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 [Figure 5].

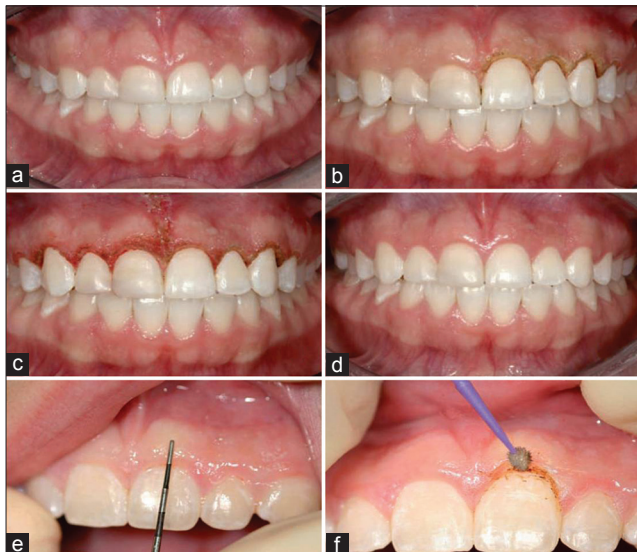


Figure 4: Aesthetic gingival re-contouring; a-e, pretreatment condition; b-c-f, after laser procedure; d, post treatment

It has the advantage of no bleeding, and an attachment can be placed immediately, and moreover, it is not painful at all.

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 [Figure 6]. The diode laser is also very useful for a number of isolated applications, such as, removing tissue that has overgrown mini-screws, springs [Figure 7a and b], and appliances,^[33] as well as for replacing a tissue punch if needed [Figure 7c], when placing mini-screws in the unattached gingiva.

Frenectomies

A high or prominent labial frenum [Figure 8a and b], when indicated, laser assisted frenectomy is a simple procedure that is best performed after the diastema is closed as much as possible.^[32] Ankyloglossia [Figure 8c and d] can lead to problems with deglutition, speech, malocclusion, and potential periodontal problems. Frenectomies performed with a laser permit excision of the frena painlessly, without bleeding, sutures, or surgical packing, and with no need for special postoperative care.

HARD TISSUE APPLICATIONS

Photochemical effects

The argon laser produces high intensity visible blue light (488 nm), which is able to initiate photopolymerization

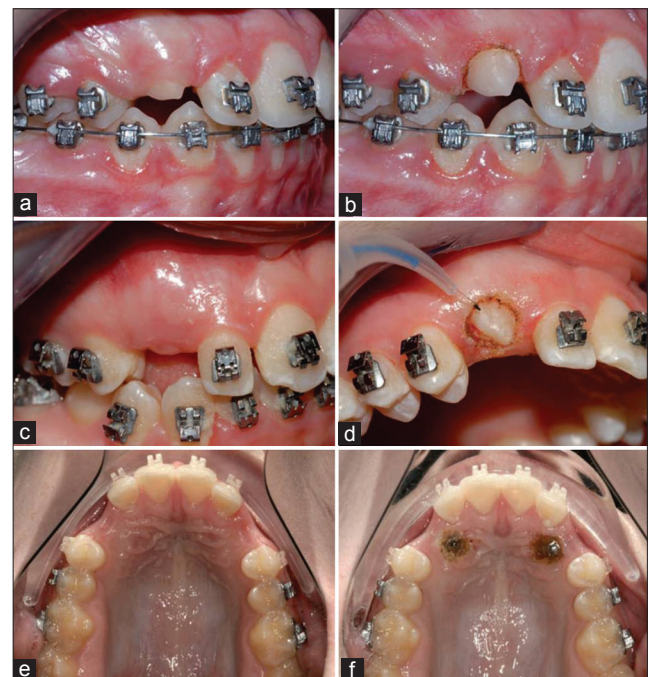


Figure 5: Crown exposure; a-c-e, before exposure; b-d-f, after laser exposure

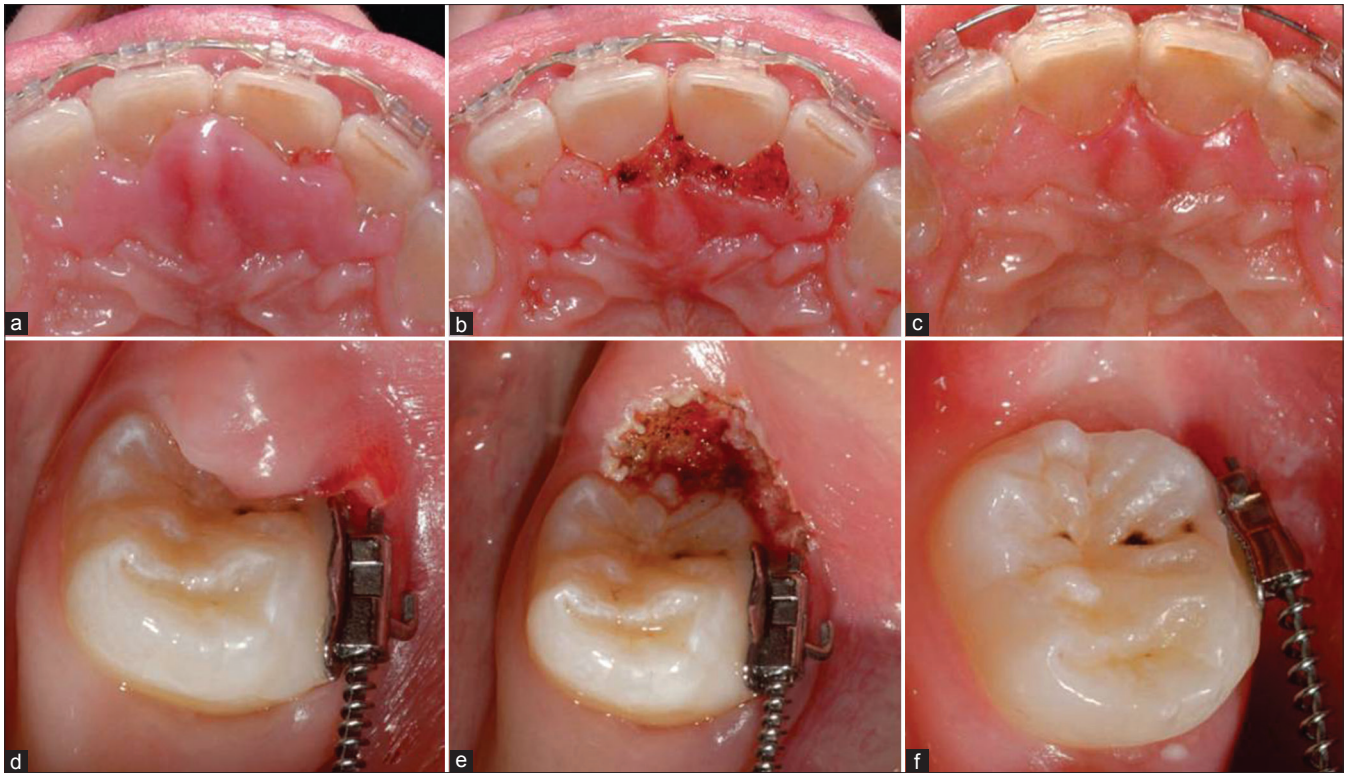


Figure 6: Removal of hyperplastic tissue; a-d, pretreatment; b-e, after laser

of light-cured dental restorative materials, which use camphoroquinone as the photoinitiator.^[54] Argon laser radiation is also able to alter the surface chemistry of both enamel and root surface dentine,^[55] which reduces the probability of recurrent caries. The bleaching effect relies on the 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.^[56] Argon and Potassium Titanyl Phosphate (KTiOPO₄, KTP) lasers can achieve a positive result in cases that are completely unresponsive to conventional photothermal 'power' bleaching.

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.^[57,58] There is evidence, however, which suggests that such small areas of superficial enamel demineralization may re-mineralize.^[59]

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,^[60] even without water-cooling,^[61] with low 'fluences' laser (LLLT), similar to air-rotor devices, except that the floor of the cavity is not as smooth.^[62] The Er: YAG laser is capable of removing cement, composite resin, and glass ionomer.^[63]

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.^[64] Adhesion to dental hard tissues after Er: YAG laser etching is inferior to that obtained after conventional acid etching.^[65,66]

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^[67] 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.

Diagnostic application

The laser is being used for diagnostic purposes [Table 2] in clinical dental practice as well as in research purposes [Table 3].

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, which can be classified as destructive or non-destructive devices,^[68] hard or soft tissue imaging devices,^[69] and contact or non-contact devices.^[70] The laser scanner can be used

as a soft tissue scanner and is a valuable tool for its ease of application and creation of 3D images of oral dental structures. There is no need of cast preparation as e-models are prepared from scanned impressions. Images have been created to establish databases for normative populations^[71] and cross-sectional growth changes,^[72] and also to assess the clinical outcomes in surgical^[73-75] and non-surgical treatments^[76,77] in the head and neck regions.

MISCELLANEOUS APPLICATIONS

Analgesic effect of the laser

In vivo studies of the analgesic effect of LLLT on nerves supplying the oral cavity have shown that LLLT decreases the firing frequency of the nociceptors, with a threshold effect seen in terms of the irradiance required to exert maximal suppression.^[78] There have been claims that successful analgesia following oral surgery can be achieved with all major LLLT wavelengths from 632 nm

to 904 nm.^[79,80] Local CO₂ laser irradiation will reduce the pain associated with orthodontic force application, without interfering with tooth movement.^[81,82]

Nerve repair and regeneration

Low level laser therapy has been seen to reduce the production of inflammatory mediators of the arachadonic acid family from injured nerves, and to promote neuronal maturation and regeneration following injury.^[83,84] The LLLT protocols used, typically involve daily irradiation for prolonged periods, for example, 10 days at 4.5 J per day.^[83] The direct application of this technique to dentistry has yielded positive results in promoting the regeneration of inferior dental nerve (IDN) tissue, damaged during surgical procedures.

Post surgical pain

A single episode of LLLT (irradiance 0.9-2.7 J) is 100% effective for apical periodontitis following root canal treatment and post-extraction pain.^[85] There are conflicting results with regard to pain reduction post extraction by LLLT verses placebo controls.^[86-88]

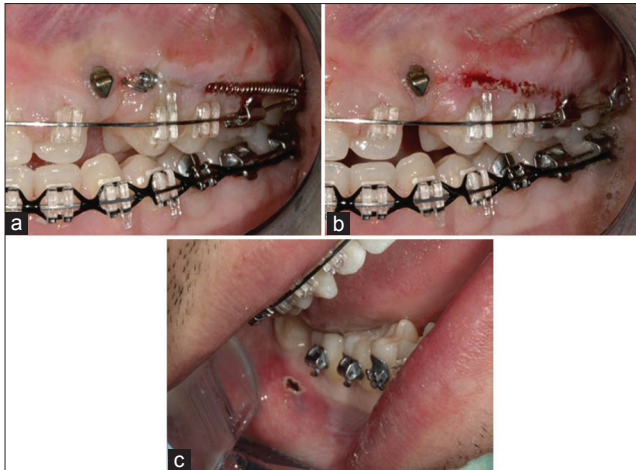


Figure 7: (a and b) Exposure of embedded coil spring used during retraction; (c) a punch hole created for implant placement

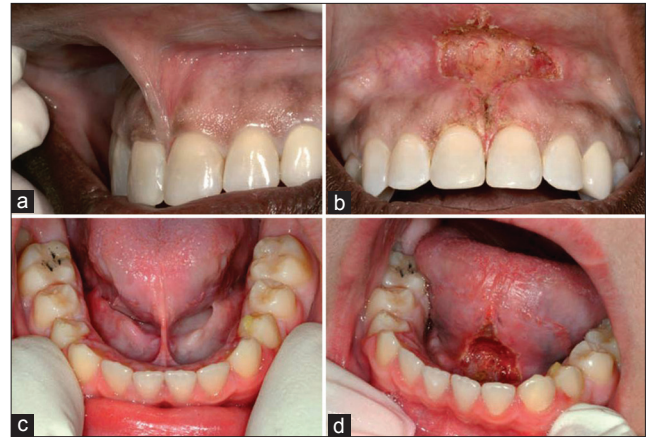


Figure 8: (a and b) labial frenectomy; (c and d) lingual frenectomy

Table 2: Diagnostic laser applications in dental practice

Laser types Applications	Argon 488 nm	Helium-neon 633 nm	Diode 633 nm	Diode 655 nm	CO ₂ 10600 nm
Laser fluorescence detection of dental caries	✓			✓	
Laser fluorescence detection of subgingival calculus (porphyrin)				✓	
Detection of fissure caries lesions by optical changes					✓
Laser Doppler flowmetry to assess pulpal blood flow			✓	✓	
Scanning of phosphor plate digital radiographs		✓			
Scanning of conventional radiographs for teleradiology		✓			

Table 3: Diagnostic laser applications used as research tools in dentistry

Laser types Applications	Nd:YAG 1064nm	Er:YAG 2940 nm	Argon 488 nm and 515 nm	Helium- neon 633 nm	Diode 633 and 670 nm
Raman spectroscopic analysis of tooth structure	✓				
Terahertz imaging of internal tooth structure	✓				
Breakdown spectroscopic analysis of tooth structure	✓	✓			
Confocal microscopic imaging of soft and hard tissues			✓		
Flow cytometric analysis of cells and cell sorting			✓		
Profiling of tooth surfaces and dental restorations				✓	✓

Sinusitis

There are conflicting findings on the benefit for sinusitis by laser therapy. One study^[89] denies any significant benefit, while others found that LLLT improved microcirculation, reduced edema, and reduced the frequency of relapses.^[90]

Of late, the diode laser has also been tried in experimental animals for controlling the excessive growth of the mandibular condyle. It was found that the laser is effective in regulating facial growth and could be a substitute for the current conventional methods such as a chin-cup.^[91] McDonald and Pitt Ford found that the human pulpal blood flow was decreased when continuous light tipping forces were applied to a maxillary canine.^[92] Barwick and Ramsay evaluated the effect of a four-minute application of intrusive orthodontic force on human pulpal blood flow with laser-Doppler flowmetry and concluded that the pulpal blood flow was not altered during the application of a brief intrusive orthodontic force.^[93]

Recent studies have demonstrated that low-energy laser irradiation stimulates bone formation *in vitro* and *in vivo*. The macrophage colony-stimulating factor (M-CSF) is essential and sufficient for osteoclastogenesis. Low-energy laser irradiation stimulates the velocity of tooth movement via the expressions of M-CSF.^[94]

Laser safety

While most dental lasers are relatively simple to use, certain precautions should be taken to ensure their safe and effective operation.^[95] First and foremost is protective eyewear [Figure 9] by anyone in the vicinity of the laser, while it is in use. This includes the doctor, chairside assistants, patient, and any observers such as family or friends. It is critical that all protective eyewear worn is wavelength-specific. Additionally, accidental exposure to the non-target tissue can be prevented through the use of warning signs posted outside the



Figure 9: Safety measures in dental office during laser application

nominal hazard zone, limiting access to the surgical environment, minimizing the reflective surfaces, and ensuring that the laser is in good working order, with all manufacturer safeguards in place. With regard to prevention of possible exposure to infectious pathogens, high volume suction should be used to evacuate any vapor plume created during tissue ablation, and normal infection protocols should be followed. Each office should have a designated Laser Safety Officer to supervise the proper use of the laser, coordinate staff training, oversee the use of protective eyewear, and be familiar with the pertinent regulations.

Medicolegal considerations

Conservative soft tissue surgery with a dental laser is considered within the scope of accepted dental practice and typically considered a covered procedure under most professional liability insurance policies designed for dental specialists. Informed consent must be routine and is best handled as part of the general consent form that all patients read and sign prior to the initiation of dental treatment. It is highly recommended that each clinician take a course from a reputable provider.

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. A further area of future growth is expected to be a combination of diagnostic and therapeutic laser techniques. Looking to the future, it is expected that specific laser technologies will become essential components of contemporary dental practice over the next decade.

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