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Lasers in laryngeal surgery☆

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The use of lasers in laryngology has evolved over the last several decades. With improving optics, instrumentation, and applications for treatment, lasers are now routinely used during laryngeal surgery performed in both the operating room and clinic settings. A variety of laser types, including carbon dioxide (CO_2), potassium-titanyl-phosphate (KTP), and pulsed-dye lasers, are used to treat an array of benign laryngeal lesions. Otolaryngologists can now consider the use of lasers to treat benign vocal fold lesions including vocal fold polyps, varices/ectasias, scar, granulomas, recurrent respiratory papillomatosis, Reinke's edema, and nodules, among others. Knowledge of available lasers and common uses aids in providing the most appropriate treatment for a variety of benign laryngeal lesions.

Introduction

The use of lasers has been an evolving practice over the last several decades. Since 1960, when the ruby laser was first used in medical practice, lasers have been increasingly used for treatment of a variety of medical issues.[1,2] The carbon dioxide (CO_2) laser has been the most used in the medical community since its development in the late 1960s. With its absorption in water, CO_2 lasers became quickly favored for use on human tissues. The first endoscopic use of CO_2 laser was in 1968 in an in vivo canine larynges study.[3] Originally, the use of lasers was anticipated to be primarily for excision of laryngeal cancers but has since gained recognition for its versatility in treating a variety of benign laryngeal lesions.[4]

Laser use for endoscopic laryngeal surgery has evolved through a number of innovations, starting with the invention of the micromanipulator.[5] With improved instrumentation, optics, and delivery modalities, lasers have become a treatment modality widely used in otolaryngologic practice. For treatment of laryngeal pathology, laser use has been expanded to use in the clinic setting in addition to the operating room. In-office procedures are still limited by the lack of magnified binocular vision and microinstrumentation that are available in the operating room; however, this continues to improve with advancing technologies.[6] Today, otolaryngologists can treat an array of lesions with in-office laser without the need for general anesthesia. The use of laser, both in the operating room and in-office, has been applied to ablative and nonablative procedures and has augmented the surgical modalities for benign laryngeal lesion beyond traditional cold surgical techniques. An understanding of laser mechanics and utility for treating benign laryngeal lesions is critical to the evolving practice of otolaryngology and head and neck surgery.

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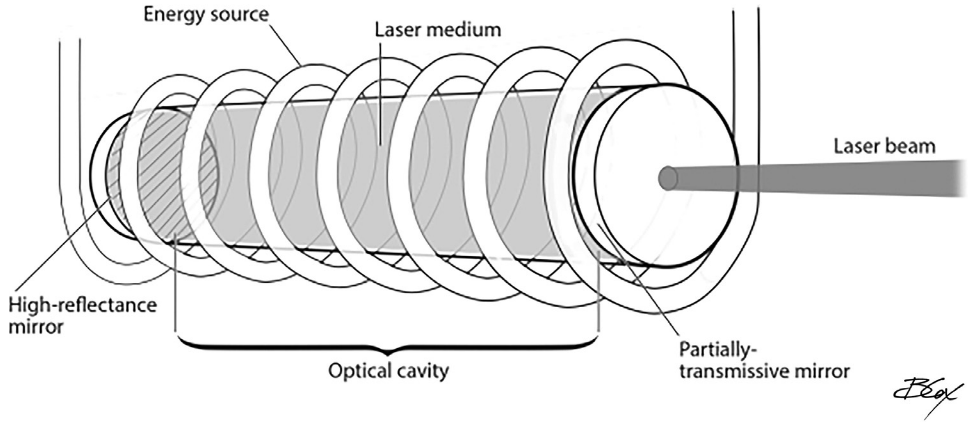

Figure 1 Optical resonating chamber of a laser. Using electrical current, gas molecules are excited and cooled by water flowing around the chamber. Mirrors are used to amplify the feedback generated from the excited gas molecules.

Laser mechanics

Laser, an acronym for *light amplification by stimulated emission of radiation*, is a device that emits organized light via optical feedback and amplification.[2] Lasers contain an optical resonating cavity with 2 mirrors. Between the mirrors is an active medium for which the laser type is named; this can include CO_2, potassium-titanyl-phosphate (KTP), or neodymium:yttrium-aluminum-garnet (Nd:YAG), among others. This laser medium can be a solid, liquid, or gas and will specify the wavelength of a given laser. An energy source, such as electricity, is then applied to the active medium in the optical resonating cavity, resulting in atoms reaching an excited state. Light emitted from this stimulation is reflected between the mirrors within the cavity. One mirror is partially transmissive and allows the laser energy to exit the optical cavity, resulting in a laser beam[7] (Figure 1).

The surgeon can modify several parameters that will alter laser delivery to the target tissue. Power, measured in watts; spot size, measured in millimeters or square centimeters; and exposure time, measured in seconds, can all be determined by the physician.[2] By altering these variables, the surgeon can determine the interaction of the laser with the tissue.

Power has the least standalone utility for changing effect on exposed tissues and is often considered with spot size to create a range of effects. Spot size can be altered to modify the depth of tissue injury in a linear relationship.[7] Spot size can be altered by modifying the focal length, with an increasing focal length resulting in increased minimum focal spot diameter. It can also be altered by the surgeon working in an out of focus, with the laser beam diameter diverging as the distance from the focal plane increases.[7] This diverging laser beam results in a larger spot size and overall lower power density.

The surgeon can also control exposure time, which is defined as the amount of time (measured in seconds), that the laser energy will be delivered to the tissue. *Fluence*, measured in J/cm^2, defines the time that a unit area of tissue is exposed to laser energy. Surgeons can alter this with laser settings, such as continuous vs pulse modes. Pulse modes can allow for overall less tissue damage, by allowing for periods of time between laser applications that the heated tissues can cool.[8] This is achieved through thermal relaxation time, defined as the time needed for tissue to lose 50% of its thermal energy via diffusion, as is achieved through pulse lasers.[2,8]

When compared to laryngeal surgery via cold steel, laser surgery offers significant technical advantages. The use of lasers allows the surgeon to operate in an unobstructed field, utilizing a longer working distance and allows for reduced tissue manipulation when compared to cold steel.[2,9,10] Additionally, the use of lasers affords better hemostasis and minimal damage to surrounding tissue, which is beneficial for voice conservation.[2,11]

Based on the nature of the lesion and planned intervention, a variety of lasers can be used to treat laryngeal pathologies. Delivery of such lasers differs based on the location (eg, clinic vs operating room) that the patient will be treated. In order to accommodate these needs, varying modes of transmission of laser can be used. Fiber optic transmission of laser allow for modifications based on the setting in which the laser is used. Additionally, flexible fiber optic systems have been developed for office-based laser procedures allowing delivery of the laser by a fiber passing through a working channel of flexible nasolaryngoscopes. With flexible fiber optic systems, the surgeon can achieve improved accuracy with delivery of laser therapy. Although laser applications can be more broadly applied in the operating room, the advances in flexible fiber optic technologies have allowed for in-office treatment of recurrent respiratory papillomatosis (RRP), Reinke's edema, and dysplasia, among others.[6]

Laser types and applications

Based on the type of pathology to be treated, specific lasers can be selected through knowledge of their

Table 1 Lasers used for treatment of benign laryngeal lesions.

Type of laser*	Wavelength (nm)	Absorbed medium	Clinical use**	Limitations
CO_2	10,600	Water	Lesion excision/ablation, RRP, stenosis	Risk of thermal injury to tissues
KTP	532	Oxyhemoglobin	Glottic varices, vocal fold ectasias, subglottic hemangiomas	Risk of thermal injury to tissues
PDL	585	Oxyhemoglobin	RRP, keratosis, leukoplakia	Poor hemostasis/risk of vessel rupture

* CO_2 = carbon dioxide; KTP = potassium-titanyl-phosphate; PDL = pulsed dye laser.
** RRP = recurrent respiratory papillomatosis.

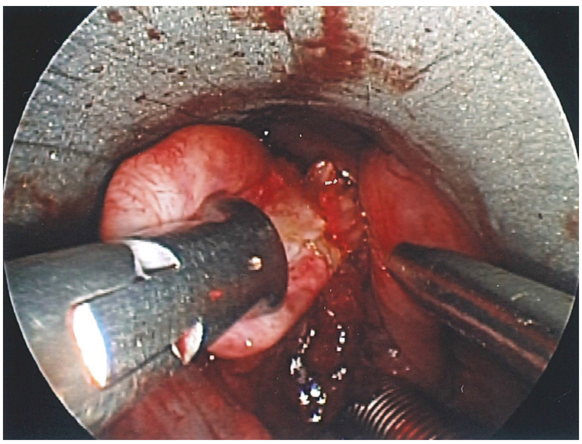

Figure 2 CO_2 laser is used to resect a right laryngocele.

properties and clinical applications. In general, lasers can be grouped into 2 categories: photoangiolytic and ablative.[2] For treatment of benign laryngeal lesions, 3 laser types are most commonly used: CO_2, KTP, and pulsed dye laser (PDL).[7] In order to select which laser will achieve the optimal surgical result, knowledge of the types and clinical applications of these lasers is critical in appropriately treating benign laryngeal lesions (Table 1).

Carbon dioxide (CO_2) laser

CO_2 laser is the most commonly used laser for treatment of laryngeal lesions, including both benign and malignant pathology.[12] As the first of the lasers to be developed, CO_2 laser has been most extensively studied and used in practice. At a wavelength of 10,600 nm, the CO_2 laser is in the infrared (invisible) range of the electromagnetic spectrum. Because of this, laser delivery systems use a coaxial neon laser to indicate for the surgeon where the laser will be targeted on the tissue. At this wavelength, CO_2 laser is absorbed by water and, therefore by tissues, making it favorable for treating a variety of lesions (Figure 2).

Specifically for benign laryngeal lesions, CO_2 lasers have been applied to an array of pathologies. Most commonly, CO_2 laser is applied to treatment of RRP, by ablating the papillomatous lesions while preserving surrounding laryngeal structures. It is also commonly used for treatment of laryngeal stenosis both at the level of the glottis and subglottis. This is often preferred over cold steel due to the laser's hemostatic properties, precision, preservation of surrounding tissues, and predictability of postoperative edema.[7]

Using fiber optic based lasers through working channels of flexible laryngoscopes, the CO_2 laser has also been applied to in-office treatment of Reinke's edema. Other hemorrhagic lesions and varices/ectasias have been treated with CO_2 laser, although there is concern of increased epithelial stiffness following the use of CO_2 laser.[13]

In treating benign laryngeal lesions with CO_2 laser, a number of settings have been trialed. Most commonly, laryngologists will use a pulsed setting, often in superpulse modes for improved tissue cooling. Depending on the lesion size and location, as well as the location in which the patient is being treated (eg, clinic vs operating room), CO_2 laser settings can range from 3 to 5 W with 0.05 seconds on/0.01 second off.[6] The power can be increased even up to 10 W per the discretion of the surgeon.

Surgeons need to be aware of laser settings and modifications that are needed to minimize thermal damage to surrounding tissue. In one study in canine larynges, thermal injury following CO_2 laser application extended up to 285 μm into the lamina propria.[14] This penetration into the lamina propria can result in higher rates of fibrosis and could impact mucosal vibration during phonation. Therefore, it is critical to be mindful of laser settings to achieve the best vocal outcomes following CO_2 laser procedures.

Potassium-titanyl-phosphate laser

KTP laser is versatile with several clinical applications within the field of otolaryngology. Specifically, for benign laryngeal lesions, KTP laser has been used quite frequently in recent years, especially in the clinic setting. With a wavelength of 532 nm, KTP is strongly absorbed in oxyhemoglobin, and as a result, has angolytic properties. KTP also causes minimal surrounding tissue damage and can be used while preserving much of the overlying epithelium of the vocal folds.[2]

KTP is used to treat a wide array of laryngologic pathologies, such as vascular as well as pedunculated lesions. Most commonly, it is chosen to treat laryngeal lesions due to its selective vascular affinity. A range of settings can be used for the KTP laser. Reported ranges of use differ based on the target pathology. Typical power settings range from 15 to 35 W, with 15-25-millisecond pulse width and 2 pulses delivered per second.[6] Although pulsed modes are more commonly used, KTP laser can also be used in a continuous mode, although collateral thermal damage will be greater with this mode compared to pulse modes.

For vascular pathologies, including varices and ectasias, KTP laser allows for lower energy settings to be used as compared to treating other lesions with KTP. Typical settings for treatment of vascular pathologies will start at 5-10 W on pulsed settings, with each laser application being 15 milliseconds and applying 2 pulses per second.[15]

For more pedunculated lesions, such as RRP and hemorrhagic polyps, KTP can also be applied. Typical settings for such lesions include 1.5 W with pulse width of 300 milliseconds at 500 millisecond intervals. For polypoid lesions, the lesion will regress over an average period of 4 weeks following the KTP laser procedure.[16] With KTP, patients have high rates of resolution of the lesion, with 85%-100% of patients showing complete resolution after in-office treatment.[17,18] When comparing voice outcomes with in-office KTP vs cold knife excision via microdirect laryngoscopy for polypoid lesions, there was no significant difference in voice outcomes,[17,18] supporting the use of lasers, even at a clinic setting, for treatment of such lesions.

Pulsed dye laser

PDL has also come into favor, especially in the clinic setting, for treatment of benign laryngeal lesions. With a wavelength of 585 nm, PDL has similar properties to KTP, as it is also selective for oxyhemoglobin. In light of this, PDL can be used to target vascular lesions such as papillomas, vascular polyps, and varices/ectasias. Especially in the clinic setting, PDL can be used through flexible channel nasolaryngoscopes for treatment of these lesions. Through its use, PDL causes involution of lesions by disruption of the lesions' vascular supply.[6]

Having similar wavelength and properties to KTP, PDL is often compared to KTP. Due to its shorter pulse width compared to KTP, PDL has a higher risk of vessel wall rupture which can result in difficulties in achieving hemostasis.[2] Regardless, several studies advocate the use of PDL, stating that it results in less disruption of the superficial lamina propria compared to KTP for treatment of leukoplakias.[19] For other lesions, however, PDL can penetrate deeper into the lamina propria compared to KTP, which can be useful for excising thicker lesions.[2] Success rates for treatment of laryngeal lesions have been found to be more variable than the outcomes seen with KTP. For example, resolution rate of hemorrhagic polyps following treatment with PDL was reported to range between 38% and 100%, which is a much wider and considerably lower rate of success compared to KTP.[16,20] Ultimately, the uses and outcomes resulting from PDL use are dependent on the operating physician but can certainly vary depending on the settings used.

Laser safety

The use of lasers requires an understanding of the necessary safety precautions to prevent injury to patients and staff. This requires educating the physician and the entire operating team regarding safety during laser procedures. First, the surgeon must be knowledgeable of the available treatment options for a given laryngeal lesion and select the use of laser after weighing risks and benefits of its use. Once laser has been selected as the desired modality for treating a lesion, the surgeon needs to ensure that he/she is well trained in its use and safety precautions. Additionally, the surgeon must ensure that the operating team has had appropriate laser safety education.

The surgeon and the operating team must communicate with one another before and during the use of the laser. Transparency in communication is critical for preventing laser injury. For example, ensuring that the anesthesiologist and surgeon communicate before and during the procedure is important in order to secure the airway with a laser-resistant endotracheal tube and to maintain oxygen concentration in the anesthetic gas to less than 30% to avoid airway fire, the most feared complication associated with laser use.[21] Other measures to avoid airway fire during laser procedures include the use of jet ventilation; reducing the laser plume via smoke evacuation during the procedure; and placement of saline-saturated cottonoids above the endotracheal tube cuff to protect it from the laser.[2,7,21] In the event of ignition of the endotracheal tube, ventilation is to be stopped immediately and the endotracheal tube withdrawn while flushing saline down the endotracheal tube. The airway should then be re-established immediately, potentially with the aid of bronchoscopy, to assess the injury and also establish an airway before significant edema obstructs the airway.[7] The patient will remain intubated and given intravenous steroids, with bronchoscopy repeated daily until the airway is found to be stable for extubation.[7] In the clinic setting, airway fire is less of a concern, although other forms of laser injury are possible.

With all laser use, preparing the operative field is important in preventing laser injuries. Besides airway fires, lasers can result in other forms of injury, which are of concern in both the clinic and operating room settings. Exposed skin and mucous membranes outside of the surgical field should be covered with saline-soaked surgical towels or lap pads to prevent burns to the skin. In addition, retinal and/or corneal burns are also a potential risk of laser use; therefore wavelength-specific eye protection must be worn by all operating room personnel. In the clinic setting, laser-safe goggles must also be worn by the patient. While in the operating room, the asleep patient should have saline-soaked eye pads placed over the eyes for additional protection.[7]

Conclusions

Laser treatment for benign laryngeal lesions has evolved over the last several decades. With its increased use in the clinic and operating room, the otolaryngologist can benefit from the availability of various lasers and settings. With anticipation for further advances and applications to emerge, an understanding of the currently available lasers physical properties, advantages, limitations, and risks, will provide the otolaryngologist with a powerful tool for treating an array of laryngeal lesions.

Disclosure

The authors have no conflicts of interest.

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