Chapter 13

Principles of Laser Microlaryngoscopy

13

13.1 Fundamental and Related Chapters

Please see Chaps. 6, 10, 21, 22, 24–30 for further information.

13.2 Laser Physics

The modern challenge of using medical lasers is the surgeon's ability to deliver the right amount of energy at the right wavelength to the right tissue while minimizing damage to collateral tissue. This process by which laser energy is restricted to a particular site is a result of the selective absorption of the chromophores at that site and was first described by Anderson et al. as "selective photothermolysis." The following section will consider the major concerns confronting surgeons when using lasers in a clinical setting.

13.2.1 Wavelength

Unlike the energy emitted from ambient light sources, laser light is monochromatic and usually of a single wavelength, with all photons collimating into a single, thin beam of homogeneous energy. The challenge of laser surgery is finding a wavelength in which energy is absorbed by target tissue and scattered or transmitted by surrounding structures. When laser light is delivered to the chromophores within the target, energy is absorbed within that tissue. Some common chromophores targeted by surgical lasers are hemoglobin, melanin, water-containing soft tissue, and covalent bonds found in major structural proteins. Depending on the chosen wavelength, either coagulation, vaporization, or a combination both will take place. Tissues heated to 80–100°C will suffer plasma denaturation, resulting in vessel closure and hemostasis. Temperatures above 100°C will cause vaporization through rapid volumetric expansion of intracellular water stores, a technique that is useful for separating or ablating tissues. A laser's wavelength also correlates with the depth at which the energy is delivered. Therefore, greater depths of tissue disruption are achieved at longer wavelengths until reaching the wavelength specific for the absorption of water, near 2,000 nm.

13.2.2 Tissue Interaction

While appropriate wavelength determination is critical for specific tissue targeting, the time in which the energy is delivered is also of consequence. Under prolonged exposure times, photothermal effects cause collateral coagulation necrosis, as heat transfers uniformly to surrounding tissues. However, if the pulse width is too short, the absorbing tissue may heat rapidly. Extreme temperature differences between target tissue and collateral structures have been shown to cause vaporization and shock wave damage, commonly referred to as a photomechanical effect. Consequently, nonspecific thermal damage occurs when the pulse width exceeds the thermal relaxation time for the tissue. Thus, the larger the specific target, the larger the thermal relaxation coefficient. Generally, subcellular organelles achieve photolysis within a nanosecond domain, cellular disruption occurs on a microsecond scale, and hemostasis is achieved within millisecond exposure times. In actual practice, all of these interactions occur concomitantly, but by selecting the proper wavelength, intensity, and pulse duration, the surgeon can maximize the desired effects.

13.2.3 Delivery Systems

While recent advancements in the field have provided more options for delivery systems, laser type is still the major determinant. Traditionally, the CO_2 laser has been of the most use for laryngologists. Traditionally, an articulating arm is required for the delivery of CO_2 laser energy to the treatment site. This delivery system requires a hollow tube with several joints or articulations that allow some maneuverability. At each articulation, a set of mirrors are positioned to reflect the beam around the corner. Great care must be taken when using such a system, as jarring or vibrations may cause misalignment within the internal mirror system. Laryngologists have also benefited from the addition of several attachments used at the end of articulating arms. Micromanipulators are used to couple laser operation and microscopy. A greater amount of precision and beam control can be managed by hand-manipulated devices.

The micromanipulators can control laser spot size. This is an essential variable from an ultimate tissue interaction perspective. Spot size, power, energy setting, and duration have a major role in the effect of the laser on the tissue. The smaller the spot size, the greater the energy delivered per unit area. Thus, when working with the typical very small spot sizes found with the CO_2 laser micromanipulators, the power settings should be kept quite low.

Many of the other lasers used in the field are delivered via fiberoptic cables. With the advent of this technology, laryngologists are able to use endoscopes, such as the flexible laryngoscope with a working channel to gain access. As with the articulating arm, fiberoptics is used in a noncontact manner. Normally a 1- to 2-mm distance from target tissue is optimal, as spot size rapidly increases with distance from tissue, causing a great reduction in laser energy delivered and lack of precision.

13.2.4 Types of Laser

Although a myriad of lasers are employed in the treatment of head and neck pathology, there are only a few types in the field of laryngology.

Traditionally the *CO_2 laser* is the workhorse of laryngologic lasers. Its specific wavelength of 10,600 nm is absorbed by water found in soft tissues and is independent of tissue color. CO_2 lasers emit continuous or pulsed waves, which can be focused into a thin beam and used to cut like a scalpel or defocused to vaporize, ablate, or shave tissue. The CO_2 laser's ability to deliver energy endoscopically, utilize no-touch technology, and provide a marked reduction in postoperative swelling, contributing to its widely accepted clinical use.

Pulse dye lasers (PDL) emit radiation at a 585-nm wavelength, which corresponds with the oxyhemoglobin absorption band. This wavelength penetrates the mucosa well, minimizes absorption by melanin in the overlying mucosa, and offers excellent selective absorption by microvasculature. A lasing medium of rhodamine dye is excited by flash lamps and is delivered with a pulse width just under the thermal relaxation time of small vessels. While pulse dye lasers have been employed in many areas of laryngology, relative small pulse width and the cost of replacement dye medium have detracted from the benefits of such technology.

YAG lasers use a yttrium–aluminum–garnet crystal rod that is manufactured with specific rare earth elements dispersed within the crystal rod. The difference in the chemical properties of each element gives the laser a specific wavelength and thus a different surgical application. All YAG lasers may be continuous, pulsed, or Q-switched. Q switching, much like a capacitor in a circuit, is the ability to pulse the laser, while at the same time increasing peak energy power, shortening pulse width, and improving the consistency of the lasers output throughout the pulse. Normally, continuous and pulsed modes are delivered via fiber optic cables, while articulating arms use Q switching.

The *holmium:YAG (Ho:YAG) laser uses* an active medium of YAG crystal with holmium dispersion. Its beam falls near the infrared region of the electromagnetic spectrum at 2,100 nm. Its principle use is to ablate bone and cartilage, and has found specific laryngologic application in laser incisions and dilation for the treatment of subglottic stenosis.

The *neodymium-coupled YAG (Nd:YAG) laser* is one of the most clinically diverse lasers in current use. A near infrared light is emitted at 1,064 or 1,320 nm. Nd:YAG lasers may be delivered fiber optically to coagulate tissue or through sapphire probes, allowing for low-powered delivery with minimal thermal diffusion. Sapphire probes create a cutting and vaporization effect similar to that of CO_2 lasers.

The *potassium–titanyl–phosphate (KTP) laser* uses a 1,064-nm YAG laser filtered through a KTP crystal that effectively halves its wavelength to 532 nm, producing a brilliant green light, well within the visible spectrum. The KTP laser is the newest addition to the laryngologist armament. Its 532-nm wavelength corresponds to a greater specific absorption for oxyhemoglobin. Recent studies have shown great promise in the surgical use of this solid-state laser, including shorter pulse width and less nonspecific tissue damage. The KTP laser also can deliver energy through a small diameter fiber optic, resulting in less mechanical damage to endoscopic channels.

It is important to recognize that a laser is nothing more than a tool in the surgeon's armamentarium, much like forceps, microscissors, or bipolar cautery. It is a common misconception that microspot CO_2 lasers allow increased precision over cold techniques. In fact, microlaryngeal cold instrumentation are superior to microspot laser technology in terms of precision, while avoiding collateral heat damage that can be associated with laser use.

13.3 Surgical Indications and Contraindications

Ideal indications for CO_2 laser are:

- Glottic/posterior glottic stenosis
- Subglottic/tracheal stenosis
- Bilateral vocal fold paralysis (arytenoidectomy, transverse cordotomy, …)
- Teflon granuloma of the larynx
- Squamous cell carcinoma of the glottis (T1–select T2)

Additional indications for CO_2 laser include:

- Papillomatosis (especially with extensive disease)
- Vocal fold varix (select cases)
- Saccular cyst of the larynx

Relative contraindications for CO_2 laser are:

- Most benign lesions of the vocal folds:
  - Nodules
  - Vascular lesions
  - Cysts
  - Polypoid corditis

Indications for Nd:YAG laser comprise:

- Large hemangioma of the larynx
- Glottic/subglottic stenosis
  (CO_2 laser generally preferred)

Indications for pulse dye laser/pulsed-KTP laser are:

- Papillomatosis

- Leukoplakia
- Granuloma
- Vascular lesions
- Polypoid corditis

13.4 Equipment: Laser Microlaryngoscopy Setup

High-quality operating microscope with 400-mm lens

Large-bore laryngoscope (largest diameter possible *if operating on vocal folds/supraglottis) (see Chap. 10, Table 10.1)*

Suspension laryngoscope with suction channel and jet ventilation port *if operating on subglottis/trachea*

- Ossoff–Pilling effective for subglottis/upper trachea (proximal)
- Subglottiscope for upper/mid-trachea (distal)

Suspension system

- Gallows suspension
- Fulcrum suspension (e. g., Lewy apparatus and table-mounted Mayo)

Operating chair with arm supports

- Alternative: Mayo stand with pillow/foam

Instrumentation (available from Karl-Storz (Culver City, CA), Medtronic ENT [Jacksonville, Fla.], Instrumentarium [Montreal, Quebec, Canada])

- Injection device for hydrodissection (Orotracheal injection device, Medtronic ENT)
- Small (0.5 × 2 cm) cotton pledgets
- 1:10,000 epinephrine
- Velcro strap or cloth/silk tape
- Microcup forceps (see Chap. 10, Fig. 10.2)
- Micro-ovoid cup forceps (see Chap. 10, Fig. 10.3)
- Microscissors
  - Curved, left and right
  - Up angled
- Curved alligator forceps
- Straight alligator forceps
- Microlaryngeal suctions
- Triangular (Bouchayer) forceps
- Hopkins Telescopes
  - Diameter 4–5mm, length 30cm or more
  - 0, 30, and 70°

CO_2 laser

Micromanipulator with 250-µm spot size (coupling device between microscope and laser)

Jet Venturi needle or Hunsaker Mon-Jet tube

Dilation equipment:

- Ventilating bronchoscopes: 5, 6, 7, and 8 French (if no trach present)
- Laryngeal rigid dilators: 20–50 French (if trach present)
- Pneumatic balloon dilator

Jet ventilation machine

Laser safety materials

- Moistened eye pads
- Moistened towels/surgical drapes
- Laser-safe endotracheal tube (if applicable)
- Eye protection for operating room personnel

13.5 CO_2 Laser Safety Guidelines

13.5.1 General Guidelines (Fig. 13.1)

In the vast majority of laryngeal laser surgery, relatively low-power settings are employed to minimize collateral heat damage. For the purposes of this chapter, all laser settings described are used in the context of a micromanipulator with a 250-µm spot size. Laser settings are generally set below 10 W, using an intermittent or superpulse mode. Continuous firing mode is rarely employed and can sharply increase the chances of immediate (laser fire) or late complications (glottic web/stenosis), due to the substantial power delivery in this mode. Intermittent delivery or pulsed delivery (e. g., superpulse) allows some thermal relaxation time in between laser delivery, thus minimizing collateral heat damage.

Fig. 13.1 Intraoperative photograph illustrating the key laser safety concepts, including wrapping the patient's head and upper body with moistened towels, the use of a laser-safe endotracheal tube, low-O_2 settings, and eye protection for operating room personnel

13.5.2 CO_2 Laser Settings

(For most applications in the larynx, the following range of laser settings can be employed):

- 4–8 W, intermittent mode (0.1 s "on" and 0.5 s "off")
  - Best for precision work at the vocal fold level
  - Least collateral damage
- 4–8 W, superpulse mode
  - Increased tissue ablation
  - Use sparingly near vocal folds to minimize collateral damage
- 4–6 W, continuous
  - Maximum laser ablation: useful for cartilage ablation (arytenoidectomy)

13.5.3 Safety Protocol

The key to laser safety in the operating room (OR) is consistent and methodical adherence to an established protocol. A simple yet effective protocol is to fully address three areas of safety prior to proceeding (Fig. 13.1). The surgeon must answer affirmatively to the following questions before firing the laser:

13

1. Is the patient's body protected?
   a) Moistened eye pads
   b) Soaked surgical towels around the face and upper chest
2. Is the endotracheal tube/airway protected?
   a) Laser-protected tube must be used
   b) Saline filled ETT balloon
   c) Moist Cottonoid covering/protecting the balloon
   d) O_2 concentration of 30–35% or less
   If jet ventilation is used, then suspend ventilation during firing of the laser.
3. Are the OR personnel protected?
   a) Eyeglasses or plastic goggles with side protectors for all personnel
   b) Laser warning signs on all OR doors

13.6 Surgical Principles

13.6.1 Smoke Evacuation

Laser vaporization results in significant smoke accumulation at the operative site, and must be rapidly removed to maintain visualization. Suction tubing should be connected to a side channel of the laryngoscope to maintain continuous smoke evacuation. It should be noted, however, that supplemental smoke evacuation may be necessary. Platform suction (Fig. 13.2) is often employed, which provides not only smoke evacuations, but also protects the distal tissues from inadvertent laser damage.

13.6.2 Protecting Surrounding Tissue from Laser Damage

Platform suction can be used, as indicated above, or a moistened Cottonoid can be placed over the area to be protected.

13.6.3 Maintenance of a Clean Surgical Field

The CO_2 laser causes the accumulation of carbonaceous debris (Fig. 13.3), or char at the surgical site. This desiccated debris is resistant to laser penetration due to the low water content. Therefore, it must be removed periodically by wiping the tis-

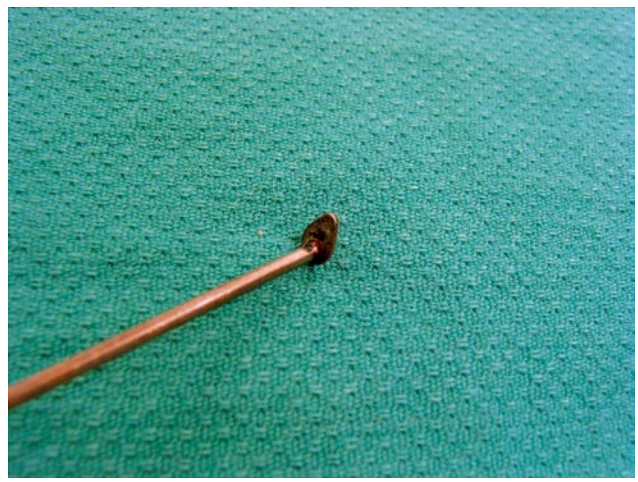

Fig. 13.2 Platform suction device

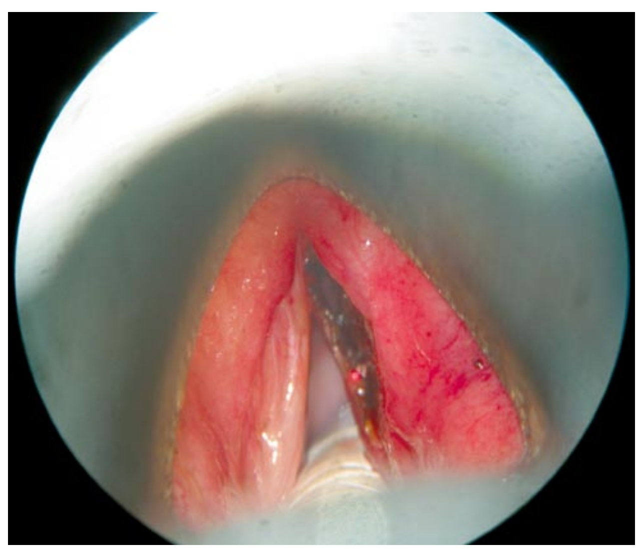

Fig. 13.3 Carbonaceous debris from laser ablated tissue, right vocal fold. This must be removed for efficient treatment of tissue with the CO_2 laser

sues with a saline-soaked Cottonoid, or suction removal. Also, active bleeding at the surgical site usually prevents laser vaporation. Hemostasis must be achieved before proceeding (by either defocusing the laser beam, or applying epinephrine-soaked Cottonoids for 1–3 min to the area of bleeding).

13.7 Complications and Their Treatments

13.7.1 Laser Fire

A laser fire is the most feared complication in laryngology, although it is quite rare today. This is likely due to better education and awareness of laser safety issues, as well as improved laser-safe endotracheal tube design. In the unlikely event of a laser fire with an indwelling endotracheal tube, the following steps should be followed:

- Immediate removal of ETT
- Turn off anesthetic gas/oxygen delivery
- Mask patient with 100% O_2
- Intubate with small 4.0–5.0 ETT
- Evaluate trachea with rigid bronchoscopy with carbon debris removal
- Flexible bronchoscopy to evaluate more distal tracheobronchial tree
- Manage airway after extent of injury is established (options to be considered):
  - Extubate, observe in monitored setting
  - Remain intubated, treat with corticosteroids/antibiotics
  - Tracheostomy

13.7.2 Tracheal Perforation

This can lead to tracking of air into the neck and down into the mediastinum. Further dissection can lead to pneumothorax. Either condition should be evaluated with a chest x-ray and consultation with cardiothoracic surgery/pulmonology specialists.

Key Points

- The key components that determine a laser's interaction with tissue are wavelength, intensity, spotsize and pulse duration.
- The CO_2 laser is the workhorse laser for laryngotracheal work, and the ideal indications include:
  - Glottic/posterior glottic stenosis
  - Subglottic/tracheal stenosis
  - Bilateral vocal fold paralysis (arytenoidectomy, transverse cordotomy)
  - Teflon granuloma of the larynx
  - Squamous cell carcinoma of the glottis (T1–select T2)
  - Papillomatosis (especially with extensive disease)
  - Vocal fold varix (select cases)
  - Saccular cyst of the larynx
- The CO_2 laser is generally not a good choice for the removal of benign lesions of the vocal fold, such as polyps, or cysts, or nodules, due to decreased precision, and unintended collateral heat damage, which can result in scarring and dysphonia.
- CO_2 laser settings generally employ low-wattage settings (4–8 W) in an intermittent or superpulse mode to minimize collateral damage to the tissues. The continuous-beam setting should be used sparingly, and is most appropriate for cartilage ablation.
- A laser safety protocol should be employed in all cases where the CO_2 laser is used. The key concepts are protection of the patient (moist towels), protection of the endotracheal tube (laser safe, with O_2 concentration of 35% or less), and protection of operating room personnel (safety glasses).

Selected Bibliography

1 Anderson R, Parrish J (1983) Selective photothermolysis: precise microsurgery by selective absorption of pulsed radiation. Science 220:524–527

2 Absten GT, Joffe SN (1985) Lasers in medicine. Chapman and Hall, London

3 Buckmire R et al (2006) Lasers in laryngology. In: Merati AL, Bielamowicz SA (eds) Textbook of laryngology. Plural, San Diego, pp 190–199

4 Ossoff RH (1989) Laser safety in otolaryngology—head and neck surgery: anesthetic and educational considerations for laryngeal surgery. Laryngoscope 99(Suppl.):1–26

5 Schramm VL, Mattox ED, Stool SE (1981) Acute management of laser-ignited intratracheal explosion. Laryngoscope 91:1417–1426

6 Zeitels S, Anderson R et al (2006) Office-based 532-nm pulsed-KTP laser treatment of glottal papillomatosis and dysplasia. Ann Otol Rhinol Laryngol 115:679–685