Physical and Electronic Properties of Lasers


Laser Safety

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Abstract

The use of lasers in medical practice has seen great expansion in the past decades. However, these devices may also pose a significant hazard. Laser hazards are generally divided into beam hazards and nonbeam hazards. Beam hazards inflict ocular and cutaneous injury, whereas nonbeam hazards stem from the laser device itself or its interaction with materials within the surgical environment. The latter include laser plume hazards, fire hazards, and electrical hazards inherent in a high-voltage system that is a laser device. Therefore, a thorough understanding of these hazards along with methods to reduce their risk is of paramount importance in order to ensure maximal safety for the surgeon, the staff, and the patient.

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Ocular Hazards

Ocular injury is a very serious complication arising from the use of a laser. Usually operating in the millisecond range of pulse duration, a laser beam cannot effectively be shielded by the eyelid blink reflex, which takes a tenth of a second to complete. Furthermore, lasers operating in the infrared spectrum do not emit a bright visible light necessary to elicit a blink reflex [1].

Ocular damage resulting from laser surgical procedures is tied directly to the laser wavelength utilized. As a general rule, optical radiation emitted by lasers operating in the ultraviolet (200–400 nm), mid-infrared (1,400–3,000 nm), and far-infrared (3,000–10,600 nm) range of wavelengths are absorbed by the anterior ocular segment, and inflict injury on the lens or the cornea. On the other hand, light emitted by lasers in the visible light (400–760 nm) and near-infrared (760–1,400 nm) spectra penetrate through, amplified by the above structures, and are absorbed in the posterior ocular segment by the retina and the vascular choroid [2].

These findings reflect the interaction between light of a given wavelength and the tissue. For example, the far-infrared 10,600 nm wavelength light emitted by the CO2 laser is highly
absorbed by water and does not penetrate beyond approximately 100 μm into the cornea, which has an aqueous composition of 78%. The resulting corneal injury is mediated by a thermal process, in which the optical radiation is absorbed by water, resulting in the generation of heat energy, the rate of which exceeds that of its dissipation by the surroundings, leading to an elevation in temperature [3].

The retina is particularly vulnerable to visible and near-infrared spectrum optical radiation, even that emitted by low-powered light devices, as a result of focusing by the ocular refractive media. Retinal injury from optical radiation is in large part related to the absorption by the melanin chromophore and, to a lesser degree, xanthophyll and hemoglobin. Concentrated densely within the retinal pigment epithelium, as well as focally within the choroid, melanin absorbs optical radiation of visible and near-infrared wavelengths [3, 4]. The injury sustained as a result of laser exposure may be insidious given the lack of nociceptors in the retina. Depending on the site of retinal injury, the insult may range from insignificant in the periphery, to a perceptible deterioration of visual acuity and color discrimination in the foveal region. The degree of visual loss is determined by the number of lost photoreceptor cells in the fovea. The inflammation and edema resulting from a laser injury in the parafoveal region may extend into the fovea, resulting in transient reduction in visual acuity that may recover over a period of days to weeks [2].

Certain lasers have the ability to inflict injury on multiple ocular structures. For instance, the 1,320 nm neodymium-doped yttrium aluminum garnet (Nd:YAG) laser may damage the lens and cornea, as well as the retina. The 755 nm alexandrite, 810 nm diode, and the 1,064 nm Nd:YAG lasers endanger the retina and the lens; the 2,940 nm erbium:YAG (Er:YAG) laser may damage the lens as well as the cornea [2]. Q-switched near-infrared lasers, such as the Q-switched alexandrite and Nd:YAG lasers present an even greater threat through a mechanism of photoacoustic waves in addition to their thermal effects [5]. Light emitted in very short pulse durations, on the order of pico- and nanoseconds, results in a photoacoustic laser-tissue interaction, a mechanical, rather than a thermal, process that is not pigment-dependent. The extremely high temperatures (exceeding 10,000°C) generated within the tissue lead to electron stripping, resulting in plasma formation, the rapid expansion of which produces tissue-damaging photoacoustic waves. Retinal injury resulting from photoacoustic waves may culminate in perforation [3, 4].

Ocular protection is, therefore, of paramount importance when operating a laser device. Any person that may possibly be exposed to optic radiation must wear appropriate protective eyewear, including the laser operator, support staff, patients, and visitors. Protective eyewear is chosen based on the wavelengths of light emitted by the laser. Each pair of laser safety eyewear is designated with a central wavelength of rejection or a rejection band of wavelengths, as well as the optical density (OD) afforded by the lens. The OD parameter is defined by the log of the attenuation of light transmitted through the lens. For example, protective laser goggles with an OD of 4 allow 1/10⁴ of the laser energy to penetrate. Thus, the higher the OD value, the greater the protection afforded by the eyewear. On the other hand, higher OD laser eyewear may significantly reduce visible transmittance and impair color discrimination, factors that may challenge a laser surgeon [2, 6].

Two common laser eyewear options include those constructed with coated glass and those made up of polymeric materials. Some of the disadvantages of the glass eyewear include their greater weight and the ability of the reflective coating to become scratched, thus compromising protection. On the other hand, polymeric material-constructed eyewear is lightweight and absorbs, rather than reflects, radiation. A disadvantage of the latter, however, is that it may crack
or melt. Protection against indirect exposure should be maintained with wrap-around goggles or side shields. Patient eye protection should be provided with corneal shields or mini-goggles that ensure complete light-proofing. Only heat-proof stainless steel corneal shields should be employed, as they reflect away the laser beam without generating heat, in contrast to plastic eye shields that heat up and may melt, causing ocular injury. Corneal shields must have a smooth polished concave surface and an anodized convex surface [2, 6].

Ocular injury may occur not only from a direct laser beam exposure, but also from exposure to the light reflected or scattered off glass, glossy metal, or plastic surfaces. Thus, all windows and mirrors in the room should be covered with opaque material, all jewelry removed, and all instruments anodized, roughened, and ebonized with black fluoropolymeric coating [5, 7].

A non-beam related ocular hazard associated with laser surgery that cannot be overlooked involves preoperative disinfectant chlorhexidine, which may cause keratitis and corneal opacification. Thus, this agent should not be used to disinfect corneal eyeshields or periorbital areas lest the substance be aerosolized into the laser plume. Instead, corneal shields should be autoclave-sterilized. They should be rinsed in sterile water and lubricated with an ophthalmic ointment prior to insertion [8].

A warning sign should clearly be displayed on the door of the room where laser surgical procedures take place informing potential visitors and staff of the potential ocular hazard inside.

**Skin and Teeth Hazards**

Cutaneous injury from a laser beam may be significant and its spectrum may range from redness to overt burns and scarring. Lasers may also be a hazard to oral health. Dental enamel, in particular, is vulnerable to ultraviolet and infrared light. Thus, lasers operating in these wavelengths, including the CO₂ and Er:YAG, pose a particular threat. Melting and resolidification of enamel at high fluences and cracking, charring, flaking, and discoloration at lower fluences has been reported. Therefore, oral protection is important in order to avoid injury. This may be achieved by keeping the mouth closed or by covering it with a moistened gauze or a protective mouthpiece [9].

**Fire Hazard**

Laser fires may result from ignition of combustible material in the vicinity of a laser procedure, resulting in burns. Common sources of fuel include flammable materials used during a laser surgical procedure, including gauze, towels or drapes, and respiratory devices, including face masks and nasal cannulae. Flammable materials, including makeup and hair spray, should be removed prior to a laser procedure. Alcohol should never be utilized to prep a laser surgical field. Caution should be exercised when performing laser procedures in hair-bearing areas, as hair can ignite and cause skin burns. In order to mitigate the risk of ignition of potentially combustible materials, the prepping with saline of the surgical area and supplies – including drapes, gauze, and tubing – is appropriate. The patient’s hair should also be kept moist during the procedure to reduce its incendiary potential [2, 10, 11].

A water reservoir, such as a bowl or an irrigation syringe should always be within easy reach during a laser procedure to combat combustion fires on the surgical field. A halon fire extinguisher should also always be readily available in the event that an electrical fire erupts within the device circuitry. Unlike the carbon dioxide fire extinguisher, this fluorohydrocarbon fire extinguisher does not generally damage the laser components [12].
**Electrical Hazard**

Given the high-voltage high-current electrical nature of lasers, these devices carry a significant hazard of electrocution, and should only be maintained and repaired by specially trained and authorized personnel [2].

**Plume Hazards**

The interaction between a heat-producing device and the treated tissue has the potential to produce surgical smoke or plume. In fact, laser is the second most common heat-generating device employed by surgeons, second only to electrosurgical units. The evaluation of laser plume as a hazard has centered on its mutagenic and carcinogenic capacity, as well as the possible role it may play in disease transmission. Plappert et al. [13] have found substances released in CO₂ laser pyrolysis of tissue to be cytotoxic, genotoxic, clastogenic, and mutagenic. Numerous chemical substances, some carcinogenic, have been detected in the laser plume, including carbon monoxide, hydrogen cyanide, ammonia, formaldehyde, acrolein, toluene, and benzene [2, 14]. Substances found in the surgical smoke have been showed to be respiratory irritants in laboratory animals, resulting in the development of pulmonary and bronchiolar inflammation [14].

Laser procedures utilizing lower irradiance energies carry the risk of liberating cellular clumps and red blood cells that may be carried in the laser plume. It is believed that laser plume may harbor a greater infectious potential compared to electrosurgical smoke [15]. The presence of viral particles in the laser plume has been documented in the literature. For instance, intact human papillomavirus DNA has been isolated from laser plume generated in the CO₂ laser treatment of verruca plantaris and respiratory tract papillomatosis [16]. Human immunodeficiency virus (HIV) DNA capable of infecting cultured cells has also been recovered from a laser plume [17].

Implications of these findings on viral disease transmission have been a subject of debate, with emerging evidence supporting infectivity potential. Type 6 and 11 human papillomavirus has been isolated in the case of laryngeal papillomatosis developed by a laser surgeon involved in the treatment of anogenital papillomatosis. Furthermore, the development by a laser operator of verrucae in the anterior nares may point to human papillomavirus transmission via smoke plume [14, 18, 19].

In light of these findings and concerns, effective methods should be employed to combat the laser plume hazard. These include a smoke evacuator and laser masks. Most surgical masks only filter particles to approximately 0.5 μm in size. However, about 77% of particles in the laser plume are 1.1 μm or smaller. Therefore, well-fitted high-filtration, or laser, masks that filter particles larger than 0.1 μm by means of electrostatically charged synthetic fibers, should be employed in place of standard surgical masks. These must be frequently changed as condensate moisture eliminates their polarity. The mask should also have a moldable nosepiece to allow it to be worn snuggly [2].

High-filtration masks should not be the only protective method utilized during a laser surgical procedure. A high-efficiency smoke evacuation device with a powerful vacuum should also be used. The device should employ a triple-filter system. This includes a high-efficiency particulate air filter that removes particles larger than 0.3 μm; an ultra-low particular air filter, which is capable of removing particular matter up to 0.1 μm in size; and a charcoal filter to remove toxic chemicals within the smoke. An appropriate smoke evacuation system should have a 30- to 50-ft³/min capacity [2]. The importance of proper operation of a smoke evacuator cannot be overemphasized. The effectiveness of the device is drastically reduced from 99 to 50% when the distance from the laser-treated site is increased from 1 to 2 cm [15].
Q-switched lasers present a particular challenge. The light energy provided by these systems in the course of treatment generates high-speed tissue fragments and particles that may escape capture by the smoke evacuation device. Safety measures that have been recommended in these situations include splatter shields or collecting cones, as well as appropriate eye protection, gloves, gowns, and laser surgical masks. Treatment through a transparent membrane has also been recommended [5, 20].

**Conclusion**

As lasers are becoming commonplace in medical practices, it is crucial more than ever to emphasize their safe use to protect all those involved in laser procedures. Potential laser hazards, including ocular and skin hazards, laser plume hazards, and fire hazards, should all be appreciated and appropriately addressed in order to ensure maximal safety for the surgeon, the staff, and the patient.

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**References**


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