Anesthetic Challenges During Laser Surgery of the Larynx Part 1. Biological Effect And Specific Laser Hazards

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Abstract

Theoretical basis: Laser is an acronym for *light amplification by stimulated emission of radiation*-a highly collimated beam of photons at a single frequency. Lasers are ubiquitous in the modern world and are increasingly used in the operating room. The **Aim** of the study is to determine different anesthetic techniques and complications during laser surgery of the larynx. **Results:** Light has a biologic effect solely from absorption in tissue (Grotthus-Draper law), specifically by raising electrons to higher energy states that, in turn, can raise kinetic energy (heat) or cause chemical reactions. Boulnois categorized the biologic effects into four types: electromechanical effects, thermal effects, photoablative effects and photochemical effects. The same properties that give lasers their clinical value also pose threats to patient and provider safety. These risks fall into three categories: atmospheric contamination, gas embolism, and inappropriate energy transfer. Laser light, because of its special qualities of beam collimation, coherence, and high-energy density, poses optical safety hazards not associated with light from conventional sources. **Conclusion:** Lasers are increasingly used in the operating room. Understanding the technology is important to safe anesthetic practice.

Key words: Laser, biologic effect, risks.

Literature review

Laser is an acronym for *light amplification by stimulated emission of radiation*-a highly collimated beam of photons at a single frequency. Lasers are ubiquitous in the modern world and are increasingly used in the operating room (OR). Understanding the technology is important to safe anesthetic practice. Some of the same properties that make laser energy useful also make it a safety threat to both the patient and the staff.

The original observation that electromagnetic radiation occurred only in discrete amounts, called *quanta*, was made by Max Planck¹ for which the Nobel Prize was awarded in 1918. The energy of these quanta is proportional to the frequency of radiation. Einstein's work on the photoelectric effect² (Nobel Prize, 1921) found that light was quantized (photons) and that transitions in electron energy states orbiting in an atom emit photons of characteristic frequencies. Certainly, the reverse is true-photons can raise electrons to higher energy states and can cause a current to flow.

Light has a biologic effect solely from absorption in tissue (Grotthus-Draper law), specifically by raising electrons to higher energy states that, in turn, can raise kinetic energy (heat) or cause chemical reactions. Lasers have been applied to medicine since 1962.³ The current uses are widespread and evolving. Boulnois categorized the biologic effects into four types.⁴ Electromechanical

effects- a pulsed laser causes a shock wave and thus an actual mechanical impulse. Thermal effects- similar to other surgical techniques (electrocautery from radiofrequency currents, harmonic scalpel), localized heat can cauterize and separate tissue, allowing bloodless incisions. Laser thermal effects differ little from other surgical sources⁵ except that they can be more finely focused with high-energy density and delivered via fiberoptic strands. Bolliger found that airway lesions were well managed by laser, electrocautery, or argon plasma coagulation.⁶ In some cases, laser coagulation may offer an advantage when laser frequencies that are absorbed by specific tissues such as the retina or hemangiomas are chosen. One treatment for port-wine stains involves pulse-dye tuned to hemoglobin, with surface dermal cooling to protect the surrounding tissue.⁷ Photoablative effects - these effects come from the molecular disruption and ablation of tissue, with the resultant gases removing heat and protecting the surrounding tissue from thermal injury. Photoablative effects can be either at the microscopic level or at a macroscopic level.⁸ Photochemical effects- photochemical effects are the newest area of interest and the least well proven mechanistically. Low-level laser therapy (LLLT) has been used in a wide variety of surgical and non-surgical conditions. Various theories suggest that specific wavelengths can modify enzyme systems,⁹ change electron transport and tissue oxidation states,¹⁰ or be mediated via nitric oxide.¹¹

The use of lasers in laryngology involves endoscopic resection of laryngeal cancers, either office based for smaller lesions¹² or with rigid suspension microlaryngoscopy.^{13,14} Precise coagulation of vascular lesions without damage of the phonatory surface is another common application. Additionally, lasers are used in resecting papillomatosis.¹⁵

The same properties that give lasers their clinical value also pose threats to patient and provider safety. These risks fall into three categories: (1) atmospheric contamination, (2) gas embolism, and (3) inappropriate energy transfer. Tissue destruction during surgical laser procedures produces a complex particulate aerosol and smoke plume. Research confirms that this plume can contain compounds and toxic gases such as polyaromatic hydrocarbons, hydrogen cyanide, formaldehyde, benzene, and cellular material (dead and alive).^{16,17} Fine particulates (mean size 0.31 μm ; range 0.1 to 0.8 μm) and combustion by-products are easily

dispersed throughout the respiratory tract. Animal studies link inhalation of the laser plume with pulmonary damage, which can lead to reduced mucociliary function, airway inflammation, interstitial pneumonia, bronchiolitis, and emphysema.^{18,19,20} The laser plume has in vitro mutagenic and teratogenic potentials. The mutagenic potential of the plume from a CO₂ laser on 1 g of tissue is equivalent to inhaling the smoke from three unfiltered cigarettes. This toxic potential is one half of that produced by electrosurgical units but is considerably more than that produced by Nd:YAG contact probes.²¹ Although controversial, the laser plume has the potential to transmit viable microorganisms into the atmosphere.^{22,23,24} However, reviews have not found strong evidence of danger.²⁵ Viral DNA has been detected in plume from human papilloma virus (HPV)²⁶ in condylomas and skin warts,²⁷ but evidence for transmission to humans is weak. On its web site, OSHA notes that „no documented transmission of infectious disease through surgical smoke” has been published (see OSHA web site statement regarding Laser/Electrosurgery Plume: <https://www.osha.gov/SLTC/laserelectrosurgery-plume/>). A recent review of the literature assessing the infectivity of HPV in the plume is contradictory and scanty.²⁸ Inoculation of bovine papillomavirus (BPV) DNA from a surgical plume produced bovine fibropapillomas in three calves.²⁹ Other studies showed plume particle viability but no infectivity in susceptible cell lines.³⁰ Investigation into a laser surgeon's development of laryngeal papillomatosis, after laser treatment of a patient, revealed that the lesions in both the patient and the surgeon shared the same, albeit common, HPV serotypes.³¹ A recent case report detailed two cases of HPV-induced airway cancers in surgeons using extensive lasering.³² The incidence of HPV infection in laser surgeons specializing in the treatment of papillomas and condylomas is comparable to the incidence in the general public.³³ Human immunodeficiency virus (HIV) was not detected in electrosurgical smoke plume³⁴ in one study, and only noninfectious DNA fragments were found in a CO₂ laser plume from HIV-infected tissue pellets.³⁵ Smoke evacuators are 99% effective at eliminating the plume when situated within 1 centimeter of the target site.³⁶ Accordingly, their use in the OR is strongly advised and supported by OSHA. The Centers for Disease Control and Prevention (CDC) states that surgical suction systems are not

interchangeable with the preferred smoke evacuator suction unit.³⁷ In addition, using high-filtration masks that filter plume particulates down to 0.3 to 0.1 μm when dry is essential. Of note, viral particles are too small to be filtered reliably, and standard surgical masks filter particles as small as 3 μm .

The Nd:YAG laser system has been associated with venous gas embolism. Specifically, the gas coolant for the laser tip has been the responsible system element.

Currently, medical lasers can all transmit an unattenuated and potentially destructive beam through air. If the intended target is not accurately being sighted, then laser activation can result in injury to patients and OR personnel or damage to property. Laser ignition of any combustible fuel (e.g., surgical drapes, plastic endotracheal tubes [ETTs], ointment on the skin) may also occur either by unintentional direct beam strike or by reflectance and scatter of the beam off of specular surfaces.

Off-target laser energy may perforate a viscus^{38,39} or a blood vessel (if the vessel is too large to be cauterized: diameter >5 mm). Pneumothorax has been reported after a laser laryngeal procedure.⁴⁰ Of note, with an Nd:YAG system, the depth of tissue injury may not be immediately apparent. Complications such as viscus, tissue plane, or vascular perforation (with resultant complications) may not occur until edema and necrosis have become maximal several days postoperatively.

Laser light, because of its special qualities of beam collimation, coherence, and high-energy density, poses optical safety hazards not associated with light from conventional sources. The extent of

damage is determined by the laser irradiance, exposure duration, and beam size. The site of laser-induced ocular damage depends on the output wavelength. Visible and near-infrared light (400 to 1400 nm) can damage the retina. Argon, potassium titanyl phosphate (KTP):Nd:YAG, or ruby lasers are likely to focus on that structure with resultant rapid permanent damage to the retina.⁴¹ Ultraviolet and far-infrared light is absorbed by the anterior structures. Infrared energy from a CO₂ laser causes corneal and lens injury.⁴² With sufficiently powered lasers, permanent ocular damage can occur within a fraction of a second. The blink reflex is too slow to guard against laser injury. Proper protective eyewear with side shields and appropriate filtering capabilities and optical density (specific for the type of laser to be used) are safety essentials for all present in the OR. The nonoperated eyes of patients should be taped closed and covered with saline-soaked opaque material or a metal shield.⁴³ CO₂ lasers emit far-infrared frequencies that are unable to pass through any clear glass or plastic lenses. Regular eyeglasses, fitted with side shields, may be sufficient protection, but contact lenses are not. All other lasers emit energy that requires specific colored lenses. Nd:YAG lasers require green-tinted goggles (which can make skin color assessment and monitor reading difficult), or clear lenses (Nd:YAG Protection Glass; Surgical Laser Technologies, Malvern, PA), which have a special coating opaque to near infrared. Argon or krypton lasers require amber-orange lenses, and KTP:Nd:YAG lasers require a red filter. The wrong eyewear will not protect.

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