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LASER SAFETY GUIDE

IN DERMATOLOGY AND PLASTIC SURGERY

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Introduction

Lasers are more popular and used by more people than ever, including non-physicians. There are over 3.5 million laser procedures a year, according to the American Society of Plastic Surgeons 2019 Plastic Surgery Statistics Report. The 2019 American Society for Dermatologic Surgery Survey on Dermatologic Procedures reported over 4.1 million laser/light/energy-based procedures. There is an ever-increasing number of devices and manufacturers. Lasers are even available to consumers at home. These devices pose potentially serious hazards. It is the responsibility of the laser surgeon to protect patients and staff. Avoiding flammable materials and limiting exposure to non-target tissue by selecting appropriate laser parameters will mitigate the danger to patients. Laser operators and assistants can be protected by wearing eye protection, using a high-filtration mask, and evacuating plume.[1]

Safety Standards

The American National Standards Institute (ANSI) is a private non-profit organization composed of professional societies, educational institutions, laser manufacturers, government agencies, and consumer and labor groups that develops voluntary consensus standards.[2] The United States Food and Drug and Administration (FDA) and the Occupational Health and Safety Administration (OSHA) recognize the ANSI Z136 series as the standards for laser safety. Z136.1 describes the safe use of lasers, and Z136.3, last updated in 2018, pertains to the safe use of lasers in healthcare. These standards are voluntary, but they have been referenced in malpractice litigation.[1,3] According to these standards, many medical lasers (and almost all surgical lasers) are Class 4, the most hazardous class. These devices are capable of causing severe eye injury even with short-duration exposures, can ignite flammable materials, produce a hazardous plume, and require a danger sign posted outside the door.[1,4]

The Center for Devices and Radiological Health (CDRH) is a branch of the FDA that regulates laser manufacturers and ensures compliance with the Federal Laser Product Performance Standard (FLPPS). The FLPPS requires the hazard class to be affixed to the laser by the manufacturer.[2,3] The Joint Commission is a non-profit group that accredits and inspects healthcare organizations and ensures adherence to ANSI standards in the clinical setting.[3]

Each facility or organization operating a Class 4 laser requires a laser safety officer (LSO). The LSO can be the operator or other person with sufficient experience and training to manage the site's laser safety program. The LSO's responsibilities are described in ANSI Z136.3 and include creating the facility's policies and procedures regarding the safety program.[4] The LSO conducts audits of the facility at least yearly. The LSO has the responsibility of training laser operators and staff. ANSI Z136.3 Appendix F has examples of laser safety education program criteria.[4]

General Safety Precautions

All doors leading to the laser treatment area must have warning signs with the wavelength of the laser while it is in use and should be removed when not in use. Similarly, windows with access to the laser treatment area should be covered when the laser is in use, especially for those wavelengths transmitted by glass: visible and near-infrared. Windows can be covered with shades, curtains, or flat covers attached with hook and loop fasteners or magnets.[2] Moveable, freestanding barriers are also available. Mirrors should be covered, and instruments and furniture should have non-reflective surfaces.[3-5]

Care should be taken that the laser activation switch is separated from other pedals and placed to prevent accidental activation. The emergency shutoff switch must be easily accessible by the laser operator at all times.[3,4]

It is well-established that checklists improve safety and reduce adverse events and mortality.[6] There are several laser safety checklists available that can be customized for each device and application; one example is provided in ANSI Z136.3 Appendix B.[2,4,7]

Eye hazards

The eye is the organ most vulnerable to injury from lasers due to its unique optical properties, and lasers can cause permanent blindness. Most reported injuries involve the eye.[3] The cornea and conjunctiva are the only living tissue exposed to the environment. The eye lacks the protective stratum corneum of the skin and is thus comparatively exposed. The eyes' aversion response to bright light (pupil constriction, eye movements, and blink reflex) protects the eye, but some lasers have a great enough intensity or short enough pulse duration that they may cause injury faster than the 0.15-0.2 second required even for the blink reflex to occur. Infrared lasers may not trigger the blink reflex at all.[1,8]

Which specific ocular tissue is injured depends on the laser wavelength. Light must be absorbed by tissue to cause injury. Generally, ultraviolet (200-400 nm), mid-infrared (1,400-3,000 nm), and far-infrared (3,000-10,600 nm) lasers injure the lens and cornea (Fig 1).[1,3,9] Lasers in these categories include ultraviolet excimer, mid-infrared erbium:YAG, diode, and thulium, and far-infrared CO_2. Far-infrared wavelengths are absorbed by water, which makes up 78% of the cornea.[9] The cornea contains nociceptors, so injury may be painful.[3] Often, only a very superficial injury occurs, affecting the corneal epithelium, which is repaired within days resulting in total recovery of vision. However, if the deeper corneal layers are injured, as is possible with mid-infrared lasers, corneal scarring can cause significant vision loss necessitating corneal transplantation.[1,3] Ultraviolet lasers such as the 308 nm Xe-Cl excimer used for psoriasis and vitiligo can cause photokeratitis or cataracts of the lens.[1,3]

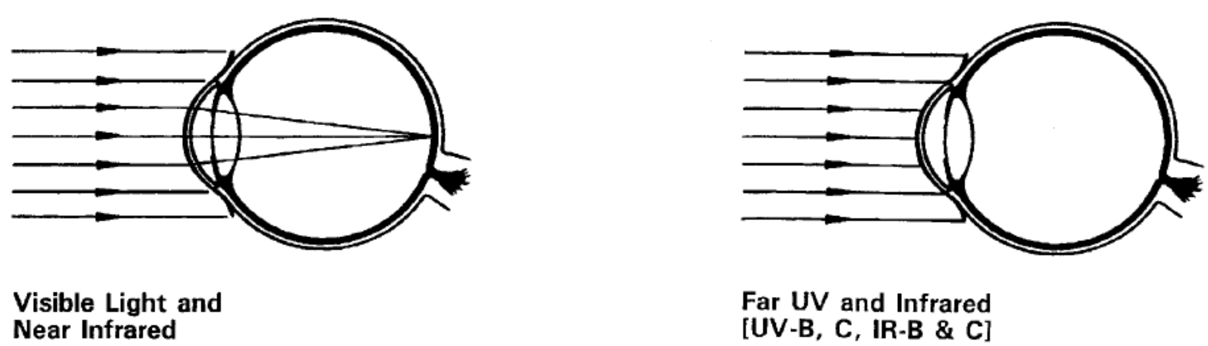

Fig. 1. The biological effects of optical radiation upon the eye depend upon the absorption properties, which vary with the spectral region.

Fig 1: Wavelength determines which part of the eye is affected by a laser. Adapted from Sliney, 1995.[1]

Visible light (400-760 nm) and near-infrared light (760-1,400 nm) are transmitted through the above structures and clear ocular media to the retina, where they are absorbed and may cause injury if sufficiently intense (Fig 1).[1,10] Lasers in the retinal hazard region include argon, "KTP" (potassium titanyl phosphate, second-harmonic Nd:YAG), pulsed dye laser, ruby, and alexandrite which are visible, as well as diode, Nd:YAG (neodymium-doped yttrium aluminum garnet) and Holmium, which are near-infrared.[3] These wavelengths are absorbed by melanin in the retinal pigment epithelium. The retina lacks nociceptors, so injury may be insidious. If an infrared laser is inadvertently firing and injuring the retina, the person may be unaware until visual change occurs. Damage to the peripheral retina may be insignificant, while damage to the fovea can result in substantial loss of visual acuity and color discrimination depending on the number of photoreceptors lost. Injury in the parafoveal region may result in inflammation and edema extending into the fovea resulting in temporary deterioration of visual acuity for days to weeks. Otherwise, the retina has poor regenerative ability, so visual loss is generally permanent. Even low power devices can injure the retina when they are focused by the ocular refractive media, resulting in a 100,000-fold increased concentration of light on the retina.[1,3,10]

The mechanism of injury is heat generated when these structures absorb light. Q-switched lasers and picosecond lasers can also cause damage through photoacoustic waves. These devices have pulse durations in the nano- and picosecond range which can generate tissue temperatures more than 10,000^{o} C, which result in the formation and rapid expansion of plasma. The expansion following the temperature change causes acoustic waves within the retina that can result in retinal perforation.[9]

The antiseptic chlorhexidine gluconate poses a non-beam ocular hazard. Chlorhexidine gluconate is toxic to the cornea and can cause keratitis severe enough to require corneal transplantation. Povidone-iodine is a safe alternative antiseptic for facial procedures. [11]

Ocular protection

These hazards are why it is essential for every person in the room to be wearing eye protection when operating a laser. ANSI and OSHA mandate protective eyewear in the treatment area for all class 3 and 4 lasers.[4] Laser safety goggles are rated using optical density (OD), the log of the attenuation of light transmitted through the filter lens. A higher OD provides better protection. Goggles with an OD of 6 will permit $1/10^6$ of the energy at a given wavelength to penetrate. Eyewear must be labeled with the wavelength range they cover, and the OD.[3] Eye protection must match the laser being used, and the use of several types of lasers with differing wavelengths at a facility can complicate safety. It may be helpful to place each laser in a separate room with appropriate eyewear outside the door.[2] Unfortunately, safety goggles can also make it difficult for the operator to see visible light clearly and recognize clinical endpoints.[10] Careful selection of eyewear without excessively high (and unnecessary) OD and choice of filter material can minimize these visual challenges.

There are a variety of different forms of eye protection available. Glass goggles are heavy, and their protective reflective coating can be scratched. In contrast, polymer goggles absorb light and are lightweight. Eye protection for the patient can be opaque and include metal or plastic eyecups, disposable adhesive shields, and corneal shields. Corneal shields can allow treatment of the eyelids. These can be applied after administering anesthetic drops to the eyes and a lubricant to the inside surface of the shield. They should be metal as plastic shields may melt and cause injury.[3,10,12] The patient may also wear the same eyewear as the operator, but bulky goggles may make treatment around the eyes challenging. Care must be taken if working in the periorbital region with near-infrared lasers, since these wavelengths can penetrate into the orbital region and produce injury to the iris and anterior segment of the eye. Goggles should prevent light from entering from the lateral aspects using side shields or a wrap-around design.[9] Sources of indirect exposure include reflection and scattering off glass, metal, and plastic surfaces such as windows, mirrors, jewelry, and instruments. These should be covered with opaque material. Instruments should be anodized, roughened, and ebonized with a black fluoropolymer coating. [5,9] Ordinary glass will protect against wavelengths shorter than 300 nm and longer than 2700 nm, but peripheral shields are essential.[1,3] Ablative and short pulse duration lasers cause tissue splatter, so face shields should be used in these cases.

If the surgeon views target tissue through an endoscope, microscope, laparoscope, or colposcope, the optics will safely attenuate laser reflection so long as the laser is not fired when the surgeon is not looking through the viewing optics.[1] Care should be taken that such auxillary optics have a laser safety filter built. Assistants and bystanders not using optics are also at risk from reflections.

Skin hazards

Skin is much less vulnerable to injury than the eye. Cutaneous injury from lasers can range from mild, transient erythema to severe burns and scarring, depending on laser parameters and patient factors such as skin phototype, photosensitivity disorders, and photosensitizing medications. UV lasers can cause sunburn-like reactions, while infrared lasers can cause thermal burns.[1,3] Laser injuries can be complicated by infection and may result in scarring or dyschromia. Antiviral prophylaxis is often given before and after laser treatments to prevent herpes simplex reactivation. Cutaneous injury is less likely to be of serious concern to the operator and staff except for their hands which can be located near the beam. Tightly woven fabrics have an optical density exceeding 4.[1]

Plume hazards

Toxic and carcinogenic risk

The plume generated by laser-tissue interaction (or electrosurgical procedures) poses a respiratory hazard and may contain viral, bacterial, toxic, and carcinogenic material. The mean particle size produced by ablative lasers is <1 µm.[13,14] Laser plume has been found to contain acetonitrile, acrolein, ammonia, benzene, ethylene, and toluene.[14,15] Benzene in plumes has been associated with hematological cancers. Toluene is a central nervous system depressant.[15] The smoke produced from 1g of tissue using a CO_2 laser is equivalent to three cigarettes.[16] Chuang et al. discovered a greater than 8-fold increase in the concentration of <1 µm particles over baseline during laser hair removal (15,300 particles per cubic centimeter (PPC) to 129,376 PPC). When the smoke evacuator was turned off for 30 seconds, this rose to a greater than 28-fold increase in particle concentration over baseline (15,300 PPC to 435,888 PPC).[17]

Infectious risk

Surgical plumes can harbor viable pathogens from the skin, mucous membranes, and body fluids, and the lower-temperature plumes of lasers are associated with higher infectivity than other surgical plumes.[15,18] CO_2 laser plumes have been found to contain coagulase-negative *Staphylococci*, *Corynebacterium*, and *Neisseria*.[19] Sawchuck et al. found human papillomavirus DNA in 62% of ablative laser plumes following genital and perianal wart treatment.[20] The incidence of nasopharyngeal warts is significantly greater among CO_2 laser surgeons than population-based controls, so it is plausible that vaporized HPV particles, which are only 55 nm in size, can infect laser operators.[21] It may be possible that inhaled HPV virions could cause oropharyngeal cancer. There is a case of laryngeal papillomatosis with HPV types 6 and 11 in a laser surgeon who treated patients with anogenital warts, which are known to be caused by HPV types 6 and 11.[22] Although there are no published cases of COVID-19 transmission from plumes, it would not be surprising given the small size of SARS-CoV-2 virus particles and their presence in skin, mucosa, and a variety of other tissue.[23] Human immunodeficiency virus DNA has been found in smoke evacuator tubing.[24]

Plume precautions

The American Society for Laser Medicine and Surgery has a laser and energy device plume position statement that recommends several safety precautions.[25] The ideal form of protection would use an external source of air, but these systems are impractical. A powered air-purifying respirator (PAPR) uses a blower to pull air through filters into a hood or helmet. However, these devices are also cumbersome. Filtering facepiece respirators (FFR) such as N95 or N100 masks will filter 95% to 99.97% of 0.3 µm particles depending on their rating.[26] Surgical masks cannot filter particles less than 5 microns effectively (99% efficacy for particles larger than 5 µm vs. 25% efficacy for 0.3 µm particles), which includes most toxic and viral particles.[2] They primarily function to protect the patient from the wearer. Masks should be kept dry because moisture will interfere with electrostatic-based filtration.[3] Staff should undergo annual fit testing and ensure the FFR fits without air leaks.

Plume hazards are best controlled with local exhaust ventilation (LEV) systems such as wall suction devices or portable smoke evacuators with appropriate filters (ultra-low penetration air filters, which are 99.999% efficient at filtering 0.12 µm or larger sized particles per ANSI Z136.3).[4,14] The evacuator is the preferred tool as wall suction systems are generally low-flow and used for liquids.[2] Filters should be replaced frequently.[25] Animal models provide evidence that pulmonary damage, including emphysematous change, caused by plume exposure can be mitigated through the use of smoke evacuators.[15] The suction nozzle should be as close as possible to the surgical site and no further than 5 cm (2 inches) away.[27] Smoke evacuator efficacy is decreased from 98.6% to 50% when the tip is moved from 1 cm away from the treatment site to 2 cm away.[14]

Unfortunately, plume safety precautions are often not observed. Neither OSHA nor The National Institute for Occupational Safety and Health (NIOSH) appear to enforce guidelines. A 2014 survey of 997 dermatologic surgeons found that 77% use no form of smoke management at all in their practice, and only 10% report using smoke management consistently.[28]

Fire and electrical hazards

Lasers can potentially ignite flammable materials and lead to serious injury. Culprit materials include hair, hair products, cosmetics, fabrics (especially rayon and nylon), towels, drapes, gauze, oxygen, tubing, alcohol, eyewear straps, and aluminum chloride hexahydrate. Several fatal patient injuries have occurred from the ignition of airway tubes, and this risk can be reduced by using metal tubes instead of plastic or rubber tubes.[1] Hairspray and cosmetics should be removed – in addition to being flammable, these can scatter light. Hair should be kept moist or covered with a wet towel to reduce the likelihood of burns. Gauze can likewise be moistened.[3,9] Alcohol should be avoided as an antiseptic, if possible, and it must be allowed to dry completely if used. Erbium:YAG and CO_2 lasers pose the greatest fire risk. Even a single pulse of a CO_2 laser can create overt flames on dry drapes and cotton balls.[29]

The potential for fire necessitates a fire-resistant drape, water reservoir, and fire extinguisher to be easily accessible.[1,3]

Lasers do not have unique electrical hazards different from other electrical devices. Electrical fires can occur inside the device from faulty wiring.[3] Facility engineers and technicians should be familiar with safe installation and operation.[1]

Auditory hazards

Lasers are unlikely to cause hearing loss. Lasers can be loud. However, Callaghan et al. tested a variety of devices and found all but a few were below the 85 decibels limit proposed by NIOSH. Even the loudest would have to be used for almost 2 hours to exceed the OSHA recommended exposure limit.[30]

Postexposure examination and reporting

Anyone suspected of receiving a laser injury should be examined within 48 hours. An ophthalmologist should perform an examination following ocular exposures, especially if they involve the retinal hazard region (400-1400 nm).[1,3] All exposures must be documented by the LSO, but only events causing severe injury or death must be reported to the FDA according to Medical Device Reporting regulations.[3]

Conclusion

Lasers have expanded the modern armamentarium and created new possibilities for previously untreatable conditions. These devices pose serious safety hazards and can cause severe injury and blindness. The increase in laser procedures has been accompanied by an increase in malpractice litigation alleging laser misuse.[31] Well-trained personnel and appropriate precautions are critical to maintaining the safety of patients, staff, and surgeons when using medical lasers. Offices should have a designated laser safety officer, and large institutions may benefit from a laser safety committee.[1] Appropriate safety equipment, including eye protection and LEV, should always be employed. Continuous education and vigilance are necessary for the continued safe use of lasers.

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