Laser Dentistry: Hazards and Safety Measures. Review

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Abstract

Laser technology is a silent revolution in the world of dentistry. Now that laser technology has emerged from hospital operating rooms, and has become available to office practices, clinics, and private enterprises, the burden of responsibility for safety has shifted from hospital staff to the individual user. It is being effectively utilized in many areas of the dental industry to provide patients with convenient, improved services. Through innovative application this technology is changing the way in which dental services are provided. Practitioners and patients are beginning to accept this tried and true form of technology. Though it is not without its drawbacks, there are many reasons to choose to introduce laser technology into a clinical setting. Over the years studies have proven that patients have grown to accept and even welcome this form of surgery. Laser technology provides patients with bloodless surgeries, reduced pain after surgery and shorter procedures. Patient satisfaction is high with this form of technology because of its less invasive nature.

What remains, regardless of the practice site, application, or system in use, is the constant goal of establishing and maintaining a laser safe environment for the patient, the staff, and the user, at all times. This should be the goal of all who are involved with the sale, purchase, application, and management of all medical laser systems - under all circumstances. Laser safety is everyone’s working team responsibility. A laser is as safe or as hazardous as the user - and that user’s knowledge and skill, defines how well laser safety is managed. When done properly, laser technology can increase the efficacy of a practice. One simply has to plan for the appropriate training and safe usage of this tool to ensure practitioner and patient well-being. For these reasons it is imperative to develop a risk management perspective on laser safety. Proper safety management requires a fourfold approach including: knowledge of standards, identification of hazards and risks, implementation of appropriate control measures, and consistent program audit to demonstrate quality assurance.

This article’s objective is to demonstrate how office dental staff and patients can remain protected by implementing precautionary steps designed specifically to reduce injuries.

Keywords: Lasers in Dentistry; Laser Hazards; Laser Safety

Introduction

Apart from the fact that dental practice is firmly rooted in the principle of “primum non nocere” – first do no harm, it is imperative the benefits and the potential harm of any treatment is balanced. The use of laser technologies can play an indispensable role in the clinical management of patients and is an important tool in the practice of modern day dentistry. However, it is accepted that it does involve risk to laser beam exposure and it is essential that any exposure has a potential net benefit to the patient against any possible detrimental effects [1].

Lasers are very beneficial to the practice if implemented properly, but they do come with hazards that must be accounted for in order to ensure patient and dental staff are properly protected. Class IV lasers are among the most powerful being used in dental practices today. These lasers result in an average of 35 injuries per year in the U.S [2].

Unfortunately, these injuries appear to be mainly in solo practices where laser use is unmonitored. Office dental staff tends to have less training in laser technology than hospital laser safety officers and laser surgical nurses. This discrepancy in experience could be the cause of some of the injuries found in solo practices that are associated with this technology [1].

Laser can damage non-target the oral tissues, skin, and eyes as the result of accidental direct exposure to the laser beam or through the combustion and inhalation of gases, chemicals, and materials used in dentistry. A requirement for the clinicians which incorporate lasers in their practice is to ensure that they and each member of the dental team are knowledgeable of and practice laser safety. The knowledge of the specific laser(s) being used and laser physics and the compliance to the local rules and regulations are mandatory. These regulations apply to laser use, according to health and safety legislation of each state/country, and a laser safety officer (LSO) has the responsibility to ensure that these measures are adhered to [3-5]. Laser is an excellent and beneficial tool that will replace conventional techniques in dentistry but also bears a high risk for severe injury and risk. Knowing these risks is mandatory so that persons working in laser field can avoid these risks.

Properties of laser light

The laser light is different from the ordinary light, being able to aim a high amount of energy in a limited space in the form of light radiation. Several characteristics differentiate laser light from ordinary light (Figure 1):

- Laser light is collimated, that is to say that the waves, thanks to the spatial coherence of emitted photons, have only one very focused direction.
- Laser light is coherent, that is to say that each wave/photon has the same phase with the other emitted waves/photons that are kept in time and space.
- It is monochromatic, that is to say that each photon has just one wavelength and just one color (if visible) [6].

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Laser Classification

There are different methods of classifications:

Classification according to wavelengths on the electromagnetic spectrum

Laser can be distinguished according to their clinical use in dentistry in soft-tissue lasers and hard-tissue lasers, also called all-tissue lasers (Table 1).

Table 1: Classification of laser according to clinical use in dentistry.

<table>
<thead>
<tr>
<th></th>
<th>Soft tissues lasers</th>
<th>Soft and hard tissue lasers</th>
<th>LLLT</th>
<th>Lasers for caries detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode 445 nm</td>
<td></td>
<td>ErCr:YSGG 2780 nm</td>
<td>KPT 532 nm</td>
<td>Diode 504 nm</td>
</tr>
<tr>
<td>KPT 532 nm</td>
<td></td>
<td>Er:YAG 2940 nm</td>
<td>Diode 635 - 675 nm</td>
<td>Diode 655 nm</td>
</tr>
<tr>
<td>Diode 810, 940, 970, and 1064 nm</td>
<td></td>
<td>CO₂ 9300 nm</td>
<td>Diode 810, 940, 970, and 1064 nm</td>
<td></td>
</tr>
<tr>
<td>Nd:YAG 1064 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nd:YAP 1340 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ 10600 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Classification considers the position of laser wavelength on the electromagnetic spectrum of light [7,8]:

- Laser in the ultraviolet spectrum
- Laser in the visible spectrum
- Laser in the near-infrared spectrum
- Laser in the mid-infrared spectrum
- Laser in the far-infrared spectrum

In the visible and infrared spectrum of light, we find the majority of the wavelengths utilized in dentistry (Table 2 and Figure 2).

Table 2: Common dental lasers and their applications.

<table>
<thead>
<tr>
<th>Type of laser</th>
<th>Wavelength(s)</th>
<th>Construction</th>
<th>Delivery system(s)</th>
<th>Major application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argon</td>
<td>488, 515 nm</td>
<td>Gas laser</td>
<td>Optical fiber</td>
<td>Bleaching</td>
</tr>
<tr>
<td>CO₂</td>
<td>9600, 10600 nm</td>
<td>Gas laser</td>
<td>Waveguide, articulated arm</td>
<td>Soft tissue removal</td>
</tr>
<tr>
<td>Diode</td>
<td>635, 670, 810, 830, 980 nm</td>
<td>Semiconductor</td>
<td>Optical fiber</td>
<td>Photostimulation, soft tissue removal</td>
</tr>
<tr>
<td>Er,Cr:YSGG</td>
<td>2780 nm</td>
<td>Solid state</td>
<td>Optical fiber</td>
<td>Treatment of dental hard tissues, soft tissue ablation</td>
</tr>
<tr>
<td>Er:YAG</td>
<td>2940 nm</td>
<td>Solid state</td>
<td>Optical fiber, waveguide, articulated arm</td>
<td>Treatment of dental hard tissues, soft tissue ablation</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>1064 nm</td>
<td>Solid state</td>
<td>Optical fiber</td>
<td>Cutting and coagulating oral soft tissues</td>
</tr>
<tr>
<td>Helium-neon</td>
<td>633 nm</td>
<td>Gas laser</td>
<td>Optical fiber</td>
<td>Wound healing</td>
</tr>
<tr>
<td>KTP</td>
<td>532 nm</td>
<td>Solid state</td>
<td>Optical fiber</td>
<td>Bleaching</td>
</tr>
</tbody>
</table>

Lasers used in dentistry are classified with regard to the potential for damage. Table 3 presents an outline of the four basic classes of lasers used in dentistry, their emission parameters, examples of their use in dentistry, potential risks to unprotected tissues, and safety measures.

**Table 3: Laser classification, power output, risk analysis, and safety measures [5,9].**

<table>
<thead>
<tr>
<th>Laser class</th>
<th>Maximum output</th>
<th>Use in dentistry</th>
<th>Possible hazards</th>
<th>Safety measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>40 µW</td>
<td>Caries detection</td>
<td>No implicit risks</td>
<td>Blink response</td>
</tr>
<tr>
<td>Class IM</td>
<td>400 µW</td>
<td>Scanner</td>
<td>Possible risks with magnified beam</td>
<td>Laser safety labels</td>
</tr>
<tr>
<td>Class II</td>
<td>1 mW</td>
<td>Aiming beam</td>
<td>No implicit risks</td>
<td>Blink response</td>
</tr>
<tr>
<td>Class IIM</td>
<td>2 mW</td>
<td>Caries beam</td>
<td>Possible risks with direct viewing</td>
<td>Laser safety labels</td>
</tr>
<tr>
<td>Class IIIR</td>
<td>Visible 5 mW</td>
<td>Aiming beam</td>
<td>Eye damage</td>
<td>Safety eyewear</td>
</tr>
<tr>
<td>Class IIIB</td>
<td>Invisible 2 mW</td>
<td>Low level lasers</td>
<td>Eye damage</td>
<td>Safety personnel training for Class IIIR and IIIB lasers</td>
</tr>
<tr>
<td>Class IIB</td>
<td>0.5 W</td>
<td>PDT, Chemotherapy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class IIIB</td>
<td></td>
<td>Mucosal scanning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class IIIB</td>
<td></td>
<td>Cytofluorescent devices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class IV</td>
<td>No upper limit</td>
<td>Surgical lasers</td>
<td>Eye and skin damage</td>
<td>Safety eyewear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-target tissue damage</td>
<td>Safety personnel training and local rules</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fire hazards</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plume hazards</td>
<td></td>
</tr>
</tbody>
</table>

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Laser Hazards

The laser hazards can be summarized as follows:

Laser effects on tooth surface

During teeth bleaching using carbamide peroxide and diode laser teeth surfaces may be impacted by laser irradiation as well. This resulted in significant reduction in shear bond strength of orthodontic brackets to these teeth [9]. Er-YAG laser with water spray caused a 20% reduction in the bending strength of the dentin and if used without water caused severe surface cracks which served as initial sites of destructive fractures, resulting in a 35% weakening of dentin under bending pressures [10]. ND:YAG 1064 nm and 980 nm diode lasers decreased the microhardness of root dentin [11]. It is proved that in-office bleaching by means of laser significantly reduced the microhardness of enamel [12].

There is controversy regarding demineralization and acid-resistance of enamel and dentin after Er:YAG laser treatment in the literature. Subablative Er:YAG irradiation resulting in 20% change in calcium solubility produces no caries but fine cracks in the enamel surface. On the other hand, ablative dry laser treatment of 400 mJ resulted in the lowest acid demineralization in enamel and dentin, which on the micromorphological level induced thermal damage [13]. Moreover, it has been shown that after bleaching with light emitting diodes (LED)/laser microhardness of tooth decreased [14]. One week after using Diode laser, shear bond values were recorded to be diminished [15]. The mechanical impact of Er:YAG laser on very breakable enamel is different when high or low energies are applied similar to drilling with different diamond bur sizes because Er:YAG laser causes vaporization of the water content in tissues to induce microexplosions. Most of the studies regarding microleakage and marginal adaptation used high energies (over 300 mJ) of Er:YAG, which induced subsurface damages into enamel leading to low marginal adaptation and a high degree of microleakage [16]. It is concluded that cavity preparation with Er:YAG laser caused more microleakage than preparation with bur in cervical regions [17]. In addition, acid etching of enamel following Er:YAG, a kind of enamel finishing method, showed much better results [16]. Microleakage of occlusal walls in acid etched cavities was significantly lower than that achieved by means of laser treatment; hence, laser treatment of enamel is not a superior alternative compared to acid etching prior to adhesion of resin composite materials [18]. Conventional rotary preparation and acid etching yielded stronger adhesion to dentin and enamel in comparison to laser preparation [19].

Some authors found that Er:YAG caused lower shear bond strength in both enamel and dentin compared to bur [20]. The same findings were also reported by other authors [16,21]. Moreover, Nd-YAG and holmium:yttrium aluminium garnet (Ho:YAG) lasers were found to decrease the tensile bond strength of a silicone-based liner to an acrylic denture [22].

Laser effects on dental pulp

Laser energy is converted into heat when absorbed by tissue components, such as DNA/RNA, chromophores, proteins, enzymes, and water. Tissue damage due to the thermal effects of laser is largely attributable to the degree of heating in a way that increasing temperature leads to more severe changes; hyperthermia begins at 42 - 45°C, which results in structural alteration and shrinkage of collagen. Reduction of enzymatic activity takes place at 50°C. Temperature of 60°C causes protein denaturation, coagulation of collagen, and membrane permeabilization. Tissue drying and formation of vacuoles occur at 100°C. Beginning of vaporization and tissue carbonization is the result of heat over 100°C. Temperature of 300 - 1000°C leads to thermoablation of tissues, photoablation, and disruption [23]. A study regarding the thermal effects of Nd:YAG, argon, and CO₂ laser beams on enamel, dentin, and dental pulp demonstrated the potency of Nd:YAG laser beam to penetrate deeply through the enamel and dentin to the pulp. Although the effects of argon laser were closely associated with the degree of enamel surface cleanness, the superficial and deep temperatures were reported to be low even after surface cleaning. With respect to CO₂ laser, very high temperatures were yielded on the enamel and dentin surfaces; however, pulp chamber reached low temperatures [24]. An increase in temperature of 6°C can cause irreversible pulpitis, whereas pulpal necrosis occurs when

temperature rises higher (11°C) [25]. There is no consensus in the literature about pulpal damage caused by laser thermal effects. Some studies reported different grades of pulpal damage whereas others showed no sign of pulpal changes in terms of laser type and power setting [26,27]. In an article the effect of Nd:YAG laser at ≤ 240 J on third molars within 3 minutes after extraction was studied and concluded that if the remaining dentin thickness was greater than 1 mm, irradiation causes no significant pulpal response [16]. In contrast, thermal insult of CO₂ laser at 5 × 10³ J/cm² was reported to cause calcification in the pulp chamber and an increase in pulpal volume by approximately one third [27]. In another study it was demonstrated that laser cavity preparation caused overheating of teeth leading to pulpitis. Moreover, different temperatures were recorded according to the anatomic site of cavity preparation; Class I preparations yielded the highest values, followed by Class V cavities in enamel. On the other hand, caries removal or preparation in cementum caused the lowest temperature increase [13]. Buchella and Attin showed that activation of bleaching agents by heat, light, or laser might increase intrapulpal temperature beyond the critical value of 5.5°C [28].

### Nontarget oral tissue hazards

**Subcutaneous and submucosal effects of laser**

Inappropriate use of dental lasers with air cooling spray might result in cervicofacial subcutaneous and mediastinal emphysema (CSE) according to numerous reports. Despite the fact that air pressure of an air turbine is higher than that of a dental laser, the application time of the instrument tip might be the causative factor for occurrence of CSE [29-31]. Use of CO₂ laser to treat gingival abscess, periapical lesion, and surgery of pharynx and larynx carcinoma has been associated with increased risk of CSE. It has been demonstrated that 69.2% of laser therapies lead to CSE, which is quite higher than those treated with routine dental operations. Regarding CSE after dental laser treatment, out of 10 patients in a case series (8 patients under CO₂ laser and 2 under Er:YAG laser therapy), 9 developed emphysema following soft tissue incision. Emphysema occurred in 5 cases after abscess incision and drainage, 2 pediatric patients after frenectomy, 2 cases following anti-inflammatory laser treatment for periapical infection, and one case after each of subgingival scaling, flap elevation, and gingivoplasty. Dentists and oral surgeons should be familiar with the potential risk of emphysema caused by air cooling spray of dental lasers to ensure proper usage of lasers [29].

**Histopathological changes of laser**

Dental laser therapy causes some histopathological changes as well. Cell necrosis in the periodontal ligament (mostly due to thermal effect) was noticed 1 day after laser treatment, whereas teeth under conventional preparation developed no evidence of cell necrosis. Fifteen days following treatment, increased size and number of osteocytes and osteoclasts were evident in the periradicular bone in both laser and conventionally-treated teeth. Moreover, initial bone resorption was detected in laser-treated teeth. Conventionally-treated teeth began to return to normal morphology within 30 days post treatment. On the other hand, the laser-treated teeth exhibited ankylosis, cemental lysis, and significant bone remodeling [32]. Laser can cause pulpal vasodilation, and high power lasers cause edema and occasional inflammation [33,34]. In an animal study, rat teeth irradiated with an acousto-optically Q-switched Nd:YAG laser at 10 W for 0.2 seconds or 5 W for 0.3 seconds using a beam diameter of 2 mm showed mild dilation of pulpal vessels at the lowest levels with some calcified tissue 4 weeks after laser irradiation [33]. It is reported that pulpal damage happened due to ruby laser at 1880 - 2330 J/cm², however, coagulation necrosis of the odontoblasts, edema, and occasional inflammation occurred between 2400 and 3000 J/cm² [34]. In addition, delayed gingival healing following laser surgery was revealed with the presence of epithelial ulcerations and dense inflammatory infiltrate [35]. Thermal interaction of laser radiant energy with tissue proteins induces damage to the skin and other nontarget tissues (oral tissue. An increase in temperature 21°C above 37°C (normal body temperature) can cause cell destruction by denaturation of cellular enzymes and structural proteins, which interrupts basic metabolic processes. The thermal effect of absorbed radiant energy is manifested histologically as thermal coagulation necrosis for wavelengths above 400 nm. Photochemical and photoacoustic mechanisms are responsible for other nonthermal tissue injuries. They occur with single or repetitive pulses of low duration. The potential for mutagenic changes of laser irradiation has been questioned; however, there have been no reports of laser-induced carcinogenesis to date.
Penetration of specific wavelengths is potentially harmful to deeper tissues, e.g. prolonged exposures of low power density of continuous wave Nd:YAG laser can cause in apparent excess thermal necrosis [36]. In addition, several side effects of laser have been mentioned following surgical procedures such as burn, itching, tissue hyperpigmentation (especially in dark-skinned people), tissue hypopigmentation, and tissue carbonization.

**Chemical and infective hazards**

**Infection transmission due to laser smoke (laser plume)**

Copious amounts of noxious smoke or plume are released as a by-product of laser vaporization mostly by CO₂ laser. In general, surgical smoke consists of 95% water and vapor and 5% other materials. One million to one billion particles have been found in laser smoke and aerosol, some of which have been identified as intact cells, cell parts, blood cells, and viral DNA fragments. Culture from tubing of the smoke evacuator yielded viable bacteria. It has been determined that high heat does not completely kill some bacterial spores regardless of the power and length of exposure. Of note, *Staphylococcus aureus* is more refractory to high temperatures than *Escherichia coli* [38,39].

The viability or risk of exposure to viruses in laser smoke remains a matter of debate. Viral DNA has been captured in laser smoke. Transmission of Human papilloma virus (HPV) during a laser procedure from patient-to-caregiver has been reported. Moreover, particles of Human immunodeficiency virus (HIV) have been detected in the inner lumen of a smoke evacuator tubing after *in vitro* laser vaporization of HIV particles. Although human-to-human transmission of viruses and bacteria from laser smoke has not been established, there is enough preliminary evidence to warrant a cautious and self-protective approach to laser plume by all operating room personnel. Biologic hazards of laser smoke are viruses (e.g. HIV, HPV, hepatitis B and C); bacteria (e.g., *S. aureus*, *Mycobacterium tuberculosis*, *E. coli*, *S. pneumoniae* and *S. pyogenes*); and cells (e.g. carbonized tissue, aerosolized blood) [40,41].

By-products of laser smoke are considered to be potentially toxic chemicals. More than 600 organic compounds have been identified in plume generated by vaporized tissue. Many of these compounds have been documented to have harmful health effects including irritation to the eyes, nose, and respiratory tract; liver and kidney damage; carcinogenic cell changes; headaches; dizziness; drowsiness; stomach pains; vomiting and nausea; and rapid breathing. Some chemical compounds that may be found in laser smoke are as follows: acetylene, benzene, creosols, methane, ethylene, formaldehyde, hydrogen cyanide, propylene, styrene, toluene, and free radicals [42].

**What is a laser plume?**

Lasers and electrocautery are used for surgery to vaporize, coagulate, and cut tissue. The vapours, smoke, and particulate debris produced during these surgical procedures are called laser plumes.

**What is the content of a plume?**

Laser plume may contain carcinogens, mutagens, irritants, and fine dusts. Plumes may also contain bioaerosols, viruses, blood fragments, and bacteria depending on the type of the procedure. They also contain carbon monoxide, polyaromatic hydrocarbons, and various toxic gases and vapours. Plumes may contain chemicals such as formaldehyde, hydrogen cyanide, acrolein, and benzene.

**Are there any health hazards associated with laser plumes?**

Medical staff and patients in hospitals and clinics can be at risk from exposure to laser plumes. Other workplaces may include dental clinics, veterinary clinics, laboratories, cosmetic treatment clinics, and others. Health symptoms resulting from laser plume exposure include eye, nose, and throat irritation. At present there is no further evidence of other short-term or potential long-term (chronic) health effects from long-term exposure to laser plume. Researchers state that more studies are required. However, carcinogens, mutagens and irritants have been found in laser plumes. The human papilloma virus (HPV) DNA and the human immunodeficiency virus (HIV) has also been found in the plume.

How can the plume be controlled?

Contaminants generated by lasers and electrosurgical units can be controlled by:

Ventilation: General room ventilation (dilution ventilation) is not sufficient to remove air contaminants. Plume scavenging system (PSS) is the term used for a portable, mobile or fixed device that captures and neutralizes plume. Plume scavenging systems are also known as smoke evacuators, laser plume evacuators, plume scavengers, and local exhaust ventilators.

Safe work practices: There should be a laser safety program in place and all staff who must work with or near the laser unit should receive:

1. Training on proper procedures for the safe use of equipment.
2. Instructions about how to keep equipment in good working order.
3. Instruction and training to protect patients and clients from exposure.
4. Education about possible health and safety hazards to all workers.

Medical personnel should wear appropriate respirators, eye protection, and gloves during laser surgery and when employing electrosurgical units.

Respirators should be used to provide additional protection and not as a substitute for an air exhaust system. Surgical masks do not eliminate the risk of infection or other hazards from inhaling viruses, germs, chemical vapours, tiny dust particles, aerosols, or cellular debris in laser plumes. If engineering controls do not provide sufficient protection then a properly fitting respirator suitable for the contaminants that staff are exposed to should be used as protection against airborne contaminants [43].

Eye Hazards

The laser beam may cause damage to the eye from direct exposure or reflection when the wearing of appropriate eyewear is not adhered to. The wavelengths in the visible to near infrared (400 - 1400 nm) may result in retinal burns in the area of the optic disk due to the relatively non-absorption by water [4,5].

In addition, the visible wavelengths may cause damage to the red or green cones in the retina, which can lead to color blindness. Corneal, aqueous, and lens damage may occur from the mid- to far-infrared wavelengths (1400 - 10,600 nm) (Figure 3 and Table 4). It is imperative and mandatory that the patient, dentist, dental personnel, and anyone within the nominal hazard zone (NHZ) should use appropriate eye protection during laser procedures. The eyes must be protected when the dental laser is on, prior to the laser being turned on. The lenses of the glasses must be constructed of wavelength-specific material to contain or attenuate the energy of exposure within the the maximum permissible exposure (MPE) values, and the specific wavelength is imprinted on the lenses. The entire periorbital region must be covered by glasses, and they must have appropriate side panels to prevent laser beam entry. Practitioners using magnification loupes or a microscope must have the appropriate inserts or filters.
Appropriate care should be taken when cleaning the laser glasses to prevent removing the protective coating on the lenses by caustic disinfecting solutions. The eyewear should be cleaned with an antibacterial soap and dried with a soft cotton cloth.

Ocular Hazards

Reflection related injuries are a possibility. Lasers can bounce off of a reflective surface and cause injury to both the patient and the staff member administering the laser treatment. Non-reflective material is recommended for use when laser technology is being applied [45]. Retinal or corneal burns may result from laser emissions. Even low intensity beams can cause extensive damage because of the nearly 95% absorption rate of the radiation entering the eye [46,47]. Retinal injuries due to laser pointers or devices have legal, financial and medical consequences. Most accidents are prevented by natural reflexive protective mechanisms [48,49]. A lack of information on the types of lasers and the hazards, mis-information or lack of information to consumers, by laser device manufacturers, easy availability of hazardous lasers that resemble safe lasers are a few of the factors that can lead to careless use [50]. Strict legislation, prohibiting the manufacture, use or possession of hazardous laser pointers, public education and education of the military sector about the hazards of lasers is mandatory, especially due to increased use of lasers for military applications [51,52].

Laser pointers are practical and safe training tools when used properly. If used incorrectly they can cause ocular damage, potentially resulting in devastating vision loss. The ocular and visual morbidity can result in significant expenses for medical care and inability to work (temporarily or permanently) for civilians and military personnel. It is reported that three cases of soldiers who experienced vision loss following exposure to laser pointers, while celebrating successful football game [53].

The rabbit corneal damage thresholds for 5 ms pulsed 1338 nm laser at incident spot sizes of 0.28, 0.94, 1.91, and 3.55 mm were 70.3, 35.6, 29.6 and 30.3 J/cm² respectively. The rabbit retinal damage threshold for this laser given in terms of total intraocular energy (TIE) was 0.904 J at 5.0 mm corneal spot size when the beam was collimated. The most sensitive ocular tissue to this laser changed from the cornea to retina as the increase of spot size. For rabbit, when the corneal spot size was smaller than about 2.0 mm the cornea would be damaged first, and as the spot size increased to larger than 2.0 mm the retina had a higher damage risk. The obtained results could be used for the refinement of the safety standards for transitional NIR lasers [54].

Table 4: Eye and skin hazards of dental lasers [5,44].

<table>
<thead>
<tr>
<th>Laser Wavelength</th>
<th>Eye Structure</th>
<th>Eye Damage</th>
<th>Skin</th>
</tr>
</thead>
<tbody>
<tr>
<td>405 &gt; 532 nm</td>
<td>Retina</td>
<td>Retinal Lesion</td>
<td>Photosensitive reaction</td>
</tr>
<tr>
<td>Caries detection 655 nm</td>
<td>See below*</td>
<td>Retinal Lesion</td>
<td>(400 &gt; 700 nm)</td>
</tr>
<tr>
<td>Oral pathology cytofluorescent devices 630 - 900 nm</td>
<td>Lens (&gt; 700 nm)</td>
<td>Retinal Burn and Cataract (&gt; 700 nm)</td>
<td></td>
</tr>
<tr>
<td>Diode 810 &gt; 1064 nm</td>
<td>Retina</td>
<td>Retinal Burn</td>
<td>Excessive Dryness</td>
</tr>
<tr>
<td>Nd:YAG 1064 nm</td>
<td>Lens</td>
<td>Cataract</td>
<td>Blisters</td>
</tr>
<tr>
<td>Er,Cr:YSGG 2780 nm</td>
<td>Lens</td>
<td>Cataract</td>
<td>Burns</td>
</tr>
<tr>
<td>Er:YAG 2940 nm</td>
<td>Aqueous Humor</td>
<td>Aqueous Flare</td>
<td></td>
</tr>
<tr>
<td>CO₂ 10,600 nm</td>
<td>Cornea</td>
<td>Corneal Burn</td>
<td></td>
</tr>
</tbody>
</table>

*Class I and II caries detection lasers may become hazardous to retina when viewed through optical aids (e.g. loupes and operative microscope), as magnification devices can make a diverging beam more hazardous [44].
Laser Dentistry: Hazards and Safety Measures. Review

Oral Tissues and Skin hazards

It is important that the laser operator be aware of accidental damage to nontarget tissues. Care must be taken to avoid accidental ablation of adjacent tissues. Anodized and non-reflective instruments should be used to avoid reflection; stainless steel instruments and rhodium mirrors may be safely used if precautions are taken to minimize reflection. Potential damage to the skin can occur depending on the laser's wavelength and its absorptive potential, power density, duration of exposure, and spot size. Photosensitive skin reactions may happen with visible-wavelength lasers; excessive dryness, blister, or burn may happen with medium and far-infrared lasers.

Chemical and Infective Hazards

The laser beam can produce plume damage. "Plume" is defined as the gaseous by-products and debris from laser-tissue interaction. It can have a smoky appearance or be completely invisible to the naked eye. The plume may pose a risk due to the aerosol developed by the laser-tissue interaction. Organic and inorganic matters include toxic gases, chemicals, bacteria, viruses, and fungi. The laser-generated airborne contaminants (LGAC) may include human immunodeficiency virus, human papilloma virus, carbon monoxide, hydrogen cyanide, formaldehyde, benzene, bacterial and fungal spore, cancer cells, and, when removing composite resin materials, methyl methacrylate monomer. Therefore, protective surgical clothing and fine-mesh face masks capable of filtering 0.1 μm particles must be worn.

Fire Hazards

Ignition of gases or material can occur due to the high temperatures of Class IV and some Class III B lasers. Nitrous oxide and oxygen are allowed for conscious sedation according to ANSI Z136.3 when used with a nosepiece during laser operation.

Also to be avoided within the NHZ are alcohol-soaked gauze, alcohol-based anesthetics, and any products containing oil-based substances such as petroleum jelly, which may be flammable. The laser should not be used if the patient uses an oxygen tank. When using general anesthesia, the flash point of some anesthetic aromatic hydrocarbons used in general anesthesia may be exceeded. Also it should be considered that materials not normally flammable may ignite in an oxygen-enriched atmosphere.

Hazards secondarily to laser removal of tattoo

The first work done at 2015 that proved the formation of highly toxic hydrogen cyanide upon ruby laser irradiation of the tattoo pigment phthalocyanine blue. The released hydrogen cyanide was found at concentrations high enough to produce cellular harm.

Hazards from laser use in photodynamic therapy (PDT)

Lasers are the most commonly used light source for PDT because of their ability to produce high intensity monochromatic light in targeted regions. Diode lasers, which are small, cost effective, and simple to install and use, are now being specifically designed for PDT use. Risk of physical injury posed by lasers can include burns to skin or ignition of other materials that may contact laser beams, eye injury from directed or reflected laser energy that enters the eye, and electrocution or burns from power supplies and electronics. Direct or reflective skin and eye contact are the most important hazards posed to healthcare professionals involved with PDT treatment, whereas electrical hazards from power supplies would present the greatest risk to engineers performing maintenance on the devices. Specific thermal effects that may arise from overexposure of non-ionizing radiation sources (most often associated with class 4 laser sources that have sufficient power to induce thermal damage, injury to the retina, lens, cornea, or skin.

Another potential mechanism of biological effects is photomechanic (or photoacoustic) damage, which occurs when light energy is transferred to tissues more rapidly than the mechanical relaxation of the tissue. Intense pulsed lasers have sufficiently high fluence rates and short laser pulses (< 1 ns) which may induce tissue disruption by shear forces or by cavitation (i.e. formation and implosion of liquid cavities), resulting in the photomechanic damage. PDT treatments offer a promising future for the treatment of a number of diseases, including different types of cancers, as new photosensitizing drugs and light supply devices are continually created and improved. As PDT

treatment evolves, care must be taken to ensure the health and wellbeing of not only the patient, but also of the healthcare providers and supporting clinical staff members who participate in patient treatment. Adherence to general health and safety principles and proper planning of PDT procedures should help to minimize potential hazards in the workplace and allow continued successful treatment of patients and protection of all healthcare workers involved [62].

Safety Measures for Laser Dentistry

Eye protection

While most dental lasers are relatively simple to use, certain precautions should be taken to ensure their safe and effective operation:

1. First and foremost is protective eyewear (Figure 4) by anyone in the vicinity of the laser, while it is in use. Laser protective eye-wear shall be inspected for damage prior to use.

2. It is critical that all protective eyewear or eyewear combined with loupes worn is wavelength-specific (Figure 5). Designed for clinicians that perform laser procedures, this loupe combines eye protection and magnification into a single lightweight product. A virtually clear glass filter is built into the telescope, while a tinted polycarbonate filter is baked onto the carrier lens.
3. Efficient suctioning to possible exposure to infectious pathogens, from vapor plume created during tissue ablation.

4. Each office should have a designated Laser Safety Officer (LSO) to supervise the proper use of the laser, coordinate staff training, oversee the use of protective eyewear, and be familiar with the pertinent regulations.

Lasers are surgical instruments, and during its use, dental practitioners and their staff must follow the standard precautions that include gloves, masks, protective glasses or face shield, and gowns. The risk of a needle stick injury with a fine quartz tip is possible. To prevent contamination, reusable fibers and tips must be heat sterilized in addition to the handpieces. To ensure effective sterilization, any debris on the end of the tip must be removed and/or cleaved prior to sterilization. Wipeable or removable barrier should be placed over the operational controls on the laser. A high-level disinfectant can be used on the laser and surrounding operatory surfaces.

Service hazards would include electrical, air, and water supply lines, in addition to connectors and filters. Tripping over wires and cables is a hazard and the lasers should be moved with caution.

Test firing of the laser should be performed by the clinician or LSO before clinical use in an appropriate environment/medium (water glass for medium- and far-infrared lasers and dark absorbing paper for visible and near-infrared lasers) with low-energy setting, to ensure for proper functioning parameters (repetition mode, pulse duration, emission mode, air/water spray) of laser, appropriate for the procedure.

Safety measures also include:

- To cover the foot switch to prevent accidental operation.
- To lock the unit panels to prevent access by unauthorized access.
- A key or password protection to prevent laser from being used by unauthorized persons.
- A remote interlock to shut off the laser if a door should be opened during operation.
- An emergency stop switch or button to shut down the laser immediately.
- A laser software diagnostics can show error messages allowing for shutdown if any component is not functioning correctly.
- Time-lapsed default to standby mode when laser is not used for a set period of time.
- Standby mode will not initiate laser when foot pedal is stepped on.
- Visible signs on the laser such as standby mode light vs. ready mode light.

Multi-chair open dental offices must have the physical dimensions of the controlled area. The surfaces within the controlled area should be non-reflective, and all supply cables for the laser system should be protected from inadvertent damage. A fire extinguisher should be available and easily accessible.

For specific health and safety regulations applied to laser use that follow the legislation of each state/country, the laser user has the responsibility and obligation to adhere to local governmental rules.

Specific hazards

- **Plasma**: Laser light generation in gas laser e.g. argon laser as well as lasers used for welding produce plasma. Laser welding and conventional welding produce a bright welding plasma emitting intense ultra violet and short waved blue light. This emission is called secondary radiation. Prolonged exposure can cause retinal damage, corneal inflammation, and erythema.
- **CO₂ laser**: Particular high frequency stimulated CO₂ lasers create ozone around the resonator, irritating the eyes and airways.

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- **Vapor and dust**: Emission of vapors and dusts during material processing is lower than with other thermal methods. The emission can be divided into:
  - Irrespirable dusts and vapor: no hazards for the user.
  - Respirable dusts and vapors: (aerodynamic diameter < 10 µm): high health risk for the user.
  - Gases.

- **Metals**: during cutting metals such as stainless steel, chromium and nickel are set free. Nickel and all its derivatives are carcinogenic, whereas for chromium only Cr VI is dangerous.

- **Organic matters**: particle diameters are between 0.07 mm and 0.25 mm, comparable to metals. The diameter tend to decrease with increasing generation of gaseous pyrolysis products [63]. In a recent review authors showed that laser ablation (LA) is gaining acceptance for the treatment of tumors as an alternative to surgical resection. This paper reviews the use of lasers for ablative and surgical applications. Also reviewed are solutions aimed at improving LA outcomes: hyperthermal treatment planning tools and thermometric techniques during LA, used to guide the surgeon in the choice and adjustment of the optimal laser settings, and the potential use of nanoparticles to allow biologic selectivity of ablative treatments. Promising technical solutions and a better knowledge of laser-tissue interaction should allow LA to be used in a safe and effective manner as a cancer treatment [64].

**Conclusion**

Lasers, for many practitioners, are a useful addition to the dental practice. They can improve quality of care through shorter, less invasive, bloodless procedures. This tool has many merits, but must be utilized with safety as a top priority. Although dental lasers have many advantages but their use without taking strict safety measures can be potentially hazardous upon soft and hard dental tissues, and other extra-oral tissues like eyes. All employees should be properly trained in the safety requirements regarding lasers. The standards set in place by Occupational Safety and Health Administration (OSHA) and American National Standard Institute (ANSI) on the subject of lasers should be followed strictly by the dental practice when creating an operation room laser safety plan. For these reasons dental employees should be warned about laser adverse side effects during laser use to avoid or at least minimize the potential risks for their patients as well as dental team.

**Recommendations (Safety is everyone’s responsibility)**

Lasers can offer patients a wonderful range of treatment options, from standard of care to experimental innovation. Laser users are constantly challenged to redefine who they are, what they do, and their scope of practice, with each new laser system or application. It must be remembered that every new system demands risk assessment and a review and revision of facility safety policies and procedures. Only through teamwork, communication, continuing professional education and training, and respect for the technology, can we establish the foundation for a truly effective laser safety program [39].

Laser safety is matter on concern while opting for any clinical laser procedures. Though it is better tool than conventional methods, Safety norms must followed. For this purpose routine audit, troubleshooting, training and wearing safety essentials is required [65].

**Bibliography**


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