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Safe Use of Medical Lasers

Seung Hoon Woo
Phil-Sang Chung
Sang Joon Lee

Department of Otorhinolaryngology-Head and Neck Surgery, Dankook University College of Medicine, Cheonan, Korea

Medical lasers have been widely used for various diseases. Despite the notable benefits, lasers could cause several complications such as skin burn, eye injury, airway fire, and so on. These accidents may occur not only with patients, users of the laser, or laser handlers but also to people passing in front of the laser treatment room. Although there is a risk associated with the laser, most of them can be prevented through good training, use of proper protection equipment, and ensuring the safe operation of the laser at all times. Due to the increasing use of lasers and the growing interest in their use, medical institutions should particularly emphasize the safe use of lasers and introduce systems for laser safety.

Key words
Medical; Laser; Safety

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Correspondence
Sang Joon Lee
Department of Otorhinolaryngology-Head and Neck Surgery, Dankook University College of Medicine, 119 Dandae-ro, Dongnam-gu, Cheonan 31116, Korea
Tel.: +82-41-550-3975
Fax: +82-41-556-1090
E-mail: lsj72@dankook.ac.kr

INTRODUCTION

The use of diagnostic and surgical lasers has a history of safety and successful results. For instance, among others, a previous report indicated that 404 cases of laryngeal microsurgery were performed successfully and safely using laser technology at a university hospital.[1] However, laser devices pose a significant hazard with a greater risk in the surgical field where doctors, nurses and other medical staff, and patients are at risk. Laser-related dangers range from minor injuries to serious irreversible damages and fatal incidences.

Contrary to the general assumption, laser hazards are not limited to beam and are generally divided into beam hazards and non-beam hazards. Beam hazards stem from the beam, and cause ocular and cutaneous related injuries, for example: (1) Direct or reflected rays can give images to the skin, hair, or cornea and retina, causing permanent damage. (2) Laser beam can cause a fire in the surgical drape, endotracheal tube and patient's hair if handled improperly. (3) Non-beam hazards stem from the laser devices or their interaction with materials within the surgical environment. They include fire, plume, and electrical hazards, for example, laser- tissue interaction produces smoke that has an irritating odor, and particulate matter that irritates the eyes, nose and lungs, and induces vomiting. Use of lacer has also been suspected to transmit infections including viral and bacterial infections; during laser-tissue interaction, blood, interstitial, and intracellular fluids can be aerosolized, and together with a possible load of viral and bacterial pathogens they are forcefully ejected in the operating room. Such risks are not limited to patients, laser users, and laser handlers, but also near passers-by or those who are in the waiting room.

Since the use of laser technology has gone beyond the hospital setup, there is an increasing risk of laser-related accidents; in South Korea, it is estimated that there are many non-hospital cases of laser-related accidents, even if there are no officially reported cases. This could be attributed to the operation of laser devices by untrained non-medical users in beauty salons and other non-hospital set ups. Laser-related accidents can be prevented through a safe laser environment, protective equipment and safe laser operation. However, reports indicate that laser users do not always follow the precautionary measures; 67% of accidents that occur while using a medical laser have been reported to results from improper handling of the laser devices.[2] This highlights the need for the development and implementation of safety measures, especially with the increased use of laser technology.

HAZARDS WHEN USING LASERS

Risk to the eyes

The American National Standards Institute (ANSI) has classified lasers into four categories, according to their potential to damage the eyes.

Class I: A laser that does not exceed the maximum permissible exposure (MPE) of the eye even when exposed to direct sunlight for a long time. As a self-contained unit used in general laboratories, it does no harm under normal limits.

Class II: IIa: It is safe to be exposed as a visible light laser within 1000 seconds.

IIb: As a visible light laser, blinking eyes are safe to be exposed within 0.25 seconds. It is not capable of emitting and output of 1 mW or more. They include He-Ne alignment light (CO2 or Nd: used for YAG lasers), and laser pointer light. There is no harm if they have not seen the light directly for a long time.

Class III: Class IIIa is a laser that cannot have an output of 1mW or more like Class II, and is used in aim beams such as architectural badges. It does not cause harm when the eyes are exposed within 0.5 seconds.

Class IIIb can output up to 0.5W CW, and when exposed directly to the intra-beam, it can harm the eyes and skin, and belongs to the infrared solid-state laser that eliminates wrinkles for molding. These types of lasers must be tested before use and can be harmful, so they must be operated with care and protective devices are required when operating them.

Class IV: As a laser with an output of 0.5 W or more, even if it is exposed momentarily, it damages both the eyes and the skin. Like a CO2 laser, it can cause damage such as fire, images and eye damage, either directly as a potentially dangerous laser or by reflected light rays.[3]

The FDA and Rockwell reported that 75% of 134 laser accidents in 1984-1989, and 73% of 272 laser accidents in1964-1994, respectively, were eye injuries.[4] Eye damage is completely preventable.

The eye is very sensitive to the laser beam and the type and extent of damage caused by laser irradiation depend on the wavelength of the light and the energy absorption characteristics of the ocular tissues. Far infrared lasers, such as CO2 lasers, are absorbed by the cornea, lens, and vitreous body. While they do not cause damage to the retina, they cause damage to the cornea (If the corneal damage is not deep, it can be recovered within a few days).

Visible light lasers, such as the Argon, KTP/532, and krypton lasers, are focused on the retina by the cornea and lens. They damage the retina, causing blind spots in the field of view and damages to the fovea. On the optic nerve, it causes far more serious visual impairment. The injury may occur immediately after beam irradiation, or it may be a chronic degenerative injury resulting from repeated exposure to a low power laser beam. Near infrared lasers with wavelengths between 800 and 2000 nm, such as Diode Laser, Nd: YAG, and Ho: YAG, are focused to the retina by the cornea and lens, and cause damages to the three tissues. The maximum permissible corneal exposure (MPE) of the eye is determined by the wavelength and duration of exposure, and protective goggles should be used when there is a risk of exceeding the MPE (Fig. 1). The eyes are vulnerable to visible light due to specific physiological factors. Parallel laser beams are focused in a similar manner as the light rays, the direct entry of these rays is called intra-beam exposure. While surgical laser beams are usually not parallel, unfortunately, since the eye can accept a wide range of rays, they can be focused on the retina like 10 μm sized spot.[5] However, even though the light beam reflected by the non-smooth surface of the laser beam also enters the eye, this light beam enters the eye at a wide angle, and therefore the image generated on the retina also occupies a wide area. This is called an extended source. It is easy to see that the risk of the retina is lower for extended sources when the exposure time is shorter than for intra-beam exposure.

Previous reports on eye damage indicated that only those with inefficient protective goggles were injured.[6] Therefore, each time a Class IIIb and IV laser is used, to reduce the risk of eye damage, you must use matching protective glasses and goggles (with goggle side shields). Extra precautions should also be taken when using an endoscope that does not have an automatic filter. Even with these protective goggles, they do not protect you from being exposed directly to the laser beam for extended periods of time. The patient's eyes should also be protected with a saline-moistened sponge or metal eye cover or appropriate eyeglasses.

Appropriate filters must be used with laser microscopes and endoscopes. In addition, the doctors, and all personnel in the surrounding operating room must wear appropriate protective goggles. The automatic filter attached to the microscope or endoscope can cause malfunctions, therefore, the filter shutter should be inspected on a regular basis.

ANSI recommends pre-employment eye examination for operating room personnel.[7]

Long time exposure

When exposed to a laser for an extended period (10 seconds or longer), there is a significant risk of photochemical effect, rather than the effect of high temperatures, at visible light wavelengths, especially in the blue region of the spectrum. However, this can be prevented with protective goggles.

Protective goggles

Practical use of all surgical lasers will always exceed MPE if exposed to intra-beam during.[8] Therefore, protective eyewear including goggles (with a side shield) suitable for the laser in use must be worn. Protective eyeglasses are comfortable to wear; however, eyeglasses alone do not provide sufficient protection. Optical density appropriate for the specific length must be displayed on the protective goggles. It should be known that any filter can penetrate the filter if it is exposed to the intra-beam for a long time.

Generally, the optical density of protective goggles appropriate for an argon laser is 10, and that of a CO2 laser is usually about 15, which is far beyond the level of safety. Notably, in some cases red therapeutic or guide beam do not show when performing laser surgery with protective goggles.

Effects on skin

Since it is largely exposed, the skin is more prone to

Fig. 1. Protective goggles (A) and patient's eye protection (B).

laser damage, but the resultant damage is less serious than that of the eyes. The skin damage, which is clearly visible as redness or black carbonization on the tissues varies depending on the laser wavelength, the exposure time, the beam density and the skin color. While laser damage on the skin can result from either the photochemical effect or thermal effect, the primary cause of laser damage on the skin is high temperatures. The high temperature alters the protein to necrotize the tissue, boils the cellular components, evaporates the tissue, and the dried tissue forms carbonization. Therefore, normal tissues other than operation site should always be overwritten with a drape or sponge soaked in water. Dried drapes and sponges are prone to ignition and need to be re-wet with distilled water or saline on a regular basis during surgery.

Gas embolism

Gas embolism was reported to have occurred during intrauterine surgery using tip of Nd:YAG fiber. Gas-cooled fibers should be restricted for use on the body surface only, as gas embolism has been reported during liver surgery.

Laser plume

The smoke generated by the laser is composed of small particles of approximately 0.1 micrometer. The smoke has a strong odor, and reaches the bronchioles and alveoli, causing damage similar to that of asbestos and tobacco.[9,10] Exposure to smoke can irritate the eyes, nose and throat, causing discomfort and chronic coughing.[11] Garden detected HPV DNA in laser smoke, therefore it important to have a thorough suction. Proper position of the smoke evacuator is essential for effective smoke suction and should be placed within 2-5 cm of the laser surgery site if possible. Inserting a 0.3 μm filter between the wall suction and the suction bottle is necessary in some situations where the smoke inhaler is not used.

A laser mask (0.3 μm filtration) must always be worn when using CO2 lasers. In the room using Q-switched lasers, normal masks are sufficient. All tubes, connectors and adapters must be changed after the surgery.

Reflected or incorrectly emitted laser

Accidentally laser beam can be reflected off surgical instruments and surrounding materials, and while such mistakes are rare, they are serious mistakes that should be avoided at all cost. To avoid the risks, all instruments using the laser and the reflective surfaces of surrounding materials must be thoroughly investigated. All reflectors (such as endoscopes) must be replaced with non-reflective ones, deformed, or covered in black.

A laser that penetrates the target tissue or spreads too far to the side will destroy the non-target tissue. For example, Nd:YAG penetrates 5-7 mm and therefore not suitable for the treatment of thinner tissues instead, holmium, CO2 lasers and Nd:YAG contact mode have can be used since they have weaker penetration than Nd:YAG. In addition, auxiliary equipment such as a platform that prevents and absorbs the over-penetrated laser behind the target tissue can be used to prevent over-penetration (especially when using an endoscope).

Fire and electrical hazards

A fire caused by a shot wrongly laser or an electric shock caused by high-voltage electricity is unpredictable and horrific accidents during laser treatment. According to experts, 100 fires occur in the operating rooms in the United States, each year. Among them, 10-20 cause severe injury to patients with 1-2 deaths.[12] The drape that covers the patient in the operating room is easily ignited by the laser since the oxygen levels are high. To prevent this, drapes with weak ignition qualities should be used. In addition, the cover of the laser site should always be kept wet.[13] The endotracheal tube fire will be described separately.

Many lasers are high voltage electric devices that can easily shock handlers, especially when the protection plates are removed. There is also a risk of unnecessary disruption in case the devices come into contact with water that can short-circuit the system wiring. For these reasons, it is important that users receive appropriate training from the manufacturer. Types of laser hazards is summarized in Table 1.

MANAGEMENT OF ANESTHESIA IN LASER SURGERY

The two most popular lasers, CO2, and Nd:YAG lasers,

Table 1. Types of laser hazards

Types	Hazards
Laser irradiation	Eye, skin, or airway injury Primary or scattered beam
Chemical hazards	Laser plume Irritation to eyes, nose and throat Spread of viral materials
Fire and electrical hazards	High voltage, flammable materials Anesthesia tube, patient's hair or clothes

use different wavelengths, and are used for different body parts. CO2 lasers can be used for upper respiratory tract surgeries through direct firing directly or using a rigid bronchoscope. Nd:YAG and KTP lasers are suitable for peripheral airways surgery using flexural endoscopy because their beams are effectively transmitted by fiber-optics.[14] In addition to pre-operative evaluation, before surgery, it is important for the otolaryngologist and the anesthesiologist to have a discussion on each team plans, and come to a common ground.

Upper respiratory tract surgery

There are several surgical techniques that can be considered for laser ablation of pharyngeal and laryngeal lesions. Insufflation techniques can be used if intubation is not necessary; this method has the advantage of a wide surgical site. However, the anesthesiologist is not able to regulate the patient's breathing, thus there is a great risk of aspiration pneumonia. In addition, the anesthesia gas fills the operating room because the depth of anesthesia cannot be adjusted. Due to these drawbacks, this method is not widely used.[15,16]

Jet ventilation can be installed using a laryngoscope, however, if the laryngoscope is not positioned accurately, oxygen will not enter the bronchi and the esophagus and stomach can be dilated. This can lead to pneumothorax, pneumomediastinum, and barotrauma, thus it is rarely used as a primary anesthesia method.[15]

Endotracheal intubation is commonly used method; the endotracheal tube narrows the practitioner's field of view and must work with the anesthesiologist through a smaller endotracheal tube. A tube with an inner diameter of 5-6 mm is moderately adjusted and is suitable for surgeries around the tube. The use of endotracheal tubes increases the risk of laser intratracheal fire. This risk can be reduced by using an intra-metal tissue tube. However, solid tubes have a risk of causing trauma on the tracheal mucosa and rupture of the bronchi because the laser beam can be reflected by the tube and the metal tube does not seal the bronchi.[17] The use of cuffs creates a risk of fire, so metal tubing that requires cuffs are not commonly used.[18]

Soft endotracheal tubes include red rubber, silicone rubber and polyvinyl chloride (PVC), all of which are flammable substances. According to a comparative study of the flammability of these tubes, PVC melts and ignites at a relatively low temperature compared to the other two substances.[19] The black letters on the tube and the radio-opaque lines absorb the heat of the laser and can be the point of ignition.[20] The cuff of the endotracheal tube is the thinnest wall and is vulnerable to ignition. To reduce the risk of ignition, cuff is filled with saline or the endotracheal tube is wrapped with a metal bandage. However, there is still the disadvantage of applying excessive pressure on the bronchi.[20]

To address these challenges, xomed tube (silicone endotracheal tube with non-reflective metal coating), Bivona tube (silicone metal tube), and Mallinkrodt (metal tube in PVC tube) were recently introduced. When the PVC tube burn, the gas pressure spreads the flame, but the metal tube prevents this phenomenon. When it has completely passed through the wall of the laser tube, the gas leaks out and begin to ignite, and the pressure of the gas creates a blow torch. Therefore, the oxygen tension is important and must be 40% or less.[18] Based on the results of tube stability experiments for several types of tubes in South Korea, there is no a type of tube that is absolutely safe during laser surgery, but Xomed Laser Shield IITM and Rusch red rubber tube wrapped with and aluminum foil has reported being relatively safe.[21]

In a German survey, 59-86 hospitals used special laser endotracheal tubes. Fifteen endotracheal tube fires were reported in 20,000 laser surgeries performed in the hospital. Six of the 15 fires occurred despite the use of a special laser tube.[22]

Lower respiratory tract surgery

CO2 lasers via a rigid bronchoscope can be used to remove lesions in the lower respiratory tracts, where the anesthetic gas is supplied via the side port of the endoscope. In this case, there is no risk of endotracheal tube ignition. Efficient ventilation in a sealed state can be achieved by covering the bronchoscope with wet gauze. In addition, the use of a bronchoscope makes it possible to operate deeper into the periphery. However, Nd:YAG and KTP lasers are operated through a flexible bronchoscope, which uses an endotracheal tube, such that the tip of the bronchoscope at the bottom of the tube, so there is a high risk of ignition.

Jet ventilation and high frequency ventilation

Jet ventilation can be done using various tubes and ventilation catheters where catheters can be inserted via the vocal cords, bronchi, and tracheostoma. Jet ventilation can achieve a normal respiratory rate of up to 60-120 beats per minute. High frequency jet ventilation (HFJV) can be done using a laryngoscope, a rigid or flexible bronchoscope. While it is helpful in several cases, it is limited by smoke and debris blown out during the procedure. Patient safety depends on the ability to measure pressure in the airways and the ability to immediately stop HFJV. Hyperinflation of lung can be avoided by proper monitoring.

Tracheal fire management

Once a fire breaks out, the following actions should be taken quickly to reduce morbidity and mortality:

1. Immediately remove the endotracheal tube.
2. Be careful not to spread the fire to the drape
3. Mask ventilate until the endotracheal intubation can be reconstructed.

Apart from high temperatures, lung damage also results from smoke, toxic scents, and tissue fragments from the fire. Damage to the larynx and bronchi should be assessed with a bronchoscope. Carbonized tissue fragments must be removed. Lavage can push tissue pieces deep into the bronchi and should be avoided. Mechanical ventilation, bronchodilators, and antibiotics should be given for several days. When the endotracheal tube (especially PVC) ignites, it emits toxic smoke causing lung alveoli damage and adult respiratory distress syndrome.

SAFE LASER USE BY MEDICAL INSTITUTIONS AND MEDICAL PERSONNEL

Since 1990, there has been growing popularity in the use of laser technology in the South Korea medical institutions. However, as mentioned above, there are many risks limiting its use. Therefore, medical institutions must ensure the implementation of administrative, medical, and mechanical protective measures. Unfortunately, unlike in the developed countries, these measures have not yet been implemented in Korean medical institutions. The American National Standards Institute (ANSI) in the United States has guidelines for the safe use of lasers in all medical institutions, and many institutions have shown adherence to these guidelines.[23] The Joint commission on the Accreditation of Healthcare Organizations (JCAHO), a US hospital review agency, also uses ANSI guidelines for hospital review.

Laser committee installation and role

The primary purpose of the Laser Committee is to provide medical and technical support for the use of lasers in hospitals. The Committee's obligations are to adopt and amend policies and procedures regarding the use of lasers, to formulate guidelines and protocols for laser safety, to determine the appropriate equipment and personnel, and vet doctors who qualify for laser technology. In addition, the committee is mandated to establish training guidelines for laser practitioners, anesthesiologists and nurses, and set standard qualifications to be used in screening during the personnel hiring process. The Committee can also regularly review the quality of care for laser patients and provide the necessary advice.

Laser safety officers (LSO), rather than a doctor, should be appointed and report to the Laser Committee. Laser physicist, medical engineer, nurse, or another medical profession can be LSO. The individual should have considerable knowledge of laser technology, and should take final responsibility for all laser safety issues in the hospital. The LSO must make a daily follow-up to make sure that the safety guidelines are followed.

Laser training and the composition of personnel

Hospitals are responsible for the quality of their laser procedures and therefore they should have their own protocols for verifying their doctors and other concerned medical personnel. Doctors will be updated with information laser education and practical training. Exemption should apply with doctors have sufficient knowledge on the diseases and lesions being treated, and the basic properties of a laser and laser safety. The requirements for surgical use of lasers are: 16-20 hours or more formal education, surgical 8-10 hours or more Hands-on practice using laser equipment, Patient Hands-on practice, and continuous medical education on laser technology. In addition, the use of lasers may only be permitted if the maintenance protocols of laser devices can be demonstrated.[24,25]

Anesthesiologists and anesthesia nurses need sufficient knowledge and experience because the overall responsibilities of laser device operation and safety during operation should be given to trained personnel only.

Start-up operation and orientation of laser equipment

After purchasing a new laser, an orientation must be done in which all physicians and laser users can participate. Regardless of how often and individuals use the laser device, all users must familiarize themselves laser equipment. Continuous education on the safe use of lasers should be given every year, and when a new user is hired. When a hospital purchases a new laser machine or a laser machine with a new wavelength, it must undergo laser surgery orientation with the participation of all the users, including practitioners, anesthesiologists, anesthesiologists, and operation room nurses. At this time, the orientation treatment must be performed like an actual procedure with all the equipment such as surgical microscopes, video equipment and protective devices. Through the orientation, important information and all problems of the device are uncovered.

Use in restricted zones

Lasers should only be used in controlled locations. Only essential personnel should be allowed in these locations, and all protective goggles must be worn. The windows in the area where the laser is used must be blocked by a substance with a material that can block the laser from being emitted outside the laser chamber. However, when a CO2 laser is used, no blocks are needed.

While using the laser, you have to use specific signs and pay attention to everyone around you. All entrances must be marked to alert incoming people of ongoing laser procedure. There must be protective goggles that match the wavelengths at the entrances to be used by the incoming people.[26] A sign may be placed around the door to indicate that the laser is in use. Also, if the practitioner is not using the laser, it is safe to change to "Stand-By" mode in "Ready" mode. The following checklist is recommended while preparing for laser surgery.

Inspection and maintenance

Pre-use inspections must be done by laser safety personnel. They include inspection of laser fiber calibration and fiber, handpiece, and waveguide defects, aiming beam and therapeutic beam matching, and laser working environment. More detailed inspections must be done on a regular basis, at which time the inspection personnel must have personnel specially trained by the manufacturer.

The American Organization of Registered Nurse (AORN) has adopted the following guidelines for safe use of laser equipment during surgery, using lasers.[27]

1) All healthcare professionals must be warned of areas where the laser is in use with appropriate labeling.

2) Adequate eye protection must be provided to the patients and healthcare professionals.

3) Adequate skin protection from accidentally emitted or incorrectly reflected laser beams must be provided to the patients and healthcare professionals must be protected.

4) Patients and healthcare professionals must be protected from breathing smoke emitted from lasers.

5) Patients and healthcare professionals must be protected against laser-related fire hazards.

6) Patients and healthcare professionals must be protected from laser-related electrical hazards.

7) For safe use of lasers, safety policies and procedures should be adopted.

In 2004, AORN installed a laser safety program in private clinics and general hospitals, which everyone who uses lasers must familiarize with and practice. Among others, he recommended that the areas where laser is in use needed extra precautionary measures, protection from flammable and explosive hazards associated with the laser.[28]

CONCLUSIONS

Medical lasers are very useful in diagnosing and treating illnesses. However, they can cause serious damages to both the patients undergoing laser treatment and the medical personnel involved. To prevent such risks, healthcare professionals need enough training on the use of lasers. Medical institutions have established appropriate guidelines and precautions for safe use of lasers, which should be implemented and practiced to prevent laser accidents.

CONFLICT OF INTEREST

Seung Hoon Woo is the Editor-in-Chief of the journal but was not involved in the review process of this manuscript. Phil-Sang Chung is an editorial board member of the journal but was not involved in the review process of this manuscript. Otherwise, there is no conflict of interest to declare.

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