5

Laser/Light Applications in Otolaryngology

Carolyn Orgain, Vanessa Rothholtz, and Brian J. F. Wong

Abstract

Lasers have been ubiquitous in otolaryngology since Jako and Strong first introduced the CO_2 laser in 1970. Since that time lasers have traditionally been used like a scalpel, able to cut and cauterize precisely. More recently, the role of lasers has been expanded in otolaryngology depending on the specific laser wavelength and dosimetry parameters. Not only can lasers be utilized to extirpate cancer, but also used to recover hearing, improve the airway, treat epistaxis, and even break up salivary stones for easy removal. The individual characteristics of the laser are important for the specific application. However, the otolaryngologist often works in areas that are either difficult to access using classic methods or require extreme precision, and the mechanism and method for delivering the laser energy is often equally important. In this chapter, we describe the many ways lasers are used in otolaryngology treat both benign conditions to life-threatening diseases. New and innovative applications are also discussed.

Keywords

Carbon dioxide laser · Potassium titanyl phosphate laser · Laser safety · Laryngeal cancer · Laryngomalacia · Laryngeal polyps · Laryngeal papillomas · Cholesteatoma · Stapedectomy · Laser myringotomy · Laser assisted uvulopalatopharyngoplasty · Zenker diverticulum · Oropharyngeal cancer · Sialendoscopy · Hemorrhagic telangiectasias · Choanal atresia · Subglottic stenosis

Introduction

History of Laser Use in Otolaryngology

In otolaryngology, the laser has been traditionally used like a scalpel or cautery to precisely incise, cauterize, and coagulate tissue particularly where a collimated beam could provide non-contact and precise tissue ablation for tissue targets that would be difficult to treat using conventional instruments. Over time other applications of lasers have evolved in the head, neck, and upper airway which capitalize not only on the precision realized by the laser, but also on it's ability to

C. Orgain, M.D. (✉) · B. J. F. Wong, M.D., Ph.D.
Department of Otolaryngology-Head and Neck Surgery, University of California, Irvine, Orange, CA, USA
e-mail: ccoughla@uci.edu; bjwong@uci.edu

V. Rothholtz, M.D., M.Sc.
Pacific Coast Ear Nose and Throat, Beverly Hills, CA, USA
e-mail: vrothholtz@rothholtzmd.com

K. Nouri (ed.), *Lasers in Dermatology and Medicine*, https://doi.org/10.1007/978-3-319-76220-3_5

achieve selective photothermolysis, spatial selective, confined thermal injury, and the generation of photoacoustic waves. By selecting the correct laser wavelength and appropriate dosimetry parameters, surgeons can control both the temporal and spatial evolution of heat within the target site leading to any of the above referenced laser-tissue interactions. Light is variably absorbed and scattered as it propagates through tissue, and the distribution of light in tissue determines the nature of the specific interaction [1].

As in dermatology, the selection of the appropriate laser in head and neck applications is critically important, and the selection of a specific device and mode of delivery are just as important as wavelength and dosimetry.

The otolaryngologist—head and neck surgeon frequently works in areas that are either difficult to access (e.g. larynx, skull base) or require extreme precision (e.g. middle ear), and in these circumstances laser technology can be extremely valuable. For example, during microsurgery of the vocal fold or stapes, a micromanipulator or microscope-mounted scanner, is needed to precisely focus and translate a laser beam as small as 100 mm. In surgery of the subglottis and trachea, flexible optical fibers (fiberoptics) or waveguides are used to deliver laser light to these difficult-to-access locations. In minimally invasive laryngeal cancer operations, high power CO_2 lasers (λ = 10.6 μm) are needed to cut tissue while maintaining hemostasis.

Frequently Used Lasers in Otolaryngology

The workhorse in Otolaryngology—Head and Neck Surgery is the carbon dioxide laser. It is used extensively in surgery of the larynx and ear because it can cut tissue precisely, seal small blood vessels and even ablate bone. In cancer surgery, CO_2 lasers may seal lymphatics potentially reducing the spread of disease. Since infrared light is invisible, the CO_2 laser is always used with a visible aiming beam. The potassium-titanyl phosphate (Neodymium-doped:YttriumAluminum-Garnet), KTP(Nd:YAG) (λ = 532 nm), laser is also becoming used increasingly more commonly in laryngotracheal surgery as well as surgery of the oropharynx and nose. The KTP(Nd:YAG) laser is most frequently used for vascular lesions because of its absorption by oxyhemoglobin. In the nose, the KTP(Nd:YAG) laser is most frequently used for treatment of hereditary hemorrhage telangiectasias (Osler-Weber-Rendu disease). This is a visible wavelength laser and hence easily transmitted using low-cost optical fibers. It can be made to produce a pulsed output beam, also known as giant pulse laser or Q-switching. This allows for the delivery of nanosecond pulses, which lead to less tissue injury to the surrounding structures [2]. Nd:YAG lasers (λ = 1064 nm) are used in otolaryngology as well, however the deep penetration depth of this wavelength has resulted in limited use (primarily for very large venous malformation coagulation in the oral cavity and pharynx); though in contact mode, this laser has applications as a precise cutting device [3–6].

The Argon laser (λ = 514 nm) is also used for nasal and middle ear surgery. It is absorbed by hemoglobin and melanin and is generally used in continuous-wave mode. The Holmium:YAG (Ho:YAG) (λ = 2.1 μm) laser is a mid-infrared laser wavelength that is moderately absorbed by water, its principal chromophore. It is valuable because it has a relatively shallow optical penetration depth like the carbon dioxide laser, but can be transmitted using low-cost silica fibers. Its use in otolaryngology has been very limited thus far due to the lack of availability of these devices in most medical centers. The Erbium:YAG laser (λ = 2.94 μm) is used for middle ear surgery, surgical planning in rhinophyma, and cosmetically for skin resurfacing. It has high absorption in soft tissue and bone and minimal thermally-induced peripheral damage. It also has a tolerable photoacoustic wave effect in the surrounding tissue [7]. Pfalz, Fisch and others have developed Erbium:YAG lasers for middle ear surgery, and has more recently been shown to have equal surgical outcomes when compared to the CO_2 laser (Table 5.1) [8].

Table 5.1 Laser applications in otolaryngology

Laser type	Wave length	Penetration depth	Delivery methods	Indications/applications
Argon	514 nm	0.8 mm	Fiber Micromanipulator Focusing handpiece	Ear—Stapes surgery Nose—telangiectasias
CO_2	106,000 nm	30 µm	Articulated arm Micromanipulator Hollow wave-guide scanner Focusing handpiece	Glottis/subglottis/larynx/oropharynx Benign/malignant Tonsils Lingual Oral cavity/tongue Benign/malignant Nose Turbinate hypertrophy
Erbium:YAG	2940 nm	3 µm	Articulated arm Sapphire fiber	Nose Rhinophyma Cosmetic Laser resurfacing
Holmium:YAG	2120 nm	0.4 mm	Fiber/bare fiber contact Hanpiece	Oral Cavity Lithotripsy Nose Sinus surgery Turbinate hypertrophy
KTP (Nd: YAG)	532 nm	0.9 mm	Fiber/bare fiber contact Side-fire Focusing handpiece Diffuser tip Micromanipulator	Nose Polyps Epistaxis Oropharynx/palatine tonsils Obstructive sleep apnea Vascular malformations Nose Telangiectasias Trachea Stenosis Subglottic hemangioma
Nd: YAG	1064 nm	4 mm	Fiber/bare fiber Contact tips	Vascular malformations Tumor removal (contact mode) Turbinate surgery

Laser Safety in Otolaryngologic Applications

As in dermatology, laser safety needs to be considered for the patient, surgeon and surgical staff. The use of a laser near the eyes and in the airway warrants the diligent practice of laser safety at all times. Blindness, burns to the skin, airway injury and death may result if precautions are not taken to prevent these devastating events. The safety precautions and measures to prevent eye injury in head and neck surgery are identical to those used in dermatology, with the exception that the laser dosimetry is often significantly more powerful than that used to treat the skin. Eye protection measures are reviewed elsewhere. The use of lasers in surgery in the airway presents a major challenge that is unique to otolaryngology—head and neck surgery. Airway fires are a serious risk in laser surgeries involving the airway. Flammable anesthetic gases provide an oxidizing agent that can initiate the fire in the presence of an ignition source such as a laser. The endotracheal tube or other surgical supplies typically used to protect the airway can serve as fuel to propogate the reaction [9]. Specialized laser-safe endotracheal tubes (Fig. 5.1) exhibit prolonged mean times to ignition in comparison to standard endotracheal tubes. Reflective metallic tape wrapped around the

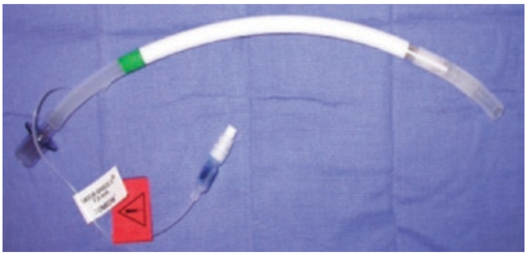

Fig. 5.1 Laser-specific endotracheal tube wrapped with reflective metallic tape. Laser-Shield II® Endotracheal Tube—Medtronic

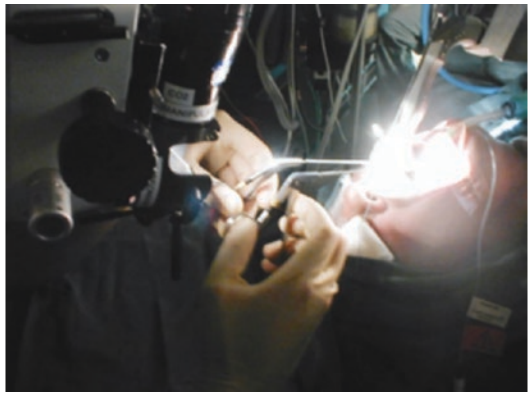

Fig. 5.2 Micromanipulator coupled surgical laser with patient placed in suspension (Photograph provided courtesy of Dr. Brian Wong)

endotracheal tube is shown to reduce the risk of ignition of all tubes [10, 11]. Each specific laser interacts differently with these laser-safe endotracheal tubes and many studies have been preformed to evaluate the safety of laser surgery in the airway [12–15]. For example, it has recently been shown that the KTP laser is unable to penetrate even PVC endotracheal tube, and suggests that laser safe endotracheal tubes may be unnecessary. However, this laser does interact with the black writing on the endotracheal tube to produce a spark and care must be taken to prevent the KTP laser from coming into contact with these markings [16].

Laryngology and Hypopharyngeal Pathology

Jako and Strong pioneered the use of the CO_2 laser in laryngeal surgery in the 1970s. They were among the first to describe the laser excision of an early laryngeal cancer [17–19]. Lasers gained popularity in the 1980s for removal of benign laryngeal lesions such as recurrent respiratory papillomatosis [20]. During this time, Steiner began his seminal work expanding the scope of laryngeal laser surgery to treat more extensive malignant tumors of the larynx and upper-aerodigestive tract. His pioneering work is perhaps the greatest contribution to organ sparing laryngeal surgery over the past 20 years and demonstrated the advantages of utilizing microsurgical laser techniques in the treatment of early-stage laryngeal cancer [21].

The CO_2 laser was the first wavelength used in laryngeal surgery and remains the laser of choice for the majority of laryngeal operations. Recent advances in laser technology, anesthesia, and surgical instrumentation have made minimally invasive laryngeal procedures more common. These new approaches have led to better organ preservation rates, improved post-operative functionality and reduced recovery time.

Chiefly among these advances, lasers can be precisely focused to provide surgeons with a cutting tool capable of incising tissue even at distances of 400 mm. Using a micromanipulator-coupled surgical laser (Fig. 5.2) at 25× to 40× magnification can allow for simultaneous use of both hands as well as focus an extremely accurate laser beam (Fig. 5.3). The line-of-sight lasers that are coupled to the micromanipulator are limited in that they cannot reach around corners, however. Newer hollow waveguides and fiberoptics continue to expand the role of lasers airway surgery. The most commonly used fiberoptic lasers used in otolaryngology at this point in time are the KTP(Nd:YAG) and CO_2 lasers. These lasers can now reach areas that are otherwise difficult to access without performing an open procedure.

Cancer

Transoral endoscopic laser laryngeal microsurgery depends upon the ability of the surgeon to determine the extent of tumor invasion prior to excision. This can be done by detailed physical

Fig. 5.3 Micromanipulator coupled surgical laser. Note the bimanual instrumentation allowed by placing the patient in suspension (Photograph provided courtesy of Dr. Brian Wong)

examination performed under general anesthesia and imaging studies. The primary objective is to achieve complete resection of the cancer with clear margins, while maintaining as much organ function as possible. Primary goals are to preserve swallowing, voice, and airway.

While transoral laser laryngeal microsurgery (TLM) has many advantages such as decreased post-operative morbidity and reduced recovery time. The potential for organ preservation, recurrence or incomplete resection are significant risks. Hence, making the decision to proceed with TLM requires skill and sound clinical judgment. It is generally contraindicated in patients with known extensive invasion into other structures and recurrent cancer in previously irradiated areas [22]. In TLM, tumor is excised piecemeal using a laser, with frozen section guidance, much like Mohs surgery, albeit over complex three-dimensional surfaces with composite tissue structures.

Glottic Carcinoma

The larynx ("voicebox") is composed of the supraglottis, glottis, and subglottis. The glottis includes the vocal cords. Use of the laser to excise glottic cancer is well established for lesions staged at T1 and early T2. For all T2a carcinomas of the glottis, laser excision is recommended regardless of the pattern of the spread of the tumor [19, 23, 24]. Provided the tumor is superficial, it is of limited significance whether the disease involves the supraglottis, subglottis or the anterior commissure. The superficial location of the tumor in T1 and early T2 disease allows it to be excised by partial mucosectomy or cordotomy. Laser-assisted endoscopic excision of T3 and T4 laryngeal carcinomas is controversial. Most experts in the field reject the idea of laser microsurgical excision of these advanced tumors unless a classic laryngectomy is not an option due to underlying co-morbid disease. Patients with T3 or T4 laryngeal lesions require the widest possible endoscopic excision followed by post-operative radiotherapy to the primary site and surrounding groups of lymph nodes; however they more often undergo a classic open total or partial laryngectomy [25, 26]. Steiner groups patients T2b, T3, and T4 together and routinely treats these tumors with laser-assisted endoscopic surgery [25].

Supraglottic Carcinoma

The supraglottis is the subsite of the larynx superior to the true vocal cords. Supraglottic tumors typically occur either in the suprahyoid epiglottis and false cord area or in the infrahyoid/epiglottic area. It is relatively rare that small, well-circumscribed tumors are diagnosed in the supraglottic area because the tumors tend to be much more advanced when the start to produce symptoms. Laser resection of early stage supraglottic carcinomas is now more commonly being performed [27]. Tumors in the suprahyoid epiglottis and false cord area are easily removed. Laser excision is indicated because wide margins can be taken without the concern of adversely affecting function. Newer techniques in otolaryngology are now progressing to transoral robotic surgery (TORS) in the resection of early supraglottic carcinomas [28]. Preliminary results shows TORS more often had positive margins on pathology, but shorter operative times. This was attributed to improved exposure in TLM.

Infrahyoid epiglottic cancers are difficult to assess preoperatively even with imaging studies and are at risk for infiltrating the pre-epiglottic space. There are conflicting opinions regarding endoscopic laser resection of carcinoma that involves the pre-epiglottic space. Iro urges caution and restraint in treatment of T3 staged supraglottic cancers with transoral laser surgery [29]. Whereas Rudert believes that even these supraglottic cancers that invade the pre-epiglottic space are candidates for endoscopic laser resection [30].

Hypopharyngeal Carcinoma

Pre-resection analysis of the airway during surgical endoscopy under general anesthesia may not be able to identify the true extent of hypopharyngeal tumors. Imaging studies can aid in this endeavor. Tumors involving the piriform sinuses can typically involve the thyroid cartilage, arytenoids, paraglottic and pre-epiglottic space as well as other soft tissues of the neck with little or no evidence seen on endoscopy. Because of these factors, the majority of laryngologists agree that partial pharyngo-laryngeal resection utilizing only a laser is insufficient for complete eradication of disease and cannot be justified. Classic open surgery (i.e., laryngectomy, laryngopharyngectomy) remains the standard of care.

Palliative Therapy

The laser is a useful tool in debulking tumors that obstruct the upper airway and may be an alternative to tracheostomy [31, 32]. Avoiding a tracheostomy greatly improves a patient's quality of life. Palliative airway surgery requires experience and judgment. If too little tumor is resected, the obstruction will persist and ultimately lead to a tracheostomy. However, aggressive resection of tumor may lead to aspiration and the need for a tracheostomy to protect the airway and provide pulmonary toilet. Laccourreye published a 10-year experience describing the use of the CO_2 laser to debulk obstructing endolaryngeal carcinomas in 42 patients for the avoidance of a tracheostomy. Ninety-three percent of patients avoided tracheostomy [33].

Recanalizing the upper digestive tract by subtotally ablating hypopharyngeal and esophageal outlet tumors poses a serious risk of hemorrhage and will only provide temporary improvement in swallowing. Placement of a percutaneous gastrostomy tube (PEG) tube is often a safer and better option for these head and neck cancer patients with dysphagia. If palliative laser surgery is considered, one should aim for sustainable symptomatic relief.

Benign Disease

The CO_2 laser has a firmly established role in the treatment of benign laryngeal disorders such as papillomas, polyps, vascular malformations and strictures (see Table 5.2). Since Jako and Strong first introduced the CO_2 laser in 1970, several groups, including those led by Shapshay, Zeitels, Ossoff, Steiner, Motta and Rudert, have published extensively on their experiences with laser surgery in benign laryngeal disease [34]. The use of other lasers such as the KTP(Nd:YAG) laser and the pulsed dye laser (λ = 585 nm) has also been reported.

Polyps

Vocal cord polyps are generally unilateral, sessile and appear to be spherical and well circumscribed. They typically originate at the free edge on the anterior two thirds of the vocal cord (Fig. 5.4). The vocal cords have a delicate subepithelial tissue layer that can be damaged as a result of repetitive collisions and shearing forces. Voice abuse and chronic inflammation from tobacco smoke irritation are common causes of injury to the vocal cord epithelium and lead to damage within the epithelial basement membrane. A large percentage of patients with polyps are heavy smokers or are exposed to a large amount of secondary tobacco smoke. When conservative

Table 5.2 Benign lesions (in laryngology section)

Disorder	Laser treatment
Polyps	CO_2 or KTP (Nd:YAG) laser excision
Papillomas	CO_2 or KTP(Nd:YAG) laser ablation
Vascular malformations	Pulse dye laser photocoagulation
Hemangiomas	CO_2 or KTP(Nd:YAG) laser for coagulation and excision
Vocal cord paralysis	CO_2 laser for enlarging glottic chink
Laryngomalacia	CO_2 laser excision of redundant tissue

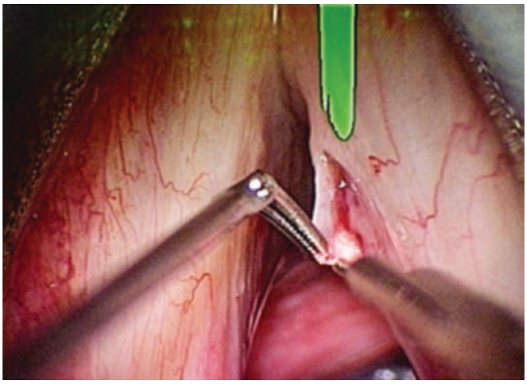

Fig. 5.4 Pulsed 532 nm KTP laser assisted subepithelial resection of fibrovascular mass (hemorrhagic polyp) on the middle 2/3 of the left true vocal cord. The green area is refraction from the laser light (Photograph provided courtesy of Dr. Steven Zeitels)

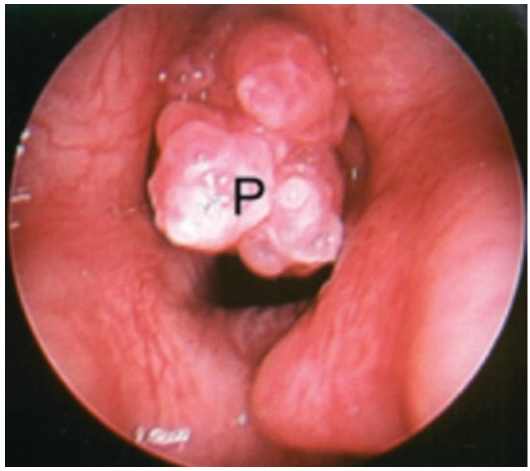

Fig. 5.5 Laryngeal papilloma (P) at the level of the glottis (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

methods (i.e., voice rest, speech therapy, etc.) fail, treatment is surgical removal. It is important to always send the excised polyps for histology to exclude an early malignancy. For this reason, these polyps should never be vaporized with the laser.

Papillomas

Laryngeal Papillomas are typically caused by HPV types 6 and 11 and can affect any age group (Fig. 5.5). The distribution of disease is bimodal, affecting children and middle-aged adults most often [35]. The virus causes formation of benign epithelial papillomas of the larynx. Diagnosis is made with flexible fiberoptic laryngoscopy or microlaryngoscopy. Although papillomas most commonly occur on the vocal cords, the larynx, esophagus and trachea must be comprehensively examined during endoscopy because the papillomas can occur anywhere along the aerodigestive system. While the CO_2 laser is still used to ablate these lesions, the concern over aerosolization of viral particles has made mechanical laryngeal microdebriders an increasingly more common treatment approach. The KTP(Nd:YAG) laser is particularly helpful in surgery for laryngeal papillomas. The advent of fiberoptic cables for the KTP(Nd:YAG) and CO_2 laser has even made it possible to treat papillomas in the clinic with the use of a flexible fiberoptic laryngoscope [36].

Hemangiomas and Vascular Malformations

Subglottic hemangiomas present with persistent cough, hoarseness or stridor, and manifest as reddish, well-circumscribed masses during surgical endoscopy. Surgery involves primarily vaporization and ablation rather than excision [37]. The CO_2, KTP or Nd:YAG laser can all be used with low power settings (1–3 W). High power settings can lead to tracheal perforation, pneumothorax or intractable bleeding.

Vascular malformations typically are located in the supraglottic area and are generally asymptomatic. Symptoms of a laryngopharyngeal vascular malformation may include foreign body sensation or mild stridor of unknown origin. Carbon dioxide laser excision or Nd:YAG coagulation is the treatment of choice, though other wavelengths can be used as well with appropriate dosimetry. Use of the Nd:YAG laser has a higher rate of postoperative scarring and stenosis due to the deeper penetration depth of this wavelength, but is extremely valuable in treating large vascular malformations where volumetric heating of large regions of tumor are required. These extensive tumors are more commonly found in the oropharynx and oral cavity [38]. Ectatic blood vessels along the vocal cord surface (Fig. 5.6) may alter the pitch and timbre of the voice and can be problematic for singers and other

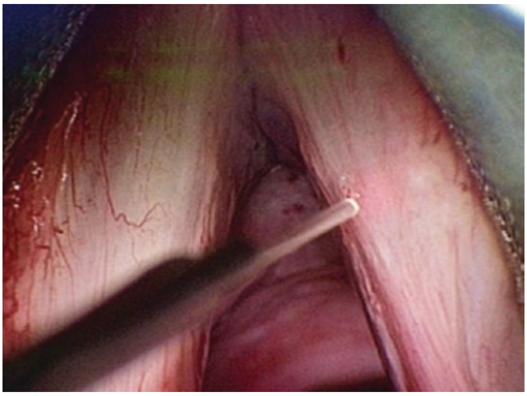

Fig. 5.6 Pulsed 532 nm KTP laser assisted photoangiolysis of ectatic blood vessels in a singer (Photograph provided courtesy of Dr. Steven Zeitels)

professionals. They are commonly treated using a pulse dye laser and KTP(Nd:YAG) [39].

Laryngomalacia

Stridor in children is most commonly caused by laryngomalacia, and 60–75% of childhood cases of stridor are associated with laryngomalacia [19]. Approximately 20% of these cases do not resolve spontaneously or cause symptoms severe enough to require surgical intervention. Dysphagia, apnea and respiratory distress are all indicators for surgical intervention. Laryngomalacia will be discussed in a later section along with subglottic hemangiomas.

Vocal Cord Paralysis

Patients that have bilateral vocal cord paralysis may develop severe respiratory distress and airway obstruction from the diminished patency of the glottic airway. Vocal cord paralysis commonly presents following surgery where the recurrent laryngeal nerve is inadvertently injured (i.e., during thyroid tumor surgery). In the immediate post-operative period the patient sometimes develops stridor and respiratory insufficiency. Acutely, treatment may involve intubation and tracheostomy. For long-term treatment, CO_2 lasers can be used to enlarge the glottic chink and increase airway patency [40] This is challenging surgery because it is important to strike a balance between airway patency and voice quality when enlarging the glottis.

Contraindications for Surgery of Benign Airway Lesions

There are few contraindications to Transoral Laser Microsurgery (TLM) for benign lesions. One important rule is that surgeons should avoid unnecessary disruption or excision of the anterior commissure and the free edge of the vocal cords. Disruption of the anterior commissure may result in change in the patients voice, extensive scar formation, or an anterior glottic web. If there is epithelial disruption of the free edges of both vocal cords, this can lead to post-operative scarring and webbing. It is imperative that the surgeon only work on the epithelium of one vocal cord at a time to prevent these complications.

Pre-operative Management

In the pre-operative evaluation, patients always undergo an indirect mirror or a flexible fiberoptic laryngoscopy examination to determine the extent of the lesion and vocal cord mobility. Video stroboscopy of the vocal cords may be included in the pre-operative evaluation to determine the dynamics of vocal cord movement. Some patients may undergo diagnostic imaging (CT or MRI of the neck) to determine the extent of disease. Vocal cord polyps warrant a trial of speech therapy for vocal coaching and training in proper voice use prior surgery. Patients with carcinoma of the larynx and recurrent papillomatosis must be strongly encouraged to quit smoking.

The most common parameters for the CO_2 laser beam using a micromanipulator is a 250 mm spot size with a working distance of 350 mm. Laser power is usually below 8 W. In the superpulse mode, where exposure time is 0.1 s or less, a low power setting of 2–3 W is used. The superpulse mode is useful in achieving maximum ablation through minimal penetration and maximum energy absorption at the surface of interest. There is almost no charring due to the minimal thermal diffusion in the surrounding areas around the target. In preparation for incision of epithelium, microvascular coagulation is required. For this, the laser is typically set for a 0.05 s pulse of 1 W of power using an unfocused beam [20].

Recently, flash scanner technological originally developed for use in dermatologic applications has been re-purposed and adapted for use in laryngeal microsurgery. This technology spreads the laser energy uniformly over the target area by using two nearly parallel, rapidly rotating mirrors [41]. It creates a uniform area of laser energy approximately 3 mm in diameter in 1 ms. The laser is able to provide surface ablation with little to no char at a depth of 0.15 mm. The high cost of these systems has limited the broad adoption of this technology.

Description of Technique

Suspension microlaryngoscopy provides a method in which the surgeon is able to directly visualize the larynx and its surrounding structures. Gustav Killian was among the first to describe suspension laryngoscopy in 1912 and later developed the Killian-Lynch suspension laryngoscope along with Robert Clyde Lynch. Zeitels showed effective use of suspension laryngoscopy in 120 cases in a prospective assessment [42]. Suspension allows for bimanual direct laryngoscopic surgery [43]. Furthermore, suspension laryngoscopy permits the use of a laryngoscope with a larger bore thereby enhancing exposure. Figure 5.7 demonstrates the positioning of a patient in suspension and Fig. 5.8 shows the normal anatomy of the larynx as visualized under suspension microlaryngoscopy.

With the patient anesthetized and lying supine, the head is fully extended. A rigid laryngeal endoscope is introduced through the oral cavity and past the epiglottis into the larynx until the desired endolaryngeal structures are visualized. The vocal cords should be clearly visualized from the anterior commissure to the vocal process on both sides. The rigid laryngoscope is then stabilized and secured using a suspension arm. Surgery is performed using a microscope with a 400 mm focal length lens or using a Hopkins rod endoscope inserted thru the laryngoscope bore. There are several instances that make suspension microlaryngoscopy very difficult or even impossible. Abnormal anatomy such as a short, stiff neck, long or protruding maxillary teeth, displaced larynx and lesions or a mass at the base of tongue may limit and prevent suspension laryngoscopy in these patients [42]. Utilizing paralysis is often necessary for successful laryngoscopy.

Suspension laryngoscopy provides a direct airway in which anesthesia may be administered either through an endotracheal tube that is inserted parallel to the laryngoscope or via jet ventilation. This direct airway also provides an

Fig. 5.7 Suspension laryngoscopy (Photograph provided courtesy of Dr. Roger Crumley)

Fig. 5.8 View of the glottis through the laryngoscope. A arytenoids, E epiglottis, V (black) vocal cords, V (white) vallecula (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

unimpeded path for the surgeon to access the vocal cords and other structures in the larynx. When using an endotracheal tube in laser surgery, it is important to use a laser-safe endotracheal tube to minimize the risk of an airway fire. These techniques allow for a minimally invasive approach to laryngeal surgery where traditional approaches have involved large external incisions and significant morbidity.

Lasers and Laser Devices

Since Jako coupled the carbon dioxide laser to the operating microscope in 1972 for laryngeal surgery, the CO_2 laser has been the wavelength of choice. The CO_2 laser is used in the majority of operations because of its widespread availability in most medical centers and its efficiency in simultaneously cutting tissue and maintaining hemostasis. Other commonly used lasers in otolaryngology include the KTP(Nd:YAG) laser and the argon laser. In laryngeal surgery, the CO_2 laser is often coupled to a micromanipulator attached to the microscope. This allows the surgeon to use microsurgical instruments and the laser at the same time. It also provides maximum surgical field visualization with high magnification and an unobstructed view of the lesion. The CO_2 laser has several advantages over conventional surgical instruments that cut or cauterize in that traditional devices may obstruct the field of view or amplify the surgeon's intention tremor via a lever arm of up to 20 cm.

The thermal damage zone when using micromanipulators introduces limited artifact into the histological assessment, and it coagulates small blood vessels and seals lymphatic channels thus minimizing the incidence of metastases [20]. The diameter of the laser beam, pulse duration and irradiance can be adjusted to produce different tissue effects. Spot sizes between 1 to 4 mm are used for tissue ablation and 0.2–1 mm used for cutting with powers varying anywhere from 2 to 10 W. Some micromanipulators further focus the beam down to an even smaller spot size, and combined with short pulse durations or flash scanner technology, can ablate tissue with minimal to no charring just as in skin resurfacing [41, 44]. Morbidity of using the CO_2 laser when appropriate is far less than cold surgery, and the cost effectiveness is much greater [45].

In certain cases where lesions extend out of the surgeon's visual field, the CO_2 laser can be delivered by a flexible hollow waveguide. However there are limitations with the use of the hollow waveguide due to its limited angulation, the diameter of the laser spot and the significant and variable loss of power during transmission [20]. Regardless, recent techniques using hollow fiber technology are evolving [46–50]. Additionally, the KTP(Nd:YAG) laser energy is similarly delivered through a fiber optic cable and various hand-pieces.

Cancer

Glottic Carcinoma

T1 and T2a carcinomas of the glottis are typically resected en bloc and clear margins of 1–3 mm are obtained. However with laser surgery, it is possible to maintain more narrow margins that allow for preservation of vocal function and reduction in post-operative edema.

Transoral Laser Microsurgery (TLM) has yielded good functional results and low rates of recurrence from multiple groups since the 1990s. Studies have shown that it is possible to preserve the larynx in over 92% of cases with a 5 year local control rate that ranges from 80% to 94% [51, 52]. Treatment of early glottic cancer with TLM has a distinct advantage over other procedures in that it maintains the availability of all treatment options for patients with local or secondary tumor recurrence including laser re-excision, radiation therapy or open partial laryngectomy [53, 54]. T2b and T3 carcinoma of the glottis typically involves the vocal cords with supraglottic or subglottic extension. The operative technique using lasers for these tumors involves subdividing the tumor into several pieces for removal. Resection of these tumors may involve the cricoid and thyroid cartilage, the arytenoids, the cricothyroid ligament and any involved laryngeal soft tissue.

The application of laser assisted endoscopic surgery via suspension laryngoscopy draws comparisons to Mohs surgery because resections are driven by frozen section histology. One of the greatest differences between endoscopic laryngeal surgery and cutaneous Mohs surgery lies in the fact that Mohs surgery aims to achieve the best cosmetic result as possible while attempting to remove as little tissue as possible without compromising the tumor resection. In laryngeal surgery, functionality remains essential post-operatively in laryngeal cancer patients. Laser assisted endoscopic laryngeal surgery has potential to allow surgeons to excise cancer piecemeal with frozen section guidance. Frozen section guidance of surgical resections in the larynx is difficult due to the complex geometry of the structures within the larynx, making this radically more complicated than Mohs surgery for cutaneous disease. It is important for the surgeon to carefully label the surfaces of the specimens and work closely with pathologists during surgery. Ambrosch's experience of 167 patients undergoing laser excision of T2b and T3 laryngeal tumors showed a 5-year rate of definitive local control to be 87%. The recurrence-free survival rate over 5 years was 62%. None of these patients required a tracheostomy after the primary resection [55].

Supraglottic Carcinoma

T1 and T2 carcinoma of the supraglottis is defined as tumor that has not infiltrated the pre-epiglottic fat, immobilized a vocal cord, or metastasized to a local lymph node. Vaughan first described carbon dioxide laser resection of supraglottic carcinoma. Since then, Steiner, Davis and Zeitels have used TLM for supraglottic resections [21, 56–58]. Laser excision of tumors in this area typically involve extensive dissection and removal of involved muscle, cartilage and even portions of the base of tongue and piriform sinuses in advanced cancer. Tracheostomy is unnecessary in most cases due to limited postoperative edema even after extensive laser dissection. However it should be considered in a procedure with high blood loss or elderly patients with decreased pulmonary function.

There are relatively few reports on laser resection of T1 and T2 cancers in the supraglottis. Ambrosch reports a series of 48 patients with supraglottic T1 and T2 carcinoma in which there was 100% and 89% local control rate for pT1 and pT2 tumors respectively at 5 years. The recurrence free survival rate over 5 years was 83%, and the overall 5-year survival rate was 76%. In patients who experienced a recurrence, none needed a laryngectomy as a secondary treatment [51]. T3 carcinoma of the supraglottis treated with laser excision is not a common practice. Hinni et al. described a series of 117 patients with T2 to T4 lesions treated with TLM [59]. Five-year Kaplan-Meier estimates were local control in 74%, locoregional control in 68%, disease free survival in 58%, and overall survival in 55%. At 2 years 92% had a functional larynx. This study concluded TLM with or without radiation is a valid treatment strategy for organ preservation.

Hypopharyngeal Carcinoma

Carcinoma located in the hypopharynx carries the worst prognosis of all upper aerodigestive tract tumors. Reasons for poor prognosis lie in the high rate of local recurrence and the increased likelihood of the presence of metastasis in cervical lymph nodes at diagnosis. Though advances have been made in diagnostic imaging, surgery, radiotherapy, and combined approaches, the mortality rate from these tumors does not reflect any improvement in survival. Though there are reports of use of TLM in excision of hypopharyngeal cancer, there are few that report any treatment results.

Steiner and Ambrosch describe a series of 129 patients with carcinoma of the piriform sinus treated with laser excision. The 5-year Kaplan-Meier survival rate was 71% for stages I and II and 47% for stages III and IV disease and the 5-year recurrence-free survival rates were 95% for stages I and II and 69% for stages III and IV [52].

Benign Lesions

Papillomas

Transoral laser microsurgery of laryngeal papillomas is done with the laser on a low power setting. This has been described by using CO_2, KTP, and pulse dye laser in both an operating room and in-office setting. This allows the surgeon to ablate the disease in a controlled manner that limits disruption of the normal surrounding tissue and ablates only the mucosa affected by the papillomas (Fig. 5.9). Small islands of healthy mucosa left between the ablated areas promote quicker re-epithelialization [19]. In cases where there is bilateral vocal cord or anterior commissure involvement, a conservative approach is advised. It is better to leave small papillomas behind than to have post-operative scarring and synechiae of the anterior commissure, also known as an anterior glottic web, which can lead to voice changes. Corticosteroid administration (3 mg/kg Prednisone) perioperatively assists decreasing edema after extubation, even if there has been extensive resection. Figure 5.10a, b show a before and after images of juvenile laryngeal papillomas. Alternatively, microdebriders have been increasingly used to debulk papillomas and are slowly replacing lasers as the method of choice for treating papillomas [60].

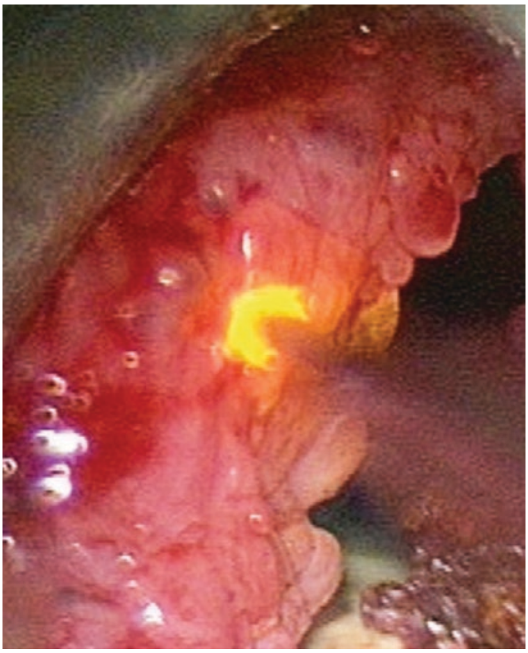

Fig. 5.9 Pulsed 532 nm KTP laser photoangiolysis and ablation of glottal papillomatosis (Photograph provided courtesy of Dr. Steven Zeitels)

Laryngomalacia

Anatomically, the cause of the problem in laryngomalacia is an inward collapse of the supraglottic mucosa during inspiration. If conservative measures fail, the surgical treatment for laryngomalacia is a supraglottoplasty. Bilateral laser incision of the aryepiglottic folds and the arytenoid cartilage region is the treatment if the cause of the stridor is from shortened aryepiglottic folds. If the stridor is caused by inward collapse of the epiglottis during inspiration an epiglottopexy is the surgery of choice. This will be described in more detail in a later section on laser use in the pediatric population.

Vocal Cord Paralysis

The most common laser-based procedure for vocal cord paralysis is unilateral microsurgical laser arytenoidectomy. In Steiner and Werner's experience, excision of the posterior portion of the vocal cords bilaterally with the microsurgical laser offers several benefits. Most of the vibrating parts of the vocal cords and arytenoids cartilage are preserved preventing aspiration while maintaining good voice quality [19].

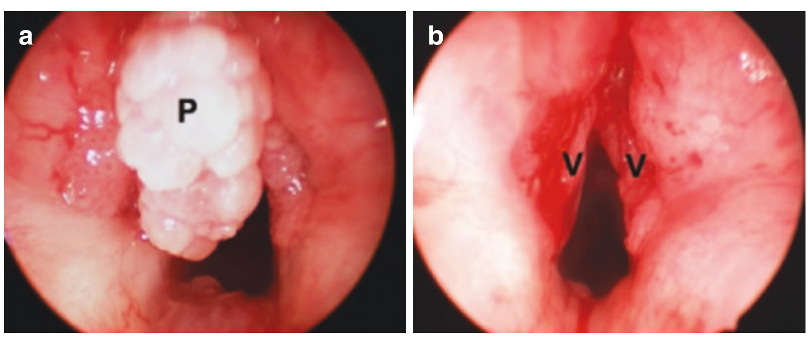

Fig. 5.10 Papilloma in the pediatric airway, before (**a**) and after (**b**) laser excision. P papilloma, V vocal cords (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

Hypopharyngeal Diverticula

To perform a Zenker's diverticulectomy, the patient is suspended in a similar fashion to that which was described previously. Treatment of Zenker's diverticulum consists of suspending the hypopharynx with a specialized "Weerda" endoscope, then taking down the "party wall" that exists between the herniated pocket and the upper portion of the esophagus [61]. Traditionally, this required a large cervical incision to excise the diverticulum and perform a myotomy of the cricopharyngeus muscle. The use of the CO_2 laser to take down the party wall endoscopically has been found to be comparable to traditional, open procedures in terms out outcomes [62, 63]. Laser myotomy is improved compared to the traditional approach in that it does not require a neck incision and requires significantly less operative time. Almost 90% of patients report normal swallowing function after undergoing the procedure.

Post-operative Management

Patients who are otherwise healthy and undergo a limited resection are routinely given a single dose of intravenous steroids, observed in the post-operative care unit and discharged on the same day. Patients who have multiple medical problems or have more extensive surgical excisions, and therefore have a higher possibility for airway compromise, are admitted overnight at minimum for airway observation and scheduled steroid dosing. Post-operative antibiotics are not routinely administered. Strict voice rest for the first 48 h is observed followed by modified voice rest (no screaming, no whispering, limited talking) for the next 1–2 weeks. Patients are then monitored in clinic with repeat flexible fiberoptic laryngoscopy exams. Any change in voice, difficulty breathing or weight loss is monitored closely and may necessitate repeated exams and procedures.

In general suspension laryngoscopy is safe for patients as long as the patient has gone through proper pre-operative evaluation by the otolaryngologist and anesthesiologist. There are several situations that preclude the use of suspension laryngoscopy that include anatomy such as a short, stiff neck, long or protruding maxillary teeth, displaced larynx and lesions or mass in the base of tongue [42]. Complications associated with TLM are more pertinent to the use of the laryngoscope instead of the actual laser itself. Difficult intubation or forceful endoscopic suspension can easily chip, loosen, or fracture teeth if the surgeon is not careful with the orientation of the laryngoscope in the oral cavity. In a study of 339 microlaryngoscopy patients, 75% were found to have small mucosal lesions of the oral cavity, oropharynx and lip [64]. Though the injuries were minor, they were a source of major concern for the patients postoperatively.

Other complications associated with laser microsurgery include lingual and hypoglossal nerve palsy. Prolonged displacement of the tongue can cause severe contusion and swelling that often leads to dysphagia and sometimes-permanent dysesthesia (sensory disturbance) in the tongue.

There are many general safety considerations involving the use of surgical lasers in surgery that were discussed earlier in this chapter. In particular to laryngeal surgery where high-powered lasers are used in small confined areas with flammable gas, the use of caution cannot be emphasized enough. Stray laser light is not a rare event and is capable of causing burns in unwanted areas. It is recommended practice to cover areas beyond the target site to protect from unwanted burns. Control of oxygen content, inhalation agents, and use of special laser endotracheal tubes in these procedures is important.

Though TLM rarely requires tracheotomy post operatively, it is nevertheless a real possibility in the intermediate and advanced cases. Surgeons must always be aware of certain indicators for tracheotomy. Prolonged compression of the tongue during TLM can cause lingual edema that can lead to airway compromise. Sudden secondary hemorrhage is a major risk in TLM and may necessitate a tracheotomy. Large arteries and vessels should not only be cauterized but clipped as well to avoid sudden secondary hemorrhage.

TLM typically causes the formation of large granulomas if cartilage is exposed by the surgical procedure. These granulomas are perpetuated by small osseocartilaginous sequestrae unless they are removed [22]. TLM involving the anterior commissure often results in a round anterior glottic effect, and this often leads to breathiness and hoarseness [65]. Laser surgery for benign lesions in the larynx is relatively safe compared to most other treatment modalities. It is a minimally invasive technique with almost no complications attributed to the laser itself.

Future directions of laser use in laryngology involves new devices for delivery, office based laser applications, the use of the laser for welding tissue and the creation of lasers that are even more precise than those which are currently available. An important recent technological advance (Omni Guide, Boston, MA) has provided surgeons the use of CO_2 lasers through a flexible fiber referred to as a "photonic band gap fiber." The fiber is placed in a handpiece coupled with a suction that eliminates the need for a micromanipulator and allows the surgeon to have the freedom of a laser cutting tool in his or her hand. The Omni Guide Beam Path has proven useful in the surgery of both benign and malignant lesions in cases where exposure is difficult [65].

Another new delivery device has recently been described by combining TORS with the CO_2 laser in resecting upper aerodigestive tract tumors. Studies to date have been proof-of-concept and no long term follow up data has been described [66, 67]. However, these reports have been encouraging. The flexible CO_2 laser provided fine incisions, excellent hemostasis, and minimal peripheral tissue injury. The exposure provided by TORS improved typical exposure and provided more range of motion than typical TLM. Further study must be performed to determine long-term outcomes and cost effectiveness of these powerful tools.

Awake office based laser surgery is gaining popularity in the treatment of benign laryngeal lesions because of the relative safety of lasers and the quick recovery period post procedure. Though the CO_2 laser has traditionally been the laser of choice for laryngeal surgery, different lasers have been reported to be useful in office-based surgery. In the office, new technologies such as distal chip endoscopy and rare-earth doped fiber lasers have allowed for creative and innovative surgical techniques. Typical diseases treated with these new techniques are dysplasias and papillomas. A 585 nm pulsed dye laser was originally the laser of choice for vascular lesions; however the 532 nm pulsed KTP laser has proven to be superior. The use of the Thulium laser (λ = 2013 nm) which mimics the CO_2 laser closely may become useful as an office based laser as well [68, 69]. Even though otolaryngologists are performing more office procedures that incorporate lasers, the breadth of procedures remains limited for important reasons such as airway compromise, which is poorly handled in the office setting.

Otology

Laser applications in otology include the treatment of vascular lesions in the external auditory canal (EAC), exostoses in the EAC, debulking of inoperable tumors, Eustachian tube dysfunction, myringotomy/tympanostomy in otitis media, graft fixation in tympanoplasty, stapedectomy/stapedotomy in otosclerosis, tympanosclerosis, removal of cholesteatoma, cochleostomy, labyrinthectomy in benign paroxysmal positional vertigo, endolymphatic hydrops and facial nerve decompression [70]. The use of the laser in middle ear surgery is one of the most elegant examples of laser technology use and applications. Perkins pioneered the use of the argon laser in middle ear surgery in the late-1970s performing the first laser stapedotomy for otosclerosis. Otosclerosis is a localized disorder of bone resorption and deposition (remodeling) in the middle and inner ear that causes progressive conductive hearing loss that typically begins in the third to fifth decade of life. This defect in bone remodeling in the vicinity the stapes footplate and oval window leads to reduced mobility of the stapes and conductive hearing loss. Mechanical causes of hearing loss can be corrected through surgery [71, 72]. Patients with otosclerosis benefited from the argon laser through its precise vaporization of the stapedial tendon, mobilizing the posterior crus of the stapes, and in stapes footplate fenestration [71, 73]. This is procedure is called a stapedectomy or stapedotomy, and is performed in order to recreate ossicular chain mobility and decrease conductive hearing loss. Knowledge of middle ear anatomy is critical in obtaining good post-operative results with minimal complications. Avoidance of injury to the facial nerve and the chorda tympani nerve is the standard of care [70, 72, 74–88].

DiBartolomeo described other uses of the argon laser in the field of otology. He utilized this laser in the tympanoplasty (repair of the tympanic membrane), stapedectomy, lysis of adhesions and myringotomy (placement of a hole in the tympanic membrane). He describes the "spot welding" technique of the laser that allows for the adherence of a fascial graft placed in substitution of the tympanic membrane onto the soft tissue annulus [85]. Delivery of a laser to the ear and temporal bone can be either via a fiber (KTP and argon) or via a micro-manipulator such as those used with CO_2 lasers [89].

Eustachian tube dysfunction is a common ear disorder in which patients may experience chronic recurrent ear infections or difficulty in clearing a blocked sensation of their middle ear. A laser myringotomy may be performed to equalize the pressures between the middle and outer ear, and to assist the ear in draining fluid [90–95]. Some studies have found improvement in postoperative outcomes such as length of temporary perforation and resolution of middle ear effusion [95]. However, it is considerably more expensive.

Laser Eustachian tuboplasty (LETP) is the practice of utilizing a diode or an argonlaser to vaporize select areas of hypertrophic mucosa and submucosa tissue along the length of the Eustachian tube. In a small number of studies with small patient numbers, it has been found that medical management combined with LETP on a select group of patients can be successful in eliminating chronic middle ear effusions [96–98].

A cholesteatoma is not a mass made of cholesterol as the name implies. Instead, it is a collection of keratinized epithelium that is located in an abnormal location at the external auditory canal, middle ear, petrous bone or mastoid. It is either congenital in etiology or is acquired due to repeated infection. It is not invasive, but it is destroys the bones of the middle ear leading to a conductive hearing loss. It can also erode the mastoid bone and tegmen that can possibly lead to a cerebral spinal fluid leak. Therefore, the cholesteatoma needs to be removed in its entirety to prevent progression and recurrence [99]. The use of a laser in this surgery may assist the surgeon in removing the mass in more difficult to reach areas of the middle ear and mastoid [100, 101]. This often requires improved visualization with endoscopy in addition to the use of laser energy directed by curved fiberoptic cables.

Contraindications to laser use for otologic applications include performing a stapedectomy in the presence of active otitis media or in an only-hearing ear that responds well to amplification. Additionally, the presence of vertigo and endolymphatic hydrops, certain inner ear malformations or an overhanging facial nerve that completely obstructs access to the oval window niche are contraindications as well. Laser stapedectomy in patients with a perforated tympanic membrane must be postponed until the perforation is fixed. In this case of an overlying facial nerve, preservation of the facial nerve is most important, and conventional instruments are used to perform the operation rather than the laser to minimize the risk of injury.

Pre-operative Management and Laser Selection

Pre-operative management of patients undergoing laser-assisted otologic surgery includes a full history and physical, an audiogram and usually a non-contrast computer tomography (CT) imaging of the temporal bone and internal auditory canal. When choosing a laser to use near a neurosensory organ like the ear, it is important to consider the potential collateral damage. The thermal and photoacoustic effects in laser use are a function of dosimetry and tissue optical and thermal properties. Bone has substantially smaller water content than skin or other soft tissues and visible wavelengths are not well absorbed. In the absence of any distinct chromophore, using an argon or a KTP(Nd:YAG) laser to ablate bone requires an initiator. An initiator absorbs laser light and undergoes pyrolysis. In middle ear surgery, a small droplet of blood or charred tissue placed on the laser target to serve this purpose. Accordingly, there is a risk of thermal injury, as considerable temperature elevations occur within this region, and ablation occurs with at best modest thermal confinement [87].

In contrast, infrared wavelengths are well absorbed by both the hydroxyapatite crystals in bone and the interwoven collagen fibers. Ablation proceeds by the classical mechanisms, though photoacoustic transients may be generated leading to audible pops. These mechanical transients may propagate through the inner ear and may result in injury to the delicate neuroepithelium. In general, shorter laser pulse durations lead to less thermal injury provided the conditions for thermal confinement are met [102, 103]. However, repeated pulses in rapid succession may lead to the build up of heat in the target site; hence successive pulses should be separated by a sufficient amount of time to allow for complete thermal relaxation. Short pulse laser systems (e.g., Erbium:YAG) generate an acoustic pressure wave that lead to a vibration of the ossicular chain that may result in “noise trauma”. The heat generated by the laser may also cause “convection currents” that also lead to vibratory stimulations. Both of these stimulations that can lead to acoustic injury and should be controlled by appropriate dosimetry selection. Regardless, the mechanical transients produced during laser ablation are comparable or even less harmful than the vibratory effects produced using conventional methods to perform surgery [7, 70, 87, 104, 105].

Description of Technique

In addition to the argon, CO_2, and KTP laser, more recently the erbium-YAG laser has been used to perform stapedectomy or stapedotomy in patients with otosclerosis. In the stapedectomy and stapedotomy, the stapedial tendon is vaporized with the laser, then the incudostapedial joint is disarticulated using mechanical instrumentation, and the posterior crus is severed with the laser (Fig. 5.11a, b). The anterior crus of the stapes is then fractured manually and the stapes superstructure is removed. The laser is then used to place a single large hole or a set of smaller holes generating a “rosette” type pattern in the stapes footplate to accommodate the prosthesis (Fig. 5.11c). A mobile prosthesis is put into place [70, 72, 75–88]. Despite multiple recent attempts, no study to date has demonstrated which laser among the three most commonly used in stapes surgery (argon, KTP and CO_2) is best [106–108]. Recently, erbium:YAG lasers have been developed for use in performing this operation, however the high cost of these lasers has limited broad adoption [8, 76, 109]. The success of laser stapes surgery is based on audiometric analysis (hearing tests) and complication rates.

Smaller cholesteatomas and residual tissue in previously attempted excisions of cholesteatoma have been vaporized with the CO_2, Argon, and KTP lasers with some reports of lower recurrence rates [70]. Laser use is particularly beneficial when removing cholesteatoma from the delicate bones of the middle ear such as the stapes or in removing disease that traverses the obturator foramen of the stapes. When using the laser in this application, its energy is absorbed more by the cholesteatoma than by the bony surroundings [100, 101]. Endoscopic cholesteatoma surgery can be helpful in obliterating cholesteatoma from hard-to-visualize locations such as the sinus tympani [110]. The laser can also be directed towards these locations using a curved, adjustable laser fiber.

Use of the laser in myringotomy and tympanoplasty is currently a boutique interest in otolaryngology, primarily due to cost. Myringotomy is performed by using an Argon, CO_2, or KTP laser directed by a fiber delivery system to create an incision in a patient’s eardrum. It most often performed in patients with chronic otitis media with effusion. Use of the laser instead of a myringotomy knife has shown to be beneficial by preventing the necessity of tympanostomy tube placement; however laser myringotomy without tube placement only creates a temporary

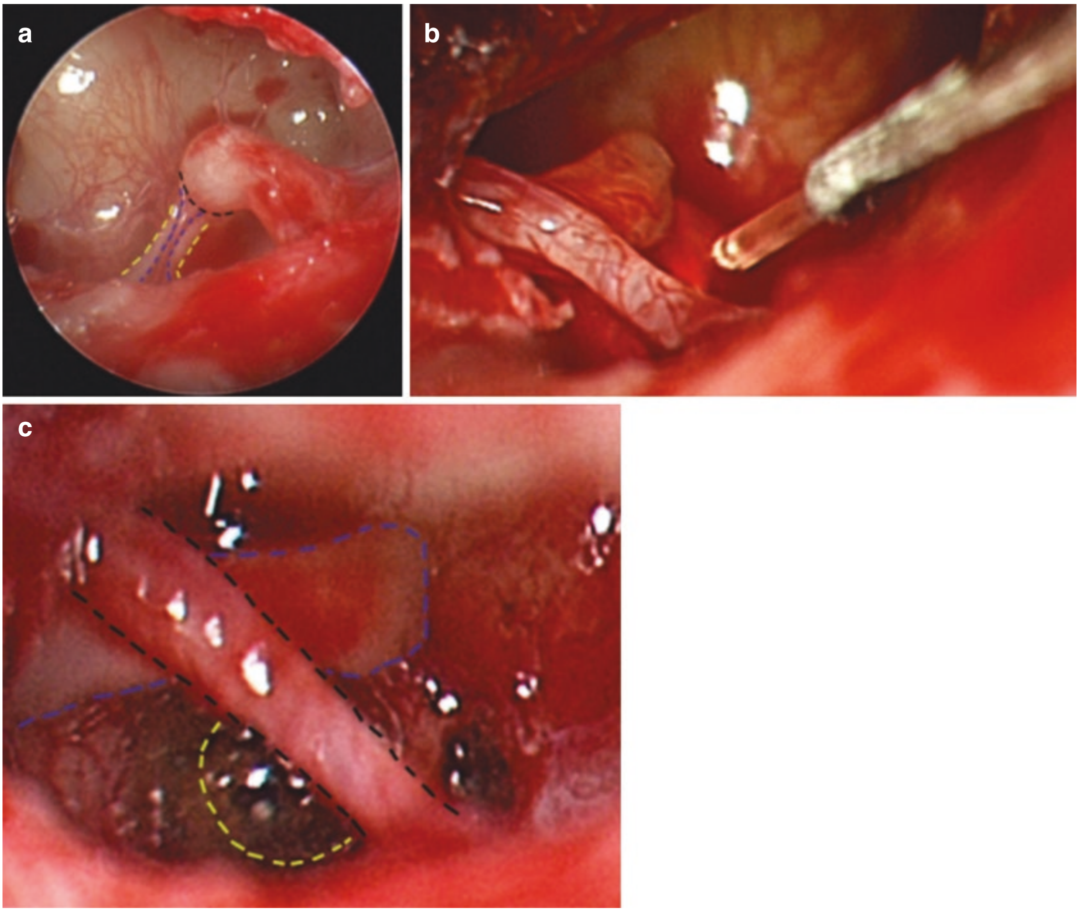

Fig. 5.11 (**a**) In stapedectomy, the stapes tendon (blue dashed line) is vaporized with the laser and the incudostapedial joint (black dashed line) is disarticulated. The posterior crus (yellow dashed line) is then severed with the laser. (Photograph provided courtesy of Dr. Hamid Djalilian). (**b**) Intraoperative image of an argon laser directed at the posterior crus of the stapes after having displaced the chorda tympani nerve from the line of fire. (Photograph provided courtesy of Dr. Hamid Djalilian) (**c**) Intraoperative image of the oval window after laser stapedectomy. Notice the charred appearance of where the stapes was located (yellow dashed line). Also note the preservation of the chorda tympani nerve (black dashed line). The long process of the incus (blue dashed line) is still intact above and will be used to anchor the stapes prosthesis (Photograph provided courtesy of Dr. Hamid Djalilian)

perforation in the tympanic membrane that lasts <6 weeks. As with traditional myringotomy, patients with recurrent or persistent episodes of otitis media with effusion may need tube placement at a later date. Office-based laser assisted tympanic membrane fenestration with a handheld otoscope combined with the CO_2 flashscanner laser, OtoLAM (ESC/Sharplan, Yokneam, Israel) and placement of a pressure equalization tube under local anesthesia has been described as well. Outcomes have shown improvement in hearing and reduced incidence of tube plugging, however this was performed in a non-randomized population [84–94, 111]. Again, these systems are very expensive, and the procedure has not been widely adopted.

Tympanoplasty is the repairing of a defect in the eardrum by placing fascia or perichondrium over the defect. In this application, the KTP laser can be used to weld the collagen fibers together along their edges [100, 101, 112–114]. While promising, neither laser application of myringotomy nor tympanoplasty been widely adopted due to the extensive cost of the system.

CO_2 laser use in acoustic neuroma surgery has shown to be advantageous due to its precision in cutting and coagulating around the facial and vestibular nerves [115]. The use of KTP and Argon lasers for acoustic neuroma excisions have also been noted, but are not widely used [116, 117]. Laser use is limited by the size of the tumor, approach to the lesion, and the surgeon's experience. For smaller tumors (2–3 cm), stereotactic radiation is beneficial in preventing further growth of the mass and preserving facial nerve function and hearing [70].

Laser use in endolymphatic hydrops [118] and labyrinthectomy for benign paroxysmal positional vertigo (BPPV) have been described, but have not been adopted due to their potentially high rate of hearing loss compared to traditional surgery [119–121]. Laser use in the decompression of the facial nerve has also been successfully performed [122].

Post-operative Management

The majority of patients are sent home on the same day of surgery. They are told to keep their ear canal and surgical site water free. Packing is frequently left in the external auditory canal for up to 2 weeks for removal by the surgeon at a postoperative visit. A repeat audiogram is performed at approximately 6 weeks post-operatively. Patients who undergo cholesteatoma surgery are followed approximately every 4–6 months or more frequently to monitor for recurrence and to adequately maintain the cleanliness of the mastoid bowl. Depending on the surgical approach, a second surgical procedure may be indicated to evaluate for recurrence at 6–12 months postoperatively. Patients with decompression of the facial nerve may need post-operative steroids.

Side Effects/Complications

Complications of laser use in otology occur at a rate that is equal to or less than conventional surgical techniques. Noted complications include temporary or permanent hearing loss, intra-operative or post-operative vertigo, cerebrospinal fluid fistula, tinnitus, prosthesis displacement, incus necrosis, fibrosis, postoperative granuloma formation, tympanic membrane fistula facial nerve injury and chorda tympani injury (dysguesia). Accidental fracturing of the stapedial footplate may also occur [75, 123]. As described above, photoacoustic or thermal injury to adjacent structures may occur. The addition of lasers in otologic surgery has been shown to reduce complication rates, but the evidence in comparing various lasers for a specific procedure use is limited.

Prevention and Treatment of Side Effects/Complications

Facial nerve monitoring is the electromyographic monitoring of facial muscles intraoperatively that is proven to be cost effective and reduce the incidence of iatrogenic facial nerve injury during surgery. It is the standard of care in any otologic procedure that is in the vicinity of the facial nerve [124]. Facial nerve monitoring also detects facial nerve injury due to the heat generated by carbon dioxide lasers thereby preventing injury [125].

Future Directions

Future directions include the adoption of all of the above techniques in routine otologic operative procedures. Laser use in acoustic neuroma surgery, tympanoplasty and myringotomy and the use of the laser Doppler vibrometry are all techniques that are emerging as methods that may become standard. Other otologic applications that are being explored include Eustachian tuboplasty for chronic otitis media and Eustachian tube dysfunction and benign paroxysmal positional vertigo [98, 121, 126].

Oral Cavity and Oropharyngeal Pathology

The carbon dioxide laser is utilized for transoral resection of T1 and limited T2 squamous cell carcinoma (SCCA) of the oral cavity and tongue. Its advantages in the oral cavity are due to its ability to simultaneous cut tissue and coagulate small blood vessels [127–134]. Oral cavity cancer has an overall poor prognosis with a high tendency to recur at the primary site and metastasize to the locoregional lymph nodes. However it has been shown recently to be an effective tool in the treatment of T1 and T2 oral cavity squamous cell carcinoma [135]. The CO_2 laser is also used to remove certain benign lesions such as persistent or suspicious leucoplakia in high-risk individuals and papillomatous lesions [136, 137].

Uvulopalatopharyngoplasty (UPPP) is a procedure that involves the reduction and removal of soft tissue in the oropharynx, such as the soft palate and the uvula, in the hopes of treating snoring and obstructive sleep apnea (OSA). If necessary, a tonsillectomy is performed as well. In the past two decades, laser assisted uvulopalatopharyngoplasty (LAUP) with a carbon dioxide laser emerged as an alternative to traditional methods of reshaping the soft palate and uvula and removing this redundant soft tissue in order to treat snoring. However, it is contraindicated in obstructive sleep apnea, and its efficacy has not been fully proven [138–145]. Laser midline glossectomy has also been attempted to treat obstructive sleep apnea in patients who failed traditional UPPP [146].

Zenker's diverticulum is a progressive herniation of mucosa and submucosa through the posterior wall of the esophagus at the junction of pharynx. Patients most commonly complain of dysphagia and the regurgitation of undigested food. Endoscopic laser excision of the wall that exists between the herniated pocket and the upper portion of the esophagus is becoming a more common procedure in otolaryngology instead of the traditional open approach via the lateral neck.

Finally, the recent development of sialendoscopy has lead to the treatment of recurrent sialoadenitis caused by sialolithiasis with the Ho:YAG laser. Preliminary studies have shown improvement in symptoms following sialendoscopy with removal of sialoliths [147–149]. Results thus far do not show a difference in outcomes depending on the salivary gland affected. In the case of large sialolithiases, laser lithotripsy is necessary to remove the sialolith. Laser lithotripsy with the Thalmium:YAG laser has also been described [150].

Pre-operative Management

Pre-operative management of squamous cell carcinoma of the oral cavity includes imaging studies of the head and neck and flexible fiberoptic laryngoscopy in the office to determine the extent of the lesion and assist in planning the surgical approach. Prior to starting the excision, the patient undergoes a direct laryngoscopy, esophagoscopy and bronchoscopy to rule out synchronous primaries and to stage the neoplasm.

To determine whether a patient has sleep apnea or simply bothersome snoring prior to an LAUP, he or she may undergo a polysomnogram. This may determine if it is more appropriate to perform an LAUP, radiofrequency ablation of the posterior tongue, a traditional UPPP, or one of many other sleep procedures.

A swallowing study is frequently performed prior to a Zenker's diverticulectomy to diagnose the condition. Before the procedure, the oral cavity, hypopharynx and supraglottis are examined thoroughly to rule out any other causes of dysphagia.

Preoperative noncontrast CT scan in patients with recurrent sialoadenitis can evaluate for sialolithiasis. Typically stones >4 mm would indicate the potential need to use the Ho:YAG laser intraoperatively [114].

Description of Technique

For safety and access when using a laser in the oral cavity, patients commonly undergo a nasotracheal intubation for enhanced surgical access and exposure. The mouth is retracted open by placing a bite block between the teeth or a Dingman mouth gag. The laser can be controlled by a micromanipulator while the operating field is visualized through an operating microscope or alternatively a hand-held fiberoptic hand piece can be utilized like a scalpel.

T1 and limited T2 oral cavity carcinoma is excised utilizing a carbon dioxide laser with margins acquired and sent for intra-operative frozen section to confirm the complete excision of neoplasm. Depending on the presence of neck disease as well as the size, location, and depth of invasion of the mass, patients may undergo a unilateral or bilateral neck dissection. Two to five-year follow-up for local control of stage I and II oral cavity carcinoma has been reported to range from 60% to 100% [128, 130, 151–154]. Local control rates for stage III and IV oropharyngeal carcinoma treated with laser excision and post-operative radiotherapy is reported to be around 50%. This is reduced to 34% for stage III and IV carcinomas located in the floor of the mouth [127]. Disease-free survival at 5 years for previously untreated T1 and T2 oral tumors is reported to range from 80% to 88%. Patients who have undergone selective neck dissections or post-operative radiation therapy and who have stage III or IV disease tend to have lower survival rates [130].

Patients who have disease located in the tonsil or tongue base have a worse prognosis than those who have more anteriorly based carcinoma of the oral cavity regardless of the technology utilized in its resection. This is attributed to the fact that posteriorly-based oral cavity SCCA is more difficult to detect and is therefore discovered later in the course of the disease at more advanced stages. Resection of tongue carcinomas by CO_2 laser oftentimes allows for the wound to be closed by primarily or it is left to heal by secondary intention without flaps or reconstruction. This can result in less postoperative scarring and tethering of the tongue than traditional surgical methods thereby allowing for more tongue mobility [155–157].

Laser assisted uvulopalatopharyngoplasty has been demonstrated to treat patients with snoring. As described above, LAUP) reshapes the soft palate and uvula, removing redundant soft tissue that may lead to snoring. When comparing thermal damage to the soft palate by the CO_2 and Nd:YAG lasers, Laranne did not find any appreciable differences [142]. The use of both the CO_2 and Nd: YAG lasers to treat snoring have been supplanted by office-based radiofrequency (RF) ablation of the palate and base of tongue. While RF ablation may not significantly benefit OSA and repeat treatment may be necessary, patients have experienced success in the reduction of snoring with RF ablation of the soft palate, tongue, uvula and inferior turbinates with less associated morbidity from the procedure [158–160].

Oral exposure in sialendoscopy is ideally performed with both a cheek retractor as well as a bite block. Technique is slightly different depending on if submandibular or parotid sialendoscopy is performed, but the overall concepts are the same. First dilation of the papilla is achieved using lacrimal probes. Once the duct is catheterized with a guide wire, further dilations using the Seldinger technique are performed until the introducer can be catheterized. This introducer stays in place throughout the procedure [161, 162]. The endoscope is then guided through the introducer to diagnose the obstruction, which is typically stenosis versus sialolith. There is a working port that can feed baskets and wires into the duct to capture and remove sialoliths. Alternatively, medicines such as kennalog can be introduced through the working port to decrease postoperative inflammation. When sialoliths are too big to be removed with a wire basket, lasers are utilized to first break up the stone into smaller components that can be removed. It is important not to force a stone that is impacted, as it may result in the avulsion of the duct or breakage of the basket. This procedure is still in its infancy and limited in patient numbers. Long-term follow up with large patient populations has not yet been described.

Post-operative Management

Patients with extensive resections of SCCA in the oral cavity or those who have SCCA involving the base of tongue are typically kept in an intensive care unit setting overnight for airway monitoring. Occasionally, if swelling is severe, the patient remains intubated and is administered steroids until the edema subsides. Rarely, a tracheotomy is necessary if the patient cannot be intubated or if the airway obstruction is anticipated to be long-term. Any patient with surgery performed in the oral cavity is placed on a liquid diet post-operatively and slowly advanced to a soft diet on which he or she remains for at least

2 weeks. The oral mucosa heals quickly, and patients are encouraged to drink as much fluids as they can handle to decrease xerostomia, infection and post-operative pain.

Patients who have undergone a Zenker's diverticulectomy are sometimes placed on a full liquid diet for at least 2 weeks or the decision is made to feed the patient by tube feeding exclusively until a negative gastrograffin swallow study is obtained. These patients are watched closely for symptoms that may indicate a dehiscence of the operative site and mediastinitis including chest pain, shortness of breath or the return of dysphagia.

Postoperative care following sialendoscopy is minimal. The decision to put the patient on post-operative antibiotics is made on an individual basis. The patient is encouraged to maintain strict oral hygiene.

Side Effects/Complications

Complication rates are significantly higher (90%) in patient with oral SCCA who have been previously irradiated than those who have not had radiation treatments (10%) [163]. Complications reported in patients who have received radiation therapy include uncontrolled pain, bleeding, infection, delayed healing and edema [164]. As discussed above, patients may have post-operative edema of the tongue and oral cavity soft tissue leading to airway obstruction. When obstruction is severe enough, intubation or a temporary tracheostomy may be warranted.

Post-operative bleeding in any oral cavity laser procedure is rare, but may be insidious in onset and potentially life threatening. If suspected, the patient must be carefully examined, and if found, the patient must be brought back to the operating room to control the bleeding.

Complications of both open and endoscopic Zenker's diverticulectomy include post-operative fever with or without mediastinitis, esophageal injury and need for re-operation. Generally, the use of the laser is less morbid than the open procedure [62, 165, 166]. Temporary edema of the affected gland is an expected postoperative outcome. Infection of the affected gland is the most common potential side effect of sialendoscopy. Ductal perforations are possible and are typically treated with a salivary stent for 2 weeks. In addition, a rare but significant complication is the fixation of the wire basket within the duct and inability to remove it from the gland. If this is to happen, the case has to be converted to an open procedure with open exploration and possible excision of the gland in order to free the foreign body from the gland [167].

Prevention and Treatment of Side Effects/Complications

Complications of oral cancer excisions can be minimized by obtaining good visualization of the surgical field and by obtaining adequate hemostasis intraoperatively. Encouraging fluid intake by mouth is important in preventing post-operative pain and dehydration. Airway obstruction may be minimized with post-operative steroids, however the primary concern is in preventing an emergent situation. This is averted by thorough preparation and close monitoring of the patient in the immediate postoperative period.

Currently, the use of the laser in head and neck SCCA is limited by the size, location and stage of the disease. Future therapeutics that may lead to the improved treatment of advanced head and neck cancer include interstitial laser therapy (ILT) with the Nd:YAG laser. Laser use in the involved tissues leads to an increase in thermal energy at the site. This is currently only used palliatively [168]. Chemotherapeutic agents, such as cisplatin are activated by this thermal energy and create a more precise and minimally invasive technique to ablate higher-staged or unresectable neoplasms [169, 170]. This has been shown to be effective in mouse models and in one case report. Further study is necessary to determine the role in cancer treatment.

Photodynamic therapy (PDT) has been proposed as a potential adjuvant treatment of head and neck cancers and pre-cancerous lesions [171, 172]. PDT takes advantage of energy that has been created by the absorption of laser light in that it can induce specifically directed photochemical changes in tissue. Photosensitizers are administered to a patient, accumulate in targeted tissues and undergo light-induced chemical reactions that may lead to selective tissue necrosis and cell death. To date, in the field of otolaryngology, photodynamic therapy has been attempted in patients with soft palate squamous cell carcinoma, recurrent nasopharyngeal carcinoma, early laryngeal malignancies, and laryngeal papillomatosis. Dosing and distribution of the photosensitizer has been difficult to track and quantify. Additionally, patients may experience symptoms of overstimulation such as anaphylaxis if exposed to daylight or neon light during treatment. However, the pilot studies show potentially promising results [173–180].

Rhinology

The area in which lasers are most commonly and successfully used in nasal surgery are in patients who have persistent recurrent epistaxis due to intranasal hereditary hemorrhagic telangiectasias (HHT). HHT is an autosomal dominant condition of the vascular tissue that presents in a person at the ages of 20–40. Friable angiodysplastic lesions that bleed easily and are millimeters in size can present anywhere, but often are located on the mucosa of the nasal cavity, tongue, lips and cheeks. Patients frequently present with epistaxis as the first sign of the disease [181].

Other areas of rhinology that are utilizing lasers, albeit in a limited fashion, include functional endoscopic sinus surgery (FESS), rhinophyma reduction, inferior nasal turbinate reduction, choanal atresia and laser cartilage reshaping. Choanal atresia can be either bilateral or unilateral. Bilateral conditions are typically addressed within the first few days of life because the neonate, who is an obligate nasal breather, is unable to breath unless actively crying, which forces the neonate to breathe through the mouth. This obstruction can potentially be remedied with laser ablation [182–184].

Hypertrophic inferior nasal turbinates can cause uncomfortable nasal congestion, a closed nasal airway and obligate oral breathing that can lead to obstructive sleep apnea and snoring. Along with LAUP described above, some patients may also undergo laser reduction of the inferior turbinates with a KTP, Nd:YAG or Ho:YAG laser [185–190].

Contraindications of laser use in nasal surgery include refractory nasal epistaxis and large sinonasal tumors. Concurrent treatment of bilateral lesions is contraindicated as it may lead to necrosis of the septum and the creation of a septal perforation.

Pre-operative Management

Patients with chronic recurrent epistaxis undergo a thorough work-up for coagulopathic disease prior to surgery. A full history and physical are performed which includes looking for cutaneous and intra-oral telangiectasias that may need to be addressed. Nasal endoscopy is performed to evaluate for the presence of tumor. Prior to undergoing FESS, patients obtain a computerized tomography (CT) scan of the paranasal sinuses to determine the extent of the disease and for anatomic surgical planning.

Description of Technique

In HHT, the argon, KTP(Nd:YAG), and more recently diode lasers can be used to photocoagulate these telangiectasias. Low power settings are used for each laser wavelength so that irradiation creates blanching and coagulation of the lesion. While patients often report improvement after one treatment, recurrent treatments are often necessary and more often the rule rather than the exception. Figure 5.12 illustrates the use of a KTP(Nd:YAG) laser and side-firing fiber aimed at a telangectasia on the anterior nasal septum [191–196].

Lasers can also be used in recurrent epistaxis due to other causes. The most frequent site of epistaxis in patients without HHT is Kiesselbach's plexus, located on the anterior septum. This area can be cauterized using laser energy, however is

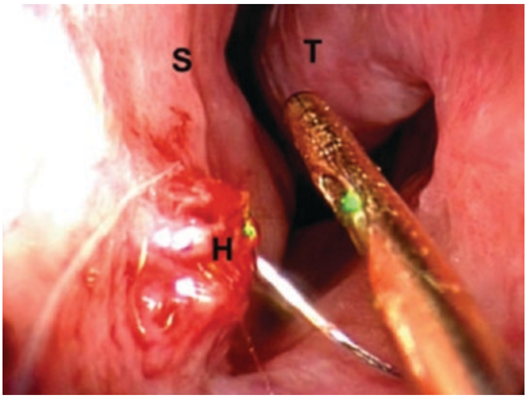

Fig. 5.12 Laser vaporization and hemostasis of a Hereditary Hemorrhagic Telangiectasia (H) along the septum (S). The inferior turbinate (T) can be seen along the lateral wall of the nasal cavity (Photograph provided courtesy of Dr. Brian Wong)

much more expensive than traditional cautery techniques.

Functional endoscopic sinus surgery is a procedure that is performed most commonly in patients with chronic sinusitis or nasal polyposis. Caution must be observed when working within the paranasal sinuses because of the close proximity to the globe, optic nerve, carotid arteries and skull base. Newer fiber optic based laser delivery systems have expanded the ability to use lasers in the sinonasal cavities [197].

When compared to cold or hot steel techniques in rhinophyma reduction, laser use leads to less intraoperative and postoperative bleeding, easier procedures and less discomfort [198, 199].

Unilateral choanal atresia is often treated anywhere from several weeks after birth up to age 12. After the atretic area is opened, a nasal stent is placed and left in for weeks to months. The KTP(Nd:YAG) and the Ho:YAG lasers have been used to treat this condition. While the CO_2 laser was the first to be described, it has fallen out of favor for this application due to the challenge of inserting a relatively large handpiece into the posterior nasal cavity. Reports have found lasers to be beneficial in the treatment of choanal atresia due to the decreased rates of re-obstruction and diminished risk of complications associated with the procedure [182–184].

Side Effects/Complications

A possible complication of laser treatment of hereditary hemorrhagic telangiectasias is the creation of a nasal septal perforation. To avoid this, laser irradiation is not targeted on adjacent septal surfaces in the left and right nasal cavity simultaneously, and treatment may be broken up into multiple separate operations. In any intranasal procedure in which a laser is used, stenosis due to scarring or synechiae may occur, this can be prevented by conservative use of the laser when treating adjacent septal and lateral nasal wall lesions. Laser use in surgery involving the septum has thus far been limited due to the potential risk of septal perforation. Ablative procedures have been performed and work well for septal spurs and other obstructive deformities [200].

Future Directions

Recently, laser cartilage reshaping (LCR) has been developed as a non-ablative way to reshape nasal septal deformities. The benefits of laser use in reshaping the cartilage of the ear in otoplasty has also been explored [201]. LCR involves the use of photo-thermal heating both the septal mucosal and cartilage without the need for incisions. In laser cartilage reshaping, specimens are held in mechanical deformation and then heated using laser radiation. Heat generation accelerates the process of mechanical stress relaxation, which allows tissue to remain in stable new shapes and geometries. Although the mechanisms underlying laser cartilage reshaping have not been completely identified, numerous animal studies have investigated the various biophysical mechanisms underlying shape change, and this method is showing great promise in the field of otolaryngology [202, 203].

Pediatric Otolaryngology

As discussed previously, choanal atresia is a condition present in neonates that can be treated by using a laser directed toward the imperforate area.

The treatment of juvenile onset recurrent respiratory papillomatosis with a CO_2 laser has also been described in a previous section [204]. Other conditions that are present in the neonate and pediatric populations that may be treated with a laser include laryngomalacia, vallecular cysts, subglottic stenosis and subglottic hemangioma.

Laryngomalacia most often presents in the neonate as "noisy breathing". The classification falls under three types. Type I is the most common and least serious. It is characterized by the intermittent prolapse of redundant supraglottic mucosa. Type II laryngomalacia is defined by shortened aryepiglottic folds, and type III is identified by a posteriorly displaced epiglottis. Types I and II can be treated with a CO_2 laser as previously discussed.

Congenital subglottic stenosis is the membranous or cartilaginous narrowing of the larynx at the cricoid area without previous intubation or trauma and may present with biphasic stridor, dyspnea, recurrent croup or other airway difficulties during the first few months of life. In Fig. 5.13a, the airway obstruction produced by the stenotic airway segment (subglottis) is readily apparent. The CO_2 laser was used to excise portions of this obstructive lesion to improve airway patency (Fig. 5.13b) [205–208]. The use of the carbon dioxide laser to treat congenital subglottic stenosis is mostly historical due the possibility of restenosis at the initial site or at a more distal site. More recently, KTP(Nd:YAG) laser has been shown to be helpful in conjunction with open laryngotracheal reconstruction in these patients to ablate portions of thickened cricoid cartilage [209]. Vallecular cysts may also present with noisy breathing and airway obstruction. Their etiology is unknown. Laser excision of vallecular cysts (Fig. 5.14a) is routinely practiced with a high success rate. Typically, a CO_2 laser is used to cut the margins of the cyst, facilitating either removal or marsupialization (Fig. 5.14b).

Subglottic hemangioma presents in a similar fashion to subglottic stenosis with stridor, hoarseness, cough, failure to thrive secondary to dysphagia and cyanosis. Cutaneous hemangiomas are present in 50% of patients with subglottic disease, and therefore suspicion should be high in any

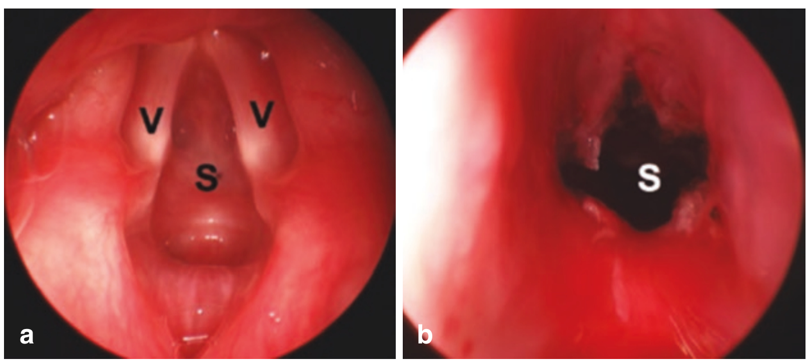

Fig. 5.13 Subglottic stenosis (S) in a pediatric patient before (**a**) and after laser excision from a subglottic view (**b**). V vocal cords (Photograph provided courtesy of Dr. Gupreet S. Ahuja

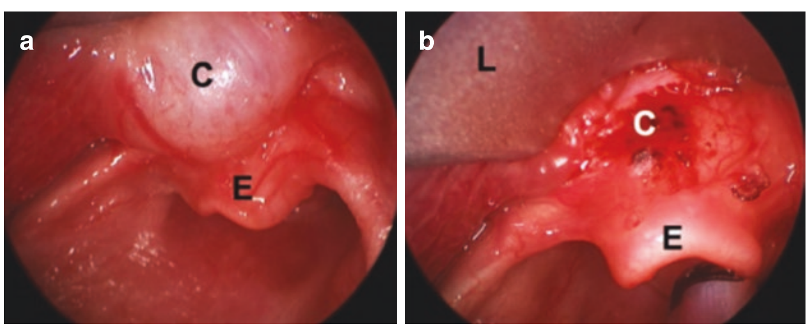

Fig. 5.14 Vallecular cyst (C) in a pediatric patient before (**a**) and after (**b**) laser excision. E epiglottis, L Blade of laryngoscope (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

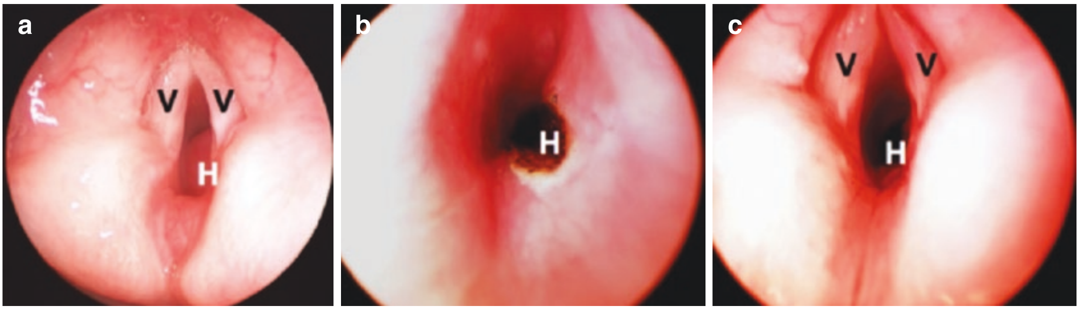

Fig. 5.15 Subglottic Hemangioma (H) in a pediatric patient before (**a**), after laser excision from a subglottic view (**b**) and after laser excision from a supraglottic view (**c**). Note how the airway has increased patency and that the lesion was not circumferential. V vocal cords (Photograph provided courtesy of Dr. Gupreet S. Ahuja)

patient with these symptoms and a history of a cutaneous lesion. Subglottic hemangiomas enlarge rapidly as they undergo proliferation, and appear a smooth, spherical, and often blue hued masses on the subglottic wall (Fig. 5.15a). They present twice as often in girls compared to boys and are typically diagnosed in the first few months of life. While they do spontaneously involute, subglottic hemangiomas have a potential for airway obstruction. To prevent airway compromise, aggressive treatment is warranted, and the laser plays an integral role in this. Tracheostomy may still be required in the short term.

Both laser myringotomy and cholesteatoma excision has been described in previous sections. Laser myringotomy with or without placement of pressure equalization tubes under local anesthesia will reduce the risk of general anesthesia that is typically employed in this procedure. Laser use in creating a myringotomy may also decrease the incidence of tube plugging, persistent bleeding and other complications associated with this procedure. However, these observations have yet to be demonstrated in a large randomized prospective study. Cholesteatoma excision may be assisted routinely by the use of lasers and endoscopy in the areas that are anatomically difficult to access.

Pre-operative Management

Laryngomalacia in a neonate is most often diagnosed using flexible fiberoptic laryngoscopy. Some neonatess might require nasogastric tube feedings due to the risk of aspiration that is associated with this condition. Severe laryngomalacia may necessitate intubatation while awaiting surgery due to frequent oxygen desaturations. Patients may also be placed on peri-operative H2 blockers or proton pump inhibitors for treatment of gastroesophageal reflux disease, a frequent co-morbid condition that can exacerbate symptomatology. Techniques In type I laryngomalacia, the CO_2 laser is used to perform a supraglottoplasty and excise or reduce the aryepiglottic folds. Type II laryngomalacia may be treated by using the CO_2 laser to divide the aryepiglottic folds [207, 210, 211]. The CO_2, Nd:YAG and KTP(Nd:YAG) lasers have been suggested as possible methods to remove hemangiomas in the subglottis (Fig. 5.15a) due to their ability to excise and coagulate these vascular lesions. The KTP(Nd:YAG) laser is favored in this application because it is more easily delivered to the area via flexible fiberoptics and is readily absorbed by hemoglobin. Figure 5.15b is an image of the subglottic region after laser treatment of a hemangioma. Figure 5.15c is a panoramic image of the larynx showing both the supra and subglottic airway after the hemangioma was removed. Most treatment methods produce some degree of subglottic stenosis. However, the stenosis grade typically does not require tracheostomy [206–208, 212–214].

Post-operative Management

All pediatric patients who undergo laser surgery of the airway are sent to the pediatric or neonatal intensive care unit post-operatively for airway observation. Whereas patients who undergo subglottic hemangioma excision via an open approach will receive a tracheostomy, those in whom a laser is used for ablation often do not. Steroids are given to reduce the formation of edema in the airway mucosa. Frequent serial examination with flexible fiberoptic laryngoscopy is performed to monitor for supraglottic edema, stenosis and hemangioma recurrence.

Side Effects/Complications

Possible adverse events that may occur when treating both laryngomalacia and subglottic hemangiomas include tracheal stenosis, granuloma formation and airway compromise. All of these events may lead to intubation of the patient post-operatively and in extreme circumstances, tracheostomy is necessary. Other complications include aspiration, pneumonia, subcutaneous emphysema, bleeding that may require re-exploration and mediastinitis. Additionally, subglottic hemangiomas or stenosis may recur post-operatively. In the immediate post-operative period, patients may experience dysphagia leading to malnutrition and require a feeding tube for supplementary alimentation.

Prevention of Side Effects/ Complications

Tracheal stenosis may be prevented by performing excision of subglottic lesions in a quadrant approach thereby minimizing the chance of circumferential scar formation. An airway emergency is prevented by preparation and monitoring in an ICU setting post-operatively. To prevent aspiration and malnutrition, a prophylactic nasogastric feeding tube is placed intra-operatively and left in until the patient demonstrates safe and adequate consumption of food and drink.

Conclusion

Laser applications in otolaryngology—head and neck surgery are extensive and diverse. While most commonly used in laryngology and otology, laser applications are being developed for use in all areas of the head and neck including the oral cavity, oropharynx, external nose, paranasal sinuses, cranial base, and in the pediatric population. As new devices and delivery systems are developed, new applications will evolve. One element that is critical in all areas of application is laser safety, and this should take the utmost importance when planning and undertaking any procedure.

Lasers are used to treat both malignant and benign laryngeal diseases ranging from cancer to vocal cord paralysis. Middle ear applications have focused on primarily treating conductive hearing loss (stapes surgery), though in recent times new applications include the treatment of Eustachian tube dysfunction and cholesteatoma. Lasers are used to excise tumors in the oropharynx and oral cavity because they precisely cut and coagulate tissue. In rhinology, treatment of hereditary hemorrhagic telangiectasias is a commonplace and elegant example of laser therapy for non-cutaneous vascular lesions. In children, the laser may be used to ablate subglottic hemangiomas, correct laryngomalacia and excise atretic choanae. Laser applications in otolaryngology continually develop and evolve with a plethora of new devices, procedures and applications are emerging each year.

References

1. Jacques SL. Role of tissue optics and pulse duration on tissue effects during high-power laser irradiation. Appl Optics. 1993;32:2447–54.
2. Ries WR. Cutaneous applications of lasers. Otolaryngol Clin North Am. 1996;29(6):915–30.
3. Janda P, Sroka R, Mundweil B, Betz CS, Baumgartner R, Leunig A. Comparison of thermal tissue effects induced by contact application of fiber guided laser systems. Lasers Surg Med. 2003;33(2):93–101.
4. Vagnetti A, Gobbi E, Algieri GM, D'Ambrosio L. Wedge turbinectomy: a new combined photocoagulative Nd:YAG laser technique. Laryngoscope. 2000;110(6):1034–6.
5. Brown DH. The versatile contact Nd:YAG laser in head and neck surgery: an in vivo and clini-

cal analysis. Laryngoscope. 2000;110(5 Pt 1): 854–67.
6. Midgley HC III. Nd:YAG contact laser surgery. The scalpel of the future? Otolaryngol Clin North Am. 1990;23(1):99–105.
7. Li ZZ, Reinisch L, Van de Merwe WP. Bone ablation with Er:YAG and CO2 laser: study of thermal and acoustic effects. Lasers Surg Med. 1992;12(1):79–85.
8. Szyfter W, Mielcarek-Kuchta D, Miętkiewska-Leszniewska D, Młodkowska A, Łączkowska-Przybylska J. Comparison between 2 laser systems, Er-Yag and CO2, in stapes surgery. Otol Neurotol. 2013;34(1):29–35.
9. Philipp CM, Berlien HP. Basic principles of medical laser technology. In: Huttenbrink K, editor. Lasers in otorhinolaryngology. New York, NY: Thieme; 2005. p. 1–20.
10. Ossoff RH, Karlan MS. Safe instrumentation in laser surgery. Otolaryngol Head Neck Surg. 1984;92(6):644–8.
11. Ossoff R. Laser safety in otolaryngology – head and neck surgery: anesthetic and educational considerations for laryngeal surgery. Laryngoscope. 1989; 99(8):1–26.
12. Foth H-J. Endotracheal tubes for laser surgery: temperature rise and clinical experiences. SPIE Proc Med Appl Lasers III. 1996;2623:522–9.
13. Ungemach J. New laser tracheal tube. SPIE Proc Lasers Med Dent Diagn Treat. 1996;2887:129–32.
14. Foth HJ. Laser resistance of endotracheal tubes I: experimental results of a compound tube in comparison to a metallic tube. Lasers Med Sci. 1998;13(4):242–52.
15. Foth HJ. Laser resistance of endotracheal tubes II: observed temperature rise and theoretical explanation. Lasers Med Sci. 1999;14(1):24–31.
16. Coughlan CA, Verma SP. Evaluating the effects of a 532-nm fiber-based KTP laser on transoral laser surgery supplies. Otolaryngol Head Neck Surg. 2013;149(5):739–44.
17. Strong MS, Jako GJ. Laser surgery in the larynx. Early clinical experience with continuous CO2 laser. Ann Otol Rhinol Laryngol. 1972;81(6):791–8.
18. Strong MS, Jako GJ, Polanyi T, Wallace RA. Laser surgery in the aerodigestive tract. Am J Surg. 1973;126(4):529–33.
19. Steiner W, Ambrosch P. Endoscopic laser surgery of the upper aerodigestive tract. Stuttgart: Thieme; 2000.
20. Oswal VH. Laser surgery for benign laryngeal pathology. The Hague: Kugler Publications; 2002.
21. Steiner W. Experience in endoscopic laser surgery of malignant tumours of the upper aero-digestive tract. Adv Otorhinolaryngol. 1988;39:135–44.
22. BWS P Jr, Hinni ML. Transoral laser micro resection of advanced laryngeal tumors. In: Cummings CW, editor. Otolaryngology: head and neck surgery. 4th ed. St. Louis, MO: Mosby; 2005.
23. Rudert H. Larynx and hypopharynx cancers – endoscopic surgery with laser: possibilities and limits. Arch Otorhinolaryngol Suppl. 1991;1:3–18.
24. Eckel HE, Thumfart WF. Laser surgery for the treatment of larynx carcinomas: indications, techniques, and preliminary results. Ann Otol Rhinol Laryngol. 1992;101(2 Pt 1):113–8.
25. Steiner W, Pfalz R. Laser surgery. HNO. 1993;41(8): A19–20.
26. Motta G, Esposito E, Cassiano B, Motta S. T1-T2-T3 glottic tumors: fifteen years experience with CO2 laser. Acta Otolaryngol Suppl. 1997;527:155–9.
27. Canis M, Martin A, Ihler F, Wolff HA, Kron M, Matthias C, Steiner W. Results of transoral laser microsurgery for supraglottic carcinoma in 277 patients. Eur Arch Otorhinolaryngol. 2013; 270(8):2315–26.
28. Ansarin M, Zorzi S, Massaro MA, Tagliabue M, Proh M, Giugliano G, Calabrese L, Chiesa F. Transoral robotic surgery vs transoral laser microsurgery for resection of supraglottic cancer: a pilot surgery. Int J Med Robot. 2014;10(1):107–12.
29. Iro H, Waldfahrer F, Altendorf-Hofmann A, Weidenbecher M, Sauer R, Steiner W. Transoral laser surgery of supraglottic cancer: follow-up of 141 patients. Arch Otolaryngol Head Neck Surg. 1998;124(11):1245–50.
30. Rudert HH, Werner JA, Hoft S. Transoral carbon dioxide laser resection of supraglottic carcinoma. Ann Otol Rhinol Laryngol. 1999;108(9):819–27.
31. Vaughan CW. Transoral laryngeal surgery using the CO2 laser: laboratory experiments and clinical experience. Laryngoscope. 1978;88(9 Pt 1): 1399–420.
32. Vaughan CW, Strong MS, Jako GJ. Laryngeal carcinoma: transoral treatment utilizing the CO2 laser. Am J Surg. 1978;136(4):490–3.
33. Laccourreye O, Lawson G, Muscatello L, Biacabe B, Laccourreye L, Brasnu D. Carbon dioxide laser debulking for obstructing endolaryngeal carcinoma: a 10-year experience. Ann Otol Rhinol Laryngol. 1999;108(5):490–4.
34. Eckel HE. Lasers for benign diseases of the larynx, hypopharynx and trachea. In: Huttenbrink K, editor. Lasers in otorhinolaryngology. New York, NY: Thieme; 2005. p. 96–105.
35. Mahnke CG, Fröhlich O, Lippert BM, Werner JA. Recurrent laryngeal papillomatosis. Retrospective analysis of 95 patients and review of the literature. Otolaryngol Pol. 1996;50(6):567–78.
36. Koufman JA, Rees CJ, Frazier WD, et al. Office-based laryngeal laser surgery: a review of 443 cases using three wavelengths. Otolaryngol Head Neck Surg. 2007;137(1):146–51.
37. Pransky SM, Canto C. Management of subglottic hemangioma. Curr Opin Otolaryngol Head Neck Surg. 2004;12(6):509–12.
38. Waner M, Suen JY. Hemangiomas and vascular malformations of the head and neck. New York, NY: Wiley; 1999.
39. Zeitels SM, Akst LM, Bums JA, Hillman RE, Broadhurst MS, Anderson RR. Pulsed angiolytic laser treatment of ectasias and varices in singers. Ann Otol Rhinol Laryngol. 2006;115(8):571–80.

40. Crumley RL. Endoscopic laser medial arytenoidectomy for airway management in bilateral laryngeal paralysis. Ann Otol Rhinol Laryngol. 1993;102(2):81–4.
41. Van De Water TR, Staecker H. Otolaryngology: basic science and clinical review. New York, NY: Theime; 2005.
42. Werner JA. Transoral laryngeal surgery. Tuttlingen: Endo-Press; 2004.
43. Killian G. Die schwebelaryngoskopie. Arch Laryngol Rhinol. 1912;26:277–317.
44. Braun M. Intense pulsed light versus advanced fluorescent technology pulsed light for photodamaged skin: a split-face pilot comparison. J Drugs Dermatol. 2007;6(10):1024–8.
45. Courey MS, Ossoff RH. Laser applications in adult laryngeal surgery. Otolaryngol Clin North Am. 1996;29(6):973–86.
46. Cheon MS, Juhn JW, Hwang YS. Design of stark-tuned far-infrared laser with circular hollow waveguide. Appl Optics. 2006;45(27):7131–6.
47. Narita S, Matsuura Y, Miyagi M. Tapered hollow waveguide for focusing infrared laser beams. Opt Lett. 2007;32(8):930–2.
48. Sato S, Shi YW, Matsuura Y, Miyagi M, Ashida H. Hollowwaveguide-based nanosecond, near-infrared pulsed laser ablation of tissue. Lasers Surg Med. 2005;37(2):149–54.
49. Soljacic M, Ibanescu M, Johnson SG, Joannopoulos JD, Fink Y. Optical bistability in axially modulated OmniGuide fibers. Opt Lett. 2003;28(7):516–8.
50. Stalmashonak A, Zhavoronkov N, Hertel IV, Vetrov S, Schmid K. Spatial control of femtosecond laser system output with submicroradian accuracy. Appl Optics. 2006;45(6):1271–4.
51. Ambrosch P, Kron M, Steiner W. Carbon dioxide laser microsurgery for early supraglottic carcinoma. Ann Otol Rhinol Laryngol. 1998;107(8):680–8.
52. Steiner W, Ambrosch P, Hess CF, Kron M. Organ preservation by transoral laser microsurgery in piriform sinus carcinoma. Otolaryngol Head Neck Surg. 2001;124(1):58–67.
53. Steiner W, Fierek O, Ambrosch P, Hommerich CP, Kron M. Transoral laser microsurgery for squamous cell carcinoma of the base of the tongue. Arch Otolaryngol Head Neck Surg. 2003;129(1):36–43.
54. Brandenburg JH. Laser cordotomy versus radiotherapy: an objective cost analysis. Ann Otol Rhinol Laryngol. 2001;110(4):312–8.
55. Ambrosch P, Rödel R, Kron M, Steiner W. Transoral laser microsurgery of laryngeal cancer: a retrospective analysis of 657 patients. Onkologe. 2001;7:505–12.
56. Davis RK, Kelly SM, Hayes J. Endoscopic CO2 laser excisional biopsy of early supraglottic cancer. Laryngoscope. 1991;101(6 Pt 1):680–3.
57. Davis RK, Shapshay SM, Strong MS, Hyams VJ. Transoral partial supraglottic resection using the CO2 laser. Laryngoscope. 1983;93(4):429–32.
58. Zeitels SM, Vaughan CW, Domanowski GF. Endoscopic management of early supraglottic cancer. Ann Otol Rhinol Laryngol. 1990;99(12):951–6.
59. Hinni ML, Salassa JR, Grant DG, Pearson BW, Hayden RE, Martin A, Christiansen H, Haughey BH, Nussenbaum B, Steiner W. Transoral laser microsurgery for advanced laryngeal cancer. Arch Otolaryngol Head Neck Surg. 2007;133(12):1198–204.
60. Goon P, Sonnex C, Jani P, Stanley M, Sudhoff H. Recurrent respiratory papillomatosis: an overview of current thinking and treatment. Eur Arch Otorhinolaryngol. 2008;265(2):147–51.
61. Mortensen M, Schaberg MR, Genden EM, Woo P. Transoral resection of short segment Zenker's diverticulum and cricopharyngeal myotomy: an alternative minimally invasive approach. Laryngoscope. 2010;120(1):17–22.
62. Chang CW, Burkey BB, Netterville JL, Courey MS, Garrett CG, Bayles SW. Carbon dioxide laser endoscopic diverticulotomy versus open diverticulectomy for Zenker's diverticulum. Laryngoscope. 2004;114(3):519–27.
63. Lippert BM, Folz BJ, Rudert HH, Werner JA. Management of Zenker's diverticulum and postlaryngectomy pseudodiverticulum with the CO2 laser. Otolaryngol Head Neck Surg. 1999;121(6):809–14.
64. Klussmann JP, Knoedgen R, Wittekindt C, Damm M, Eckel HE. Complications of suspension laryngoscopy. Ann Otol Rhinol Laryngol. 2002;111(11): 972–6.
65. Pearson BW, Salassa JR. Transoral laser microresection for cancer of the larynx involving the anterior commissure. Laryngoscope. 2003;113(7):1104–12.
66. Desai SC, Sung CK, Jang DW, Genden EM. Transoral robotic surgery using a carbon dioxide flexible laser for tumors of the upper aerodigestive tract. Laryngoscope. 2008;118(12):2187–9.
67. Kucur C, Durmus K, Dziegielewski PT, Ozer E. Transoral robot- assisted carbon dioxide laser surgery for hypopharyngeal cancer. Head Neck. 2015;37(5):743.
68. Zeitels SM, Anderson RR, Hillman RE, Burns JA. Experience with office-based pulsed-dye laser (PDL) treatment. Ann Otol Rhinol Laryngol. 2007;116(4): 317–8.
69. Zeitels SM, Burns JA. Office-based laryngeal laser surgery with local anesthesia. Curr Opin Otolaryngol Head Neck Surg. 2007;15(3):141–7.
70. Jovanovic S. Lasers in otology. In: Huttenbrink K, editor. Lasers in otorhinolaryngology. New York, NY: Thieme; 2005. p. 21–52.
71. Chole R. Pathophysiology of otosclerosis. Otol Neurotol. 2001;22(2):249–57.
72. Perkins R, Curto FS Jr. Laser stapedotomy: a comparative study of prostheses and seals. Laryngoscope. 1992;102(12 Pt 1):1321–7.
73. Schuknecht H. Cochlear otosclerosis: fact or fantasy. Laryngoscope. 1974;84(5):766–82.
74. Perkins RC. Laser stapedotomy for otosclerosis. Laryngoscope. 1980;90(2):228–40.
75. Jovanovic S. CO2 laser stapedotomy with the "one shot" technique –clinical results. Otolaryngol Head Neck Surg. 2004;131:750–7.

76. Arnoldner C, Schwab B, Lenarz T. Clinical results after stapedotomy: a comparison between the erbium: yttrium-aluminum-garnet laser and the conventional technique. Otol Neurotol. 2006;27(4):458–65.
77. Buchman CA, Fucci MJ, Roberson JB Jr, De La Cruz A. Comparison of argon and CO2 laser stapedotomy in primary otosclerosis surgery. Am J Otolaryngol. 2000;21(4):227–30.
78. Keck T, Burner H, Rettinger G. Prospective clinical study on cochlear function after erbium:yttrium-aluminum-garnet laser stapedotomy. Laryngoscope. 2005;115(9):1627–31.
79. McGee TM. The argon laser in surgery for chronic ear disease and otosclerosis. Laryngoscope. 1983;93(9): 1177–82.
80. McGee TM. Laser applications in ossicular surgery. Otolaryngol Clin North Am. 1990;23(1):7–18.
81. McGee TM, Diaz-Ordaz EA, Kartush JM. The role of KTP laser in revision stapedectomy. Otolaryngol Head Neck Surg. 1993;109(5):839–43.
82. Poe DS. Laser-assisted endoscopic stapedectomy: a prospective study. Laryngoscope. 2000;110(5 Pt 2 Suppl 95):1–37.
83. Sedwick JD, Louden CL, Shelton C. Stapedectomy vs stapedotomy. Do you really need a laser? Arch Otolaryngol Head Neck Surg. 1997;123(2):177–80.
84. Silverstein H, Rosenberg S, Jones R. Small fenestra stapedotomies with and without KTP laser: a comparison. Laryngoscope. 1989;99(5):485–8.
85. Vernick DMA. comparison of the results of KTP and CO2 laser stapedotomy. Am J Otol. 1996;17(2):221–4.
86. Wiet RJ, Kubek DC, Lemberg P, Byskosh ATA. meta-analysis review of revision stapes surgery with argon laser: effectiveness and safety. Am J Otol. 1997;18(2):166–71.
87. Wong BJ, Lee J, Hashisaki GT, Berns MW, Neev J. Thermal imaging of the temporal bone in CO2 laser surgery: an experimental model. Otolaryngol Head Neck Surg. 1997;117(6):610–5.
88. Lesinski SG, Newrock R. Carbon dioxide lasers for otosclerosis. Otolaryngol Clin North Am. 1993;26(3):417–41.
89. DiBartolomeo J. The argon laser in otology. Laryngoscope. 1980;90:1786–96.
90. Brodsky L, Cook S, Deutsch E, et al. Optimizing effectiveness of laser tympanic membrane fenestration in chronic otitis media with effusion. Clinical and technical considerations. Int J Pediatr Otorhinolaryngol. 2001;58(1):59–64.
91. Deutsch ES, Cook SP, Shaha S, Brodsky L, Reilly JS. Duration of patency of laser-assisted tympanic membrane fenestration. Arch Otolaryngol Head Neck Surg. 2003;129(8):825–8.
92. Jassir D, Odabasi O, Gomez-Marin O, Buchman CA. Doseresponse relationship of topically applied mitomycin C for the prevention of laser myringotomy closure. Otolaryngol Head Neck Surg. 2003;129(5):471–4.
93. Silverstein H, Kuhn J, Choo D, Krespi YP, Rosenberg SI, Rowan PT. Laser-assisted tympanostomy. Laryngoscope. 1996;106(9 Pt 1):1067–74.
94. Valtonen HJ, Poe DS, Shapshay SM. Experimental CO2 laser myringotomy. Otolaryngol Head Neck Surg. 2001;125(3):161–5.
95. Yousaf M, Malik SA, Zada B. Laser and incisional myringotomy in otitis media with effusion-a comparative study. J Ayub Med Coll Abbottabad. 2014;26(4):441–3.
96. Jumah MD, Jumah M, Pazen D, Sedlmaier B. Laser Eustachian tuboplasty: efficiency evaluation in the pressure chamber. Otol Neurotol. 2012;33(3):406–12.
97. Jumah MJ, Jumah MD, Sedlmaier B. Restoring middle ear pressure equalization in divers by laser Eustachian tuboplasty. Undersea Hyperb Med. 2013;40(3):299–306.
98. Poe DS, Grimmer JF, Metson R. Laser eustachian tuboplasty: two year results. Laryngoscope. 2007;117(2):231–7.
99. Semaan M. The pathophysiology of cholesteatoma. Otolaryngol Clin North Am. 2006;39:1143–59.
100. Nishizaki K, Yuen K, Ogawa T, Nomiya S, Okano M, Fukushima K. Laser-assisted tympanoplasty for preservation of the ossicular chain in cholesteatoma. Am J Otolaryngol. 2001;22(6):424–7.
101. Saeed SR, Jackler RK. Lasers in surgery for chronic ear disease. Otolaryngol Clin North Am. 1996;29(2):245–56.
102. Jacques S. Time-resolved propagation of ultrashort laser pulses within turbid tissues. Appl Optics. 1989;28:2223–9.
103. Anderson R, Beck H, Bruggemann U, Farinelli W, Jacques SL, Parrish JA. Pulsed photothermal radiometry in turbid media: internal reflection of back-scattered radiation strongly influences optical dosimetry. Appl Optics. 1989;28:2256–62.
104. Gherini S, Horn KL, Causse JB, McArthur GR. Fiberoptic argon laser stapedotomy: is it safe? Am J Otol. 1993;14(3):283–9.
105. Gherini S, Horn KL. Laser stapedotomies. Laryngoscope. 1990;100(2 Pt 1):209–11.
106. Fang L, Lin H, Zhang TY, Tan J. Laser versus non-laser stapedotomy in otosclerosis: a systematic review and meta-analysis. Auris Nasus Larynx. 2014;41(4):337–42.
107. Kamalski DM, Wegner I, Tange RA, Vincent R, Stegeman I, van der Heijden GJ, Grolman W. Outcomes of different laser types in laser-assisted stapedotomy: a systematic review. Otol Neurotol. 2014;35(6):1046–51.
108. Lesinski SG. Lasers for otosclerosis – which one if any and why. Lasers Surg Med. 1990;10(5):448–57.
109. Pfalz R, Hibst R, Bald N. Suitability of different lasers for operations ranging from the tympanic membrane to the base of the stapes. Adv Otorhinolaryngol. 1995;49:87–94.
110. Yau AY, Mahboubi H, Maducdoc M, Ghavami Y, Djalilian HR. Curved adjustable fiberoptic laser for endoscopic cholesteatoma surgery. Otol Neurotol. 2015;36(1):61–4.
111. Brodsky L, Brookhauser P, Chait D, et al. Office-based insertion of pressure equalization tubes: the

role of laser-assisted tympanic membrane fenestration. Laryngoscope. 1999;109(12):2009–14.
112. Gerlinger I, Rath G, Szanyi I, Pytel J. Myringoplasty for anterior and subtotal perforations using KTP-532 laser. Eur Arch Otorhinolaryngol. 2006;263(9):816–9.
113. Kakehata S, Futai K, Sasaki A, Shinkawa H. Endoscopic transtympanic tympanoplasty in the treatment of conductive hearing loss: early results. Otol Neurotol. 2006;27(1):14–9.
114. Pyykko I, Poe D, Ishizaki H. Laser-assisted myringoplasty – technical aspects. Acta Otolaryngol Suppl. 2000;543:135–8.
115. Scheich M, Ginzkey C, Harnisch W, Ehrmann D, Shehata-Dieler W, Hagen R. Use of flexible CO_2 laser fiber in microsurgery for vestibular schwannoma via the middle cranial fossa approach. Eur Arch Otorhinolaryngol. 2012;269(5):1417–23.
116. Nissen AJ, Sikand A, Welsh JE, Curto FS. Use of the KTP-532 laser in acoustic neuroma surgery. Laryngoscope. 1997;107(1):118–21.
117. Glasscock MEIII, Jackson CG, Whitaker SR. The argon laser in acoustic tumor surgery. Laryngoscope. 1981;91(9 Pt 1):1405–16.
118. Adamczyk M, Antonelli PJ. Selective vestibular ablation by KTP laser in endolymphatic hydrops. Laryngoscope. 2001;111(6):1057–62.
119. Anthony PF. Laser applications in inner ear surgery. Otolaryngol Clin North Am. 1996;29(6): 1031–48.
120. Antonelli PJ, Lundy LB, Kartush JM, Burgio DL, Graham MD. Mechanical versus CO2 laser occlusion of the posterior semicircular canal in humans. Am J Otol. 1996;17(3):416–20.
121. Nomura Y. Argon laser irradiation of the semicircular canal in two patients with benign paroxysmal positional vertigo. J Laryngol Otol. 2002; 116(9):723–5.
122. Kelly J. Laser decompression of the facial nerve. Otolaryngol Clin North Am. 1996;29(6):1049–61.
123. Vernick MD. Laser applications in ossicular surgery. Otolaryngol Clin North Am. 1996;29(6):931–41.
124. Wilson L, Lin E, Lalwani A. Cost-effectiveness of intraoperative facial nerve monitoring in middle ear or mastoid surgery. Laryngoscope. 2003;113(10):1736–45.
125. Wiegand DA, Mertz PS, Latz B. Detection of intraoperative laser injury to the facial nerve by electromyographic monitoring of facial muscles. Laryngoscope. 1991;101(7 Pt 1):771–4.
126. Kujawski OB, Poe DS. Laser eustachian tuboplasty. Otol Neurotol. 2004;25(1):1–8.
127. Ambrosch P. Lasers for malignant lesions in the upper aerodigestive tract. In: Huttenbrink K, editor. Lasers in Otorhinolaryngology. New York, NY: Thieme; 2005. p. 131–4.
128. Burkey BB, Garrett G. Use of the laser in the oral cavity. Otolaryngol Clin North Am. 1996; 29(6):949–72.
129. Davis RK. Laser surgery for oral cavity and oropharyngeal cancer. In: Davis RK, editor. Lasers in otolaryngology: head and neck surgery. Philadelphia, PA: Saunders Company; 1990. p. 132–44.
130. Eckel HE, Volling P, Pototschnig C, Zorowka P, Thumfart W. Transoral laser resection with staged discontinuous neck dissection for oral cavity and oropharynx squamous cell carcinoma. Laryngoscope. 1995;105(1):53–60.
131. Schuller DE. Use of the laser in the oral cavity. Otolaryngol Clin North Am. 1990;23(1): 31–42.
132. Carruth JA. Resection of the tongue with the carbon dioxide laser: 100 cases. J Laryngol Otol. 1985;99(9):887–9.
133. Duncavage JA, Ossoff RH. Use of the CO2 laser for malignant disease of the oral cavity. Lasers Surg Med. 1986;6(5):442–4.
134. Strong MS, Vaughan CW, Jako GJ, Polanyi T. Transoral resection of cancer of the oral cavity: the role of the CO2 laser. Otolaryngol Clin North Am. 1979;12(1):207–18.
135. Jerjes W, Upile T, Hamdoon Z, Mosse CA, Akram S, Hopper C. Prospective evaluation of outcome after transoral CO(2) laser resection of T1/T2 oral squamous cell carcinoma. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;112(2):180–7.
136. Stevens RH, Davis RK. Laser surgery for benign conditions in the oral cavity. In: Davis RK, editor. Lasers in otolaryngology: head and neck surgery. Philadelphia, PA: Saunders Company; 1990. p. 121–31.
137. Van der Hem PS, Nauta JM, van der Wal JE, Roodenburg JL. The results of CO2 laser surgery in patients with oral leukoplakia: a 25 year follow up. Oral Oncol. 2005;41(1):31–7.
138. Ducic Y, Marsan J, Olberg B, Marsan S, Maclachlan L, Lamothe A. Comparison of laser-assisted uvulopalatopharyngoplasty to electrocautery-assisted uvulopalatopharyngoplasty: a clinical and pathologic correlation in an animal model. J Otolaryngol. 1996;25(4):234–8.
139. Han S, Kern RC. Laser-assisted uvulopalatoplasty in the management of snoring and obstructive sleep apnea syndrome. Minerva Med. 2004;95(4):337–45.
140. Hanada T, Furuta S, Tateyama T, Uchizono A, Seki D, Ohyama M. Laser-assisted uvulopalatoplasty with Nd:YAG laser for sleep disorders. Laryngoscope. 1996;106(12 Pt 1):1531–3.
141. Krespi YP, Kacker A. Laser-assisted uvulopalatoplasty revisited. Otolaryngol Clin North Am. 2003;36(3):495–500.
142. Laranne J, Lagerstedt A, Pukander J, Rantala I, Hanamure Y, Ohyama M. Immediate histological changes in soft palate after uvulopalatopharyngoplasty with CO2, contact Nd:YAG or combined CO2 and Nd:YAG laser beams. Acta Otolaryngol Suppl. 1997;529:206–9.
143. Terris DJ. Comparing uvulopalatopharyngoplasty and laserassisted uvulopalatoplasty. Arch Otolaryngol Head Neck Surg. 1997;123(3):278–9.

144. Terris DJ, Wang MZ. Laser-assisted uvulopalatoplasty in mild obstructive sleep apnea. Arch Otolaryngol Head Neck Surg. 1998;124(6):718–20.
145. Vaidya AM, Petruzzelli GJ, Walker RP, McGee D, Gopalsami C. Identifying obstructive sleep apnea in patients presenting for laserassisted uvulopalatoplasty. Laryngoscope. 1996;106(4):431–7.
146. Fujita S, Woodson BT, Clark JL, Wittig R. Laser midline glossectomy as a treatment for obstructive sleep apnea. Laryngoscope. 1991;101(8):805–9.
147. Phillips J, Withrow K. Outcomes of holmium laser-assisted lithotripsy with sialendoscopy in treatment of sialolithiasis. Otolaryngol Head Neck Surg. 2014;150(6):962–7.
148. Sionis S, Caria RA, Trucas M, Brennan PA, Puxeddu R. Sialoendoscopy with and without holmium:YAG laser-assisted lithotripsy in the management of obstructive sialadenitis of major salivary glands. Br J Oral Maxillofac Surg. 2014;52(1):58–62.
149. Sun YT, Lee KS, Hung SH, Su CH. Sialendoscopy with holmium:YAG laser treatment for multiple large sialolithiases of the Wharton duct: a case report and literature review. J Oral Maxillofac Surg. 2014;72(12):2491–6.
150. Durbec M, Dinkel E, Vigier S, Disant F, Marchal F, Faure F. Thulium-YAG laser sialendoscopy for parotid and submandibular sialolithiasis. Lasers Surg Med. 2012;44(10):783–6.
151. Bier-Lanig C, Adams GL. Patterns of recurrence after carbon dioxide laser excision of intraoral squamous cell carcinoma. Arch Otolaryngol Head Neck Surg. 1995;121:1239–44.
152. Panje WR, Scher NN, Karnell M. Transoral carbon dioxide laser ablation for cancer, tumors and other diseases. Arch Otolaryngol Head Neck Surg. 1989;115:681–8.
153. Williams SR, Carruth JA. The role of the carbon dioxide laser in treatment of carcinoma of the tongue. J Laryngol Otol. 1988;102(12):1122–3.
154. Wang CP, Chang SY, Wu JD, Tai SK. Carbon dioxide laser microsurgery for tongue cancer: surgical techniques and long-term results. J Otolaryngol. 2001;30(1):19–23.
155. Strong MS, Vaughan CW, Healy GB, Shapshay SM, Jako GJ. Transoral management of localized carcinoma of the oral cavity using the CO2 laser. Laryngoscope. 1979;89(6 Pt 1):897–905.
156. Ben-Bassat M, Kaplan I, Shindel Y, Edlan A. The CO2 laser in surgery of the tongue. Br J Plast Surg. 1978;31(2):155–6.
157. Ishii J, Fujita K, Komori T. Clinical assessment of laser monotherapy for squamous cell carcinoma of the mobile tongue. J Clin Laser Med Surg. 2002;20(2):57–61.
158. Riley RW, Powell NB, Li KK, Weaver EM, Guilleminault C. An adjunctive method of radiofrequency volumetric tissue reduction of the tongue for OSAS. Otolaryngol Head Neck Surg. 2003;129(1):37–42.
159. Powell NB, Zonato AI, Weaver EM, et al. Radiofrequency treatment of turbinate hypertrophy in subjects using continuous positive airway pressure: a randomized, double-blind, placebo-controlled clinical pilot trial. Laryngoscope. 2001;111(10):1783–90.
160. Li KK, Powell NB, Riley RW, Troell RJ, Guilleminault C. Radiofrequency volumetric reduction of the palate: an extended follow-up study. Otolaryngol Head Neck Surg. 2000;122(3):410–4.
161. Marchal F, Dulguerov P, Lehmann W. Sialendoscopy. N Engl J Med. 1999;341:1242–3.
162. Marchal F, Dulguerov P, Becker M, Lehmann W. How I do it: Interventional sialendoscopy. Laryngoscope. 2000;110:318–20.
163. Frame JW, Morgan D, Rhys-Evans PH. Tongue resection with the CO2 laser: the effects of past radiotherapy on postoperative complications. Br J Oral Maxillofac Surg. 1988;26:464–71.
164. Christiansen H, Hermann RM, Martin A, et al. Long-term followup after transoral laser microsurgery and adjuvant radiotherapy for advanced recurrent squamous cell carcinoma of the head and neck. Int J Radiat Oncol Biol Phys. 2006;65(4):1067–74.
165. Miller FR, Bartley J, Otto RA. The endoscopic management of Zenker diverticulum: CO2 laser versus endoscopic stapling. Laryngoscope. 2006;116(9):1608–11.
166. Zbaren P, Schar P, Tschopp L, Becker M, Hausler R. Surgical treatment of Zenker‘s diverticulum: transcutaneous diverticulectomy versus microendoscopic myotomy of the cricopharyngeal muscle with CO2 laser. Otolaryngol Head Neck Surg. 1999;121(4):482–7.
167. Walvekar RR, Razfar A, Carrau RL, Schaitkin B. Sialendoscopy and associated complications: a preliminary experience. Laryngoscope. 2008;118(5):776–9.
168. Paiva MB, Blackwell KE, Saxton RE, et al. Nd:YAG laser therapy for palliation of recurrent squamous cell carcinomas in the oral cavity. Lasers Surg Med. 2002;31(1):64–9.
169. Graeber IP, Eshraghi AA, Paiva MB, et al. Combined intratumor cisplatinum injection and Nd:YAG laser therapy. Laryngoscope. 1999;109(3):447–54.
170. Paiva MB, Bublik M, Castro DJ, Udewitz M, Wang MB, Kowalski LP, Sercarz J. Intratumor injections of cisplatin and laser thermal therapy for palliative treatment of recurrent cancer. Photomed Laser Surg. 2005;23(6):531–5.
171. Vohra F, Al-Kheraif AA, Qadri T, Hassan MI, Ahmed A, Warnakulasuriya S, Javed F. Efficacy of photodynamic therapy in the management of oral premalignant lesions: a systematic review. Photodiagnosis Photodyn Ther. 2015;12:150.
172. Pietruska M, Sobaniec S, Bernaczyk P, Cholewa M, Pietruski JK, Dolińska E, Skurska A, Duraj E, Tokajuk G. Clinical evaluation of photodynamic therapy efficacy in the treatment of oral leukoplakia. Photodiagnosis Photodyn Ther. 2014;11(1): 34–40.
173. Biel MA. Photodynamic therapy and the treatment of head and neck cancers. J Clin Laser Med Surg. 1996;14(5):239–44.

174. Biel MA. Photodynamic therapy in head and neck cancer. Curr Oncol Rep. 2002;4(1):87–96.
175. D'Cruz AK, Robinson MH, Biel MA. mTHPC-mediated photodynamic therapy in patients with advanced, incurable head and neck cancer: a multicenter study of 128 patients. Head Neck. 2004;26(3):232–40.
176. Biel M. Advances in photodynamic therapy for the treatment of head and neck cancers. Lasers Surg Med. 2006;38(5):349–55.
177. Mioc S, Mycek MA. Selected laser-based therapies in otolaryngology. Otolaryngol Clin North Am. 2005;38(2):241–54.
178. Essex RW, Qureshi SH, Cain MS, Harper CA, Guymer RH. Photodynamic therapy in practice: a review of the results of the first 12 months experience with verteporfin at the Royal Victorian Eye and Ear Hospital. Clin Experiment Ophthalmol. 2003;31(6):476–81.
179. Ofner JG, Schlogl H, Kostron H. Unusual adverse reaction in a patient sensitized with Photosan 3. J Photochem Photobiol B. 1996;36(2):183–4.
180. Davis RK. Photodynamic therapy in otolaryngology-head and neck surgery. Otolaryngol Clin North Am. 1990;23(1):107–19.
181. Lippert BM. Lasers in rhinology. In: Huttenbrink K, editor. Lasers in otorhinolaryngology. New York, NY: Thieme; 2005. p. 54–73.
182. Pototschnig C, Volklein C, Appenroth E, Thumfart WF. Transnasal treatment of congenital choanal atresia with the KTP laser. Ann Otol Rhinol Laryngol. 2001;110(4):335–9.
183. Tzifa KT, Skinner DW. Endoscopic repair of unilateral choanal atresia with the KTP laser: a one stage procedure. J Laryngol Otol. 2001;115(4):286–8.
184. Healy GB, McGill T, Jako GJ, Strong MS, Vaughan CW. Management of choanal atresia with the carbon dioxide laser. Ann Otol Rhinol Laryngol. 1978;87(5 Pt 1):658–62.
185. Levine HL. The potassium–titanyl phosphate laser for treatment of turbinate dysfunction. Otolaryngol Head Neck Surg. 1991;104(2):247–51.
186. Oswal VH, Bingham BJ. A pilot study of the holmium YAG laser in nasal turbinate and tonsil surgery. J Clin Laser Med Surg. 1992;10(3):211–6.
187. Janda P, Sroka R, Baumgartner R, Grevers G, Leunig A. Laser treatment of hyperplastic inferior nasal turbinates: a review. Lasers Surg Med. 2001;28(5):404–13.
188. Lippert BM, Werner JA. Reduction of hyperplastic turbinates with the CO2 laser. Adv Otorhinolaryngol. 1995;49:118–21.
189. Lippert BM, Werner JA. Comparison of carbon dioxide and neodymium: yttrium-aluminum-garnet lasers in surgery of the inferior turbinate. Ann Otol Rhinol Laryngol. 1997;106(12):1036–42.
190. Lippert BM, Werner JA. Long-term results after laser turbinectomy. Lasers Surg Med. 1998;22(2):126–34.
191. Velegrakis GA, Prokopakis EP, Papadakis CE, Helidonis ES. Nd:YAG laser treatment of recurrent epistaxis in heredity hemorrhagic telangiectasia. J Otolaryngol. 1997;26(6):384–6.
192. Lennox PA, Harries M, Lund VJ, Howard DJ. A retrospective study of the role of the argon laser in the management of epistaxis secondary to hereditary haemorrhagic telangiectasia. J Laryngol Otol. 1997;111(1):34–7.
193. Bergler W, Riedel F, Baker-Schreyer A, Juncker C, Hormann K. Argon plasma coagulation for the treatment of hereditary hemorrhagic telangiectasia. Laryngoscope. 1999;109(1):15–20.
194. Ben-Bassat M, Kaplan I, Levy R. Treatment of hereditary haemorrhagic telangiectasia of the nasal mucosa with the carbon dioxide laser. Br J Plast Surg. 1978;31(2):157–8.
195. Ducic Y, Brownrigg P, Laughlin S. Treatment of haemorrhagic telangiectasia with the flashlamp-pulsed dye laser. J Otolaryngol. 1995; 24(5):299–302.
196. Harries PG, Brockbank MJ, Shakespeare PG, Carruth JA. Treatment of hereditary haemorrhagic telangiectasia by the pulsed dye laser. J Laryngol Otol. 1997;111(11):1038–41.
197. Agarwal G, Kupferman ME, Holsinger FC, Hanna EY. Sinonasal and nasopharyngeal applications of the hand-held CO2 laser fiber. Int Forum Allergy Rhinol. 2011;1(2):109–12.
198. Har-El G, Shapshay SM, Bohigian RK, Krespi YP, Lucente FE. The treatment of rhinophyma. 'Cold' vs laser techniques. Arch Otolaryngol Head Neck Surg. 1993;119(6):628–31.
199. Goon PK, Dalal M, Peart FC. The gold standard for decortication of rhinophyma: combined erbium-YAG/CO2 laser. Aesthetic Plast Surg. 2004;28(6):456–60.
200. Kamami YV, Pandraud L, Bougara A. Laser-assisted outpatient septoplasty: results in 703 patients. Otolaryngol Head Neck Surg. 2000;122(3):445–9.
201. Trelles MA, Mordon SR. Correction of ear malformations by laser-assisted cartilage reshaping (LACR). Lasers Surg Med. 2006;38(7):659–62. Discussion 658.
202. Ovchinnikov Y, Sobol E, Svistushkin V, Shekhter A, Bagratashvili V, Sviridov A. Laser septochondrocorrection. Arch Facial Plast Surg. 2002;4(3):180–5.
203. Wong BJ, Milner TE, Harrington A, et al. Feedback-controlled laser-mediated cartilage reshaping. Arch Facial Plast Surg. 1999;1(4):282–7.
204. Hartnick CJ, Boseley ME, Franco RA Jr, Cunningham MJ, Pransky S. Efficacy of treating children with anterior commissure and true vocal fold respiratory papilloma with the 585-nm pulsed-dye laser. Arch Otolaryngol Head Neck Surg. 2007;133(2):127–30.
205. Bagwell CE. CO2 laser excision of pediatric airway lesions. J Pediatr Surg. 1990;25(11):1152–6.
206. Bent JP. Airway hemangiomas: contemporary management. Lymphat Res Biol. 2003;1(4):331–5.
207. Ahmad SM, Soliman AM. Congenital anomalies of the larynx. Otolaryngol Clin North Am. 2007;40(1):177–91. viii.

208. Karamzadeh AM, Wong BJ, Crumley RL, Ahuja G. Lasers in pediatric airway surgery: current and future clinical applications. Lasers Surg Med. 2004;35(2):128–34.
209. Okamoto M, Nishijima E, Yokoi A, Nakao M, Bitoh Y, Arai H. Strategy for surgical treatment of congenital subglottic stenosis in children. Pediatr Surg Int. 2012;28(11):1115–8.
210. Crockett DM, Strasnick B. Lasers in pediatric otolaryngology. Otolaryngol Clin North Am. 1989;22(3):607–19.
211. Whymark AD, Clement WA, Kubba H, Geddes NK. Laser epiglottopexy for laryngomalacia: 10 years' experience in the west of Scotland. Arch Otolaryngol Head Neck Surg. 2006;132(9):978–82.
212. Nicolai T, Fischer-Truestedt C, Reiter K, Grantzow R. Subglottic hemangioma: a comparison of CO2 laser, Neodym-Yag laser, and tracheostomy. Pediatr Pulmonol. 2005;39(3):233–7.
213. Madgy D, Ahsan SF, Kest D, Stein I. The application of the potassium-titanyl-phosphate (KTP) laser in the management of subglottic hemangioma. Arch Otolaryngol Head Neck Surg. 2001; 127(1):47–50.
214. Ishman SL, Kerschner JE, Rudolph CD. The KTP laser: an emerging tool in pediatric otolaryngology. Int J Pediatr Otorhinolaryngol. 2006;70(4):677–82.