Chapter 113: Lasers in Otolaryngology

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Many lasers are now available to the otolaryngologist, and the choice of the appropriate wavelength may be confusing when the laser is used only occasionally. An essential condition for the proper and successful use of lasers in any specialty is an understanding of the characteristics and limitations of wavelengths, interaction with tissue, mode of transmission, delivery system (optics, contact and noncontact modes), and settings (power, repetition rate, continuous versus pulse modes). This knowledge permits the application of laser technology in the proper clinical setting, and it provides the best results. Lack of understanding often leads to the misuse and abuse of lasers, causing detrimental results and otherwise avoidable complications.

In the last few years, the availability of many different laser wavelengths has extended the applications of laser technology to include laryngology, bronchology, rhinology, otology, general otolaryngology, and photocoagulation of vascular lesions. The wavelengths from which the surgeon can choose are CO_2, Nd:YAG in contact and noncontact modes, argon, potassium titanyl phosphate (KTP/532), and argon dye. New experimental lasers that may soon be available are the holmium:YAG, erbium:YAG, and ultimately the free electron laser.

The most widely used laser is the CO_2 laser, which is known for its precision, particularly when coupled to an operating microscope for delicate atraumatic surgery. When only one laser can be purchased for use in otolaryngology the CO_2 laser is recommended.

This chapter presents an overview of the different lasers available and discusses the optimal wavelenth for each procedure and organ system.

Historical Review

CO_2 laser

The CO_2 laser is the mainstay of lasers in otolaryngology. It is the most widely used, well understood, and well studied of the medical lasers and can be used for incision, excision, and vaporization of tissue. It was the first laser to be used clinically in otolaryngology and the first to be used in laryngology by Strong and Jako (1972).

Its wavelength of 10.6 microm is at the peak of absorption of water. This characteristic is important because absorption of this wavelength into soft tissue (90% water content) will concentrate the energy, permitting little heat to dissipate to adjacent tissues. The laser light is transformed within the tissue to thermal energy, raising the tissue temperature to 100°C and vaporizing the tissue's water content. This wavelength makes the CO_2 laser a precise cutting tool, ideal for the excision of small lesions located on delicate structures, such as the vocal cords. Basic studies of soft tissue in the canine trachea by Shapshay (1987) showed excellent depth of penetration with minimal damage to adjacent tissue. The energy curve (TEM00) that is delivered to tissue is in the shape of a gaussian curve; that is, the maximal power is at the center of the beam and fades at the margins.

Mihashi et al (1976) described the interaction of the CO_2 laser with human tissue. The rapid thermal drop of laser energy in the tissue surrounding the incision results in shallow and predictable tissue penetration with minimal edema. The hemostatic capability of the CO_2 laser is limited, however, to blood vessels not larger than capillaries (0.5 mm). The CO_2 laser beam can be focused to create a precise cut and defocused to produce coagulation of small blood vessels (approximately 1 mm).

A disadvantage of the CO_2 laser is that it cannot be transmitted through flexible fibers but can only be delivered through a somewhat awakward articulated mirror system.

The CO_2 laser is sometimes misused for the excision of benign laryngeal lesions. A surgeon who does not understand the effects and soft tissue interaction of the CO_2 laser may choose a large spot size (> 0.5 mm), continuous exposure, or high power (> 10 W) when performing phonatory surgery. Such choices are likely to result in poor voice quality because of mucosal scarring and fibrosis.

Advancements in laser technology and micromanipulator optics have enabled the diameter of the CO_2 laser spot to be reduced when used with a 400 mm focal length. The focal length was reduced from 2 mm in the early 1970s to 0.8 mm in the early 1980s and to 0.3 mm in 1987 (Shapshay et al, 1988). Necessary laser wattage has been reduced from 10 to 2 to 3 W because of the higher beam concentration or power density.

Neodymium:YAG

The Nd:YAG laser has a wavelength of 1.06 microm that is poorly absorbed by water, and, therefore, penetrates tissue deeply. The energy is not dissipated at the surface, as is the case with the CO_2, KTP/532, and argon lasers; it scatters within the tissue depending on the degree of tissue pigmentation for absorption.

The Nd:YAG laser can be transmitted through commonly available flexible quartz fibers that make possible its use in the tracheobronchial tree. The Nd:YAG laser wavelength is well absorbed by pigmented and vascular tissue, which, along with its deep penetration into most tissues, enables it to be a good coagulator. Because the laser beam diverges approximately 10 degrees as it leaves the fiber, the closer the fiber to the tissue, the smaller the spot size. Care must be taken to aplly the Nd:YAG laser energy in brief exposures of 1 second or less at a power setting below 50 W. Continuous application of the Nd:YAG laser at high power settings may result in a "popcorn" effect, which is an explosion of the tissue caused by concentration of high energy below the tissue surface that creates an expanding cavity.

The Nd:YAG laser wavelength has little visible effect on colorless tissue, and the laser beam readily traverses it, causing thermal damage to the more pigmented underlying structures. This may be the case when treating a lesion in the tracheobronchial tree. The white color of the tracheal cartilage will not absorb the laser energy, and the energy will be transmitted through the cartilage and possible damage the underlying vascular and lung tissues. It is well known that the thermal effect of the Nd:YAG laser goes beyond its immediate area of visible impact. Relying on knowledge of the laser's soft tissue interaction, the surgeon should take care to protect the underlying soft tissues. A study (Shapshay, 1987) comparing the CO_2 laser with different Nd:YAG laser delivery systems has shown that thermal damage in the normal tracheobronchial tree delays healing and reepithelialization and may cause scarring. Mucosal charring and blood deposition on the tracheal wall enhance the absorption of the Nd:YAG laser beam. Rapid propagation of thermal energy can ensue, causing tracheal perforation.

The Nd:YAG laser has two modes of delivery: a contact and a noncontact mode. In the noncontact mode, the Nd:YAG laser is useful in the treatment of vascular tumors and pigmented lesions because of its excellent penetration into tissue. Because absorption is efficient in this type of tissue, laser power is decreased to half that necessary for vaporization. Photocoagulation is the desired effect. In the contact mode, the Nd:YAG laser is good for cutting soft tissue and even thin bone; however, it is not adequate for hemostasis. When used in the contact mode, the Nd:YAG laser energy concentrates at the tip of the fiber and causes limited vaporization of tissue and little damage to the surrounding tissue. The contact mode is good for coagulating blood vessels less than 1 mm in diameter; its effect on soft tissue is similar to that of the CO_2 laser (Shapshay, 1987).

Durtschi et al (1980) applied the Nd:YAG laser in the contact mode like a thermal knife to perform hepatectomy in a canine model. The tip of the fiber was attached to a sharp, transparent quartz blade; however, blood loss was similar to conventional techniques. Later, Joffe (1986) described the use of contact probes designed to be used with Nd:YAG laser. These probes, with their varying geometric shapes for cutting, ablation, and coagulation, permit the desired tissue effects when used in the contact mode. The high power density is localized, which reduces the depth of tissue damage, prevents backscatter, and thus requires lower laser power. Studies performed in our laboratory on liver, skin, bone, and blood vessels showed that, when used in the contact mode, the Nd:YAG laser cuts bone and soft tissue readily, achieving little hemostasis on the surface. However, when larger vessels are approached, such as in the center of the liver, hemostasis is poor. In the contact mode, the Nd:YAG laser probe is thus wavelength independent for its soft tissue effects, relying instead on high power density.

Potassium titanyl phosphate/532 and argon lasers

The KTP/532 and argon lasers have similar characteristics. Both operate in the visible spectrum at the wavelength of 532 and 518 nanom, respectively, and can be delivered through flexible fibers. Both lasers are well absorbed by pigmented tissue and hemoglobin and are poorly absorbed by pale tissue, thus making them good coagulators with fairly good ablation of pigmented tissue. Compared with the Nd:YAG laser, however, this effect on tissue is superficial. Spot sizes of 0.15 mm can be achieved, depending on the optics used that create high power densities capable of cutting and ablating tissue independent of its wavelength absorption.

Because of the excellent absorption of the argon laser by hemoglobin, the major clinical application has been in ophthalmology and dermatology. This laser has been useful for coagulation of retinal blood vessels in instances of diabetic retinopathy and for the treatment of port-wine stain.

Further applications of the argon and KTP/532 lasers in otolaryngology on soft tissue (for example, in tonsillectomy) will depend on their capacity for small spot size delivery (high power density). Both the KTP/532 and argon lasers can be delivered through quartz fibers, handpieces, and micromanipulators and provide great flexibility in delivery to the operative site.

Studies of the effect of a high-powered argon laser on the tracheobronchial tree (Gillis et al, 1984) showed extensive subepithelial damage with a somewhat variable delayed reaction between the time of application of the laser and the detectable break in the epithelium. Postoperative edema and acute inflammation laster for 3 and 7 days, respectively. The extent of the injury was 30% greater than the original defect. The unpredictable effects of the argon laser on soft tissue limit its application in the airway.

Laryngology

Laryngology is one of the specialty areas in which lasers are most often used. The CO_2 laser is by far the laser of choice. Because of the precise cutting and superficial well-delineated effect of the CO_2 laser, it is widely used in laryngology for delicate phonatory surgery, precise excision of carcinoma in situ or early (T1) tumors, and vaporization of bulky obstructing carcinoma of the upper airway.

Benign lesions

For benign lesions of the larynx, the endoscopic approach using the CO_2 laser with a modern microspot manipulator permits elegant microprecision and hemostatic ability impossible to achieve with standard instruments, such as scissors and forceps. In particular, the modern concept of phonatory surgery using a small spot CO_2 laser (approximately 0.3 mm with a 400 mm lens) and the concept of mucosal preservation have extended the potential for endoscopic surgical techniques. Appreciable improvement in functional results have followed from these advancements in technology and refined techniques.

The CO_2 laser can be used for delineating or circumscribing the lesion. The lesion is then excised using either microscissors or the laser. The development of a microspot micromanipulator, as described by Shapshay et al (1988), facilitated tissue excision with precise cutting and minimal damage to the surrounding mucosa and underlying vocalis muscle. The CO_2 laser is used in a no-touch mode that permits unobstructed observation of the surgical field so as to note the effect of the laser on tissue, layer by layer. The CO_2 laser has been used to remove benign laryngeal lesions and is especially effective for vascular polyps, large sessile nodules, and cysts and for the evacuation of polypoid myxomatous changes. The technique of excising benign laryngeal lesions by the CO_2 laser is simple and has been well described (Shapshay et al, 1990).

The key to successful laryngoscopic excision is good exposure. The laryngoscope preferred by the authors is Jako-Dedo anterior commissure laryngoscope (Pilling Company, Fort Washington, Penn) or a Kleinsasser laryngoscope (Karl Storz Endoscopy-America Inc, Culver City, Calif) held in place by a Boston University (BU) (Pilling Company) suspension system. When these laryngoscopes cannot be used because of anatomic reasons (for example, a narrow dental arch or a small larynx) and when adequate exposure cannot be achieved, a smaller Holinger type of anterior commissure laryngoscope (Pilling Company) can be inserted. In this instance, the laser is not suitable for use, and the preferred technique is to use standard cold microsurgical instruments to excise the lesion.

The CO_2 laser is usually used with the microspot delivery system (0.3 mm spot diameter) to outline the area around the lesion. A power setting from 1 to 3 W is sufficient with intermittent pulses of 1/10 second. The usual magnification setting on the microscope is 16 times, but for a smaller lesion, a magnification of 25 times is useful. When the outline of the lesion is completed through the mucosal surface, the mucosa is easily separated from the surrounding tissue using a microlaryngeal forceps (Fig. 113-1). At that moment, if a vessel is seen, coagulation can be accomplished by defocusing the laser beam. The technique of excision is described in the section on treatment.

The use of the CO_2 laser for the welding of tissue is controversial. Although the mechanism of adherence of the mucosal edges, or welding, is not well known, it is believed to result from the coagulation of proteins at the mucosal edges. The CO_2 laser has been used at the Lahey Clinic (Shapshay et al, 1988) for welding vocal cord mucosa, particularly after removing a cyst or raising a mucosal flap. Welding is achieved by approximating the mucosal edges using a microlaryngeal forceps, defocusing the beam and aiming at the junction of the mucosa, and firing at power ranges between 100 and 500 mW.

Nodules

Vocal cord nodules usually occur bilaterally and are seen most commonly in children and young women. They usually result from trauma inflicted on the vocal cord mucosa during vibration. Nodules are seen as areas of thickened mucosa overlying the vocal folds. The process starts as edema in Reinke's space and later becomes organized. Histologically, nodules show a hyperplastic epithelium with submucosal edema; however, fibrosis of the submucosal connective tissue may occur if vocal trauma continues. On laryngeal examination, the lesions appear whitish and shining with a wide base and are located at the junction between the anterior and middle third of the cord (Fig. 113-2).

Treatment usually consists of resting the voice and undertaking speech therapy. Excision is required when the lesion is well organized or fibrotic or when the nature of the lesion is uncertain. In children, the larynx should be visualized by indirect or direct laryngoscopy to rule out other lesions, such as recurrent respiratory papillomatosis. Nodules in children are usually poorly demarcated and will resolve spontaneously as vocal habits change. The nodules should be removed only when they become large and thickened because of voice deterioration.

Polyps

Laryngeal polyps present as sessile or, more commonly, as pedunculated masses and are unilateral in 90% of patients, appearing at the free edge between the anterior and middle third of the true vocal cord (Fig. 113-3, A). They are by far the most common benign lesions of the adult larynx. The two major types are mucoid and angiomatous. Macroscopically, mucoid polyps are translucent grayish lesions with little vascularity. Angiomatous polyps are dark red, protuberant, and multinodular (Fig. 113-3, B). Transitional forms depend on the extent of the inflammatory response and fibrosis (Strong and Vaughan, 1971). The localized pedunculated polyp usually arises as a result of acute vascular disruption and formation of a localized hematoma. Continued chronic irritation secondary to vocal abuse leads to inflammatory changes and fibrosis. The most common cause is severe vocal abuse, possibly resulting in acute submucosal bleeding followed by organization.

Removal of vocal cord polyps by microlaryngoscopic techniques is considered standard treatment. Precise removal with preservation of underlying muscle can be accomplished with microlaryngeal instruments.

The CO_2 laser permits precise removal of polyps because of its hemostatic capability and no-touch mode that does not obscure the surgeon's view. The laser is used to coagulate the feeding vessel, after which the lesion is excised in the manner described later in this chapter.

Postsurgical management includes complete voice rest for 48 hours followed by soft, limited vocalization for 10 days. Inhalation of cool mist during the first week prevents drying of the mucosa and promotes better healing.

Polypoid degeneration

Polypod degeneration of the vocal cords is evidenced by a collection of fluid in the loose areolar tissue below the epithelium along the whole length of the cord. These changes can be unilateral or bilateral, and they are commonly attributed to tobacco smoking or vocal abuse. Although this condition can be treated by surgical excision, the patient should stop smoking and avoid abusing the voice to prevent recurrence.

Cysts

Cysts are most commonly present in the supraglottic larynx but may be also found in the true vocal cords. They are thought to originate from minor salivary glands within the larynx. Cysts rarely cause obstructive symptoms but will cause hoarseness when present in the vocal cords.

Cysts found in the supraglottic larynx are easily treated using the CO_2 laser by unroofing the cyst, aspirating its contents, and masupializing it completely. Healing is usually excellent. Vocal cord cysts, on the other hand, are carefully dissected with microlaryngeal probes, forceps, and scissors and must be excised completely to prevent recurrence.

Granuloma

Vocal cord granulomas usually arise posteriorly in the area of the vocal process. A history of gastric reflux, previous traumatic or prolonged endotracheal intubation, or hyperkinetic speech should be ascertained before treatment is begun. The best treatment of vocal cord granulomas is to remove the factor that is causing chronic irritation. Patients may require speech therapy and should be treated for reflux even when radiologic studies do not confirm gastric acid reflux. When surgical treatment is required, the CO_2 laser is ideal for excision. Coupled to an operating microscope, the laser can be used to excise the granuloma precisely followed by vaporization of any remaining granulation tissue without exposing the underlying perichondrium of the arytenoid cartilage. Because the pathologic process is inflammatory in nature, treatment with antibiotics and systemic steroids for up to a month postoperatively is usually necessary for complete resolution and healing.

Surgical technique

The characteristics of benign vocal cord lesions dictate the choice of technique to be used. The key to successful laryngoscopic excision of a lesion is good exposure with a large-bore fiberoptic laryngoscope that includes a suction channel for evaucation of smoke on a suitable suspension system. The preferred laryngoscope suitable for most patients is the Dedo-Jako anterior commissure laryngoscope attached by a BU suspension system to the side of the operating table. When modified to fit the BU suspension system, the Kleinsasser laryngoscope is also suitable. The patient's eyes and face are well protected with moist cotton eyepads and wet towels.

The usual magnification setting on the microscope is 16 times. For a smaller lesion, however, magnification of 25 times may be desirable. The higher magnification is usually used for vocal cord nodules. Because benign lesions are usually superficial and involve only the mucosa, the mucosa should be incised to the level of Reinke's space. The CO_2 laser is used with the microspot delivery system (0.3 mm spot diameter) to outline the area around the lesion. When the outline is completed, the mucosal surface is released and should separate easily from its surrounding tissue. This defines the disease process and the depth of resection.

The procedure proceeds with good hemostasis, permitting unobscured visibility. At this point, the lesion can be excised in one of two ways. The lesion can be grasped with a 1 mm microforceps, retracted medially, and dissected with a 1 mm upturned microscissors (see Fig. 113-1, B). In the other method, the lesion can be excised using the microspot CO_2 laser, creating a plane of dissection between the lesion and underlying Reinke's space. The advantage of the CO_2 laser is mainly gained for vascular lesions, such as hemorrhagic polyps. When the small laser impact spot and intermittent exposures (0.1 second) at 1 to 2 W are used, minimal heat is transmitted to the underlying vocalis muscle and the surrounding mucosa. No thermal charring of the pathologic specimen is noted.

The decision to use CO_2 laser microspot excision or the microscissors mainly depends on the size of the lesion, its character (pedunculated versus sessile), and the degree of vascularity. When the lesion is small (1 to 2 mm) or pedunculated with a narrow stalk, the preferred technique for excision is by microforceps and microscissors. This is a quicker and more efficient method that avoids thermal damage. When the laser is used for excision of benign lesions, it is extrmely important to provide constant tissue tension throughout the procedure to avoid heat coagulation of the specimen and to prevent damage to surrounding tissue. To keep the laser excision in an even plane of dissection, it is important to outline the lesion at the beginning of the procedure (see Fig. 113-1, A). This step will loosen the specimen from the surrounding mucosa and define the appropriate depth of excision.

The CO_2 laser with a 0.3 mm impact spot is used at 1 to 3 W of power in a pulse mode of 0.1 second. All patients receive dexamethasone (Decadron), 10 mg, immediately before operation to prevent postoperative laryngeal edema.

Treatment of vocal cord nodules by laser excision is safe and easy. Some surgeons use the laser to vaporize the lesion until it reaches the level of healthy tissue. This is a good technique for sessile indistinct lesions, but it does not permit histologic examination of the lesion. If possible, it is better to outline the lesion using the CO_2 laser and to excise it with either the microscissors or the laser. At the end of the operation for laryngeal nodules, a slight divor or indentation should be present at the surgical site because the site is under tension or stretch when on suspension.

Good exposure of the glottis is essential when treating polypod degeneration, and the entire length of both cords should be visualized. An incision is made on the superolateral aspect of the vocal cord (Fig. 113-4, A) with the CO_2 laser power set at 2 to 3 W and intermittent pulses at 1/10 second. The polypoid material is removed with microsuction (Fig. 113-4, B) or, if viscid, it is vaporized with the laser. A microflap is developed, and microlaryngeal probes are used to free loculations of the thick gluelike myxomatous material without traumatizing the healthy mucosa or the vocalis muscle (Fig. 113-4, C). The excess mucosa of the microflap is trimmed using upcutting spot microlaryngeal scissors (Fig. 113-3, D). The mucosa is welded by approximating the edges and using the CO_2 laser in a defocused mode at a power setting of 100 to 200 mW (Fig. 113-3, E). When the mucosal ablation technique is used, reepithelialization will require several weeks, and scarring is variable.

Papillomatosis

Recurrent respiratory papillomatosis affects mucous membranes of the respiratory tract (Figs. 113-5 and 113-6). It is characterized by multiple and recurrent squamous papillomas, causing hoarseness and respiratory obstruction (Strong et al, 1976). The most common site is the larynx (Fig. 113-5), but other areas of the upper and lower respiratory tract (Fig. 113-6) may also be involved. Recurrent respiratory papillomatosis is less common and usually less troublesome in adults than in children. Histologic, ultrastructural, and immunohistochemical studies implicate the human papillomavirus in the cause of this disease (Duggan et al, 1990).

Although no treatment has been successful in curing this disease, spontaneous remission can occur. Frequent excisions are recommended to try to avoid tracheotomy and to permit the child to develop good phonation, preserving normal vocal cord anatomy as much as possible.

The CO_2 laser has been helpful in the treatment of these lesions in the larynx, pharynx, upper trachea, and nasal and oral cavities, permitting longer disease-free intervals than is possible when using cold instruments. When coupled to an operating microscope, the laser vaporizes the lesions with precision, causing minimal bleeding. When used with a no-touch technique, it minimizes damage to the vocal cords and prevents scarring (Fig. 113-5, B). In a review of 200 patients with respiratory papillomatosis, Simpson and Strong (1983) were able to avoid performing tracheotomy in 99% of these patients.

Laser excision of laryngeal papillomas is performed at a power setting of 2 to 3 W (0.3 mm spot size) and at an exposure of 0.5 to 1 second. It is important always to take a biopsy from the lesion before treatment, particularly when it appears invasive. The lesions are gradually vaporized to the level of the mucosa, avoiding entry into Reinke's space and the deeper vocalis muscle. Intermittent exposure at low power settings may lengthen the time of operation; however, it is important to limit thermal injury of the surrounding tissue. A microwhistletip type of suction device (Karl Storz Endoscopy-America Inc) is kept close to the laser impact site to remove the hot steam of vaporization. The blunt tip can also be used as a probe to retract the false cord or roll the true cord for exposure of the subglottic region. The anterior commissure should also be avoided, leaving at least 1 mm of untreated mucosa so that a web does not develop during the healing period. The patient should be seen every 6 weeks or less, depending on growth rate. Adult patients are usually treated when deterioration of the voice occurs.

Arytenoidectomy

Another common application of the CO_2 laser is endoscopic arytenoidectomy for treatment of bilateral vocal cord paralysis. Endoscopic techniques of arytenoidectomy that avoid an open laryngofissure approach with its attendant imprecision and potential morbidity were described by King (1939). Unpredictable formation of scar tissue and failure of treatment led Ossoff et al (1990) to improve this technique by using the CO_2 laser for more precise vaporization and hemostasis.

It is important to expose the posterior commissure during endoscopic arytenoidectomy; this exposure can be accomplished using a posterior commissure laryngoscope (Ossoff et al, 1983) or wide-bore laser laryngoscope. The arytenoid to be resected should be well exposed, as should the posterior commissure and at least half of the other arytenoid cartilage. Placement of a 5.0 or 5.5 red rubber endotracheal tube wrapped with reflective metallic tape separates the vocal cords anteriorly, providing more working space and facilitating exposure.

The CO_2 laser is coupled to an operating microscope with a 400 mm objective lens. The laser is set at pulse duration of 0.1 second in repeat intermittent mode at a power of 10 W and a focused spot size of 0.8 mm (2000 W/cm^2) (Ossoff et al, 1990). Laser power is lowered accordingly when a smaller spot impact is used. The mucosa overlying the arytenoid cartiage is vaporized, exposing the underlying cartilage. The corniculate cartilage and apex of the arytenoid are vaporized using the laser in the continuous mode (Fig. 113-7, A). The upper body of the arytenoid cartilage is vaporized after ablating the perichondrium that overlies it, using the laser in the continuous mode at a power setting of 15 W. The lower body of the arytenoid cartilage is vaporized working laterally to medially, with the laser set at 0.1 second in intermittent pulses and the power set at 10 W. The vocal and muscular processes are vaporized using the same laser settings. The mucosa is cut 2 to 3 mm in front of the vocal process so as to create a triangular posterior airway. A small area lateral to the vocalis muscle is vaporized to induce scarring and promote further lateralization during healing. It is extremely important not to traumatize the posterior commissure mucosa because scarring in this region will result in treatment failure (Fig. 113-7, C). In a series of 28 patients reported by Ossoff and associates (1990) the success rate of this procedure was 86%.

The use of the CO_2 laser attached to the operating microscope enables precise, hands-off, relatively bloodless endoscopic laryngeal surgery. The disadvantages include inaccurary in placement of the vocal cord compared with external procedures and the learning curve associated with new instrumentation and a new procedure. Potential complications include granuloma formation, posterior commissure strictures, complete or partial failure with medialization of the cord, loss of good voice production, perichondritis, and aspiration through a largely patent posterior commissure.

Infantile subglottic hemangioma

Infantile subglottic hemangioma is rarely seen or reported in the literature, but when present, its treatment is challenging. Cavernous hemangioma is covered later in this chapter (see Vascular Lesions). Infantile subglottic hemangioma occurs in children a few months old and presents as a lateral bluish subglottic and submucosal mass that causes respiratory symptoms. When mildly symptomatic, patients with these lesions are treated conservatively with steroids and observation. Although the lesions usually involute spontaneously with time, tracheotomy is occasionally needed when the airway is severely compromised. Healy et al (1984) reported using CO_2 laser to vaporize the hemangioma until an adequate airway was achieved.

The Nd:YAG laser, although ideal for low-flow venous malformations, is not recommended for a subglottic hemangioma because this lesion is a more compact capillary type of vascular lesion. The depth of penetration of the Nd:YAG laser presents a serious risk to the infant's larynx and trachea, with the potential for stricture formation and tracheal perforation.

Glottic carcinoma

The use of microlaryngeal techniques with laser technology has also been applied to malignant tumors of the larynx, namely, squamous carcinoma. Strong and Vaughan (1971) described the first applications of the CO_2 laser for the endoscopic treatment of early dysplasia and carcinoma of the vocal cord. These early results were substantiated by other investigators (Blakeslee et al, 1984; Koufman, 1986; Ossoff et al, 1985), indicating excellent control of carcinoma in situ and early (T1) carcinoma of the vocal cords given the appropriate indications. Laser resection of well-defined lesions confined to the mobile segment of the vocal cord with good endoscopic exposure provided results equal to those of radiation therapy. Endoscopic laser techniques have been extended to the supraglottic larynx, but the indications are not as clear-cut.

Since the introduction of the CO_2 laser for microlaryngeal application, controversy has arisen about its use in the treatment of patients with laryngeal carcinoma. Laser excision is one of the many treatment options available for carcinoma in situ and early (T1) laryngeal carcinoma, along with open partial laryngectomy, extended 75% laryngectomy, total laryngectomy, and radiotherapy. The CO_2 laser has many uses in the treatment of laryngeal carcinoma: excisional biopsy of tumors, excision of carcinoma in situ, invasive T1 laryngeal carcinoma, diagnosis and staging of laryngeal carcinoma, tumor debulking, salvage after radiation therapy, endoscopic laser excision of large tumors to avoid tracheotomy before laryngectomy, and palliation of nonresectable tumors, such as in the case of elderly or debilitated patients.

The microsurgical CO_2 laser system is an excellent endoscopic tool for the diagnosis and staging of laryngeal carcinoma. The key concept is excisional biopsy by obtaining an adequate specimen for pathologic examination. Because mucosal neoplastic multicentricity is common, all early neoplastic processes of the vocal cords are examined microsurgically with supravital staining with 2% toluidine blue. Normally, the squamous lining of the true vocal cord does not stain at all, whereas the respiratory epithelium and areas of superficial carcinoma do stain. Excisional biopsies of these areas are taken for pathologic examination. The staining technique helps define areas for biopsy.

The technique of excisional biopsy for early vocal cord carcinoma varies according to the lesion. Margins of at least 1 to 2 mm around the area of the carcinoma are necessary. The same basic technique is used: the CO_2 laser outlines the area of excision and provides a bloodless field (Fig. 113-8). The laser is used in an intermittent mode to take a somewhat deeper margin through Reinke's space down to, but not exposing, the vocalis muscle in cases of carcinoma in situ. When the CO_2 laser is used for staging, the biopsy is taken deeper and includes part of the vocalis muscle to degtermine its involvement. Magnification of 16 times with the operating microscope is necessary. Although these lesions may still be staged clinically as T1 or T2, the clinician should suspect a more biologically aggressive and advanced tumor when the muscle is invaded.

When transoral laser excision is used as a curative treatment for early carcinoma of the vocal cords, a success rate of about 90% is possible when patients are selected carefully. Laser resection is highly cost-effective: one session of treatment takes about an hour and is associated with minimal morbidity. Vocal function is satisfactory several weeks after operation, with scar tissue filling in the defect of the resected muscle with a normal mucosal surface. No aspiration occurs even in patients who have undergone subtotal cordectomy as long as the arytenoid cartilage is not removed. Contraindications for transoral resection of early carcinoma of the vocal cords are involvement of the anterior commissure (Krespi and Meltzer, 1989) or vocal process, supraglottic extension beyond the floor of the ventricle, and subglottic extension. With subglottic extension, laser excision would leave a positive margin near the cricothyroid membrane. This was clearly shown on whole organ laryngeal sections by Kirchner et al (1974). During endoscopic excision of early vocal cord carcinoma, laser power of 4 to 6 W is needed in exposure burtsts of 0.5 to 1 second (spot size of 0.3 mm). Cancer control rates in the range of 89% to 96% have been reported by Blakeslee et al (1984), Ossoff et al (1985), Koufman (1986), and Wetmore et al (1986). These control rates are comparable to those reported by radiotherapists for the same type of early carcinoma.

Supraglottic carcinoma

Laser excision of benign lesions of the supraglottis is an acceptable mode of therapy. In 1983, Davis et al reported the first series of patients who underwent laser excision of epiglottic lesions. The procedure was performed for cancer staging, excision of benign lesions, and treatment of malignant disease. The main problem at that time was exposure of the supraglottic area even with large-bore laryngoscopes, such as the Jako laryngoscope.

In 1990, Zeitels et al reported laser excision of supraglottic carcinoma in five patients using an adjustable supraglottiscope. Good results were achieved without delayed healing, complications, or the need for tracheotomy. The supraglottiscope is inserted, and the blades are opened after positioning the scope for optimal view of the tumor. The size and location of the tumor are noted, and careful palpation is performed to assess the depth of tumor invasion. The vallecular mucosa and the hyoepiglottic ligament are incised, and dissection is carried out anteriorly into the preepiglottic space. When no invasion is seen, excisional biopsy is completed with adequate margins aided by frozen section examination. Assessment of invasion of the pre-epiglottic space is facilitated by using the operating microscope. When clinical staging is substantiated and margins are free on final pathologic study, no further treatment is required.

Endoscopic management of epiglottic carcinoma is useful for surgical staging and appears to be a good therapeutic option in selected early lesions. When the preepiglottic space is invaded by tumor, the procedure is terminated, and definitive treatment (open laryngectomy with or without radiotherapy) should be planned.

Rhinology

Most of the lasers now available to the otolaryngologist have applications in nasal surgery. The CO_2 laser, which mainly cuts and ablates tissue, is used most often for vaporization of hypertrophied turbinates and occasionally for coagulation of small blood vessels in the milder forms of hereditary hemorrhagic telangiectasia (Kluger et al, 1987).

In the noncontact mode, the Nd:YAG laser is a good coagulator. It has been used successfully for coagulation of vascular lesions of the nose, such as low-flow venous malformations and hereditary hemorrhagic telangiectasia. Injury to the septum and turbinates can occur because of the scatter or reflection of the laser beam, but injury can be avoided by using low power (20 to 25 W) and short exposures (0.5 to 0.7 second).

Various procedures for the correction of choanal atresia have been advocated in the past. A transpalatal approach permits good exposure, whereas the transnasal approach is more risky because of poor visualization. The use of the CO_2 laser in this procedure has many advantages. The approach is simple, and, when coupled to an operating microscope, the laser permits the delivery of the beam inside the nasal cavity. The procedure can be performed rapidly and accurately because of the hemostatic effects of the laser, and postoperative edema is minimal or absent. The CO_2 laser was helpful in opening the bony plate in seven patients with choanal atresia who were treated by Healy et al (1978). Bone ablation was not possible in one patient in whom the bony plate was more than 1 mm thick; however, 7 of 10 choanae remained patent, and no complications were encountered.

The KTP/532 and argon lasers have similar characteristics. Thei wavelengths can be transmitted through small, flexible fibers, which make their application in endonasal surgery easy. These lasers can cut and coagulate adequately, but their effect on tissue is superficial.

Both lasers have been used for endoscopic sinus surgery. Their use is limited to mucosal incisions and hemostasis in the case of minor bleeding, the coagulation and debulking of large polyps, and the reduction of turbinate bone in cases of vasomotor rhinitis.

The KTP/532 laser has been reported by Levine (1989) for its use in rhinology. The laser was used in a focused beam at 9 to 12 W for cutting tissue and at 4 to 5 W for coagulating or vaporizing. Before cutting any tissue where bleeding may occur, the laser is used as a coagulator in a defocused low power density mode. For the treatment of vascular lesions, the laser is used in a circular fashion, peripherally to centrally, starting at the edges of the lesion and finally approaching the central vessels.

Choanal polyps are removed by identifying the stalk coming out of the natural ostium and cutting across its base attachment. Vasomotor rhinitis that is not responsive to medial therapy can be treated by cross-hatching the anterior half of the inferior or middle turbinates to achieve coagulation and reduction in size.

Otology

Laser use in otology has been met with skepticism since the first otologic application in human subjects in 1979 by Escudero et al. After performing animal studies and setting the optimal power and exposure time, they used the argon laser for achieving hemostasis and welding of fascia during tympanoplasty. Controversy about the use of lasers in otology has arisen concerning potential damage to the inner ear. Silverstein et al (1989) reported good results when performing stapedotomies using the KTP/532 laser; however, they pointed out that more dizziness was associated with the laser than with conventional techniques, which they ascribed to possible heating of the perilymph. Gantz et al (1980) reported the occurrence of a perforation in the cat saccule using the argon laser.

Perkins (1980) performed stapedotomies on 11 patients using the argon laser and reported good results and no complications. To vaporize the stapes footplate, they used the laser with a spot size of 50 to 100 microm, a pulse duration of 10 msec, and a power of 0.7 W. A study of human temporal bones showed no evidence of damage to the macula of the saccule (Perkins, 1980). Gardner (1984) used the CO_2 laser to perform stapedotomies on cats and human temporal bone. His results indicated that the CO_2 laser can be used effectively and safely. Bartels (1990) reported on the use of the KTP/532 on 80 subjects for primary and revision stapedectomy. He reported good results with no complications.

Laser stapedotomy appears to have some advantages over traditional techniques. The chance of fracturing or mobilizing the stapes footplate is less when the posterior crus is vaporized before removing the superstructures, thus decreasing the risk of a floating footplate. The stapedotomy can also be performed easily with minimal trauma and without vibration.

The argon, CO_2, and KTP/532 lasers have been useful for ossicular surgery and particularly stapedotomy. The CO_2 laser is especially easy to use because of its articulating arm delivery system that can be connected to the operating microscope and because of its small spot size (0.2 to 0.3 mm at a focal length of 250 mm). The surgeon can operate using a no-touch technique, with good visualization and precise ablation of the ossicles.

The argon and KTP/532 laser beams are usually delivered through a flexible fiber that is held in the hand like a middle ear instrument. The surgeon may also choose to use a micromanipulator.

The excellent absorption by water of the CO_2 laser energy, and, to a lesser degree the argon and KTP/532, is a good protective measure of the neuroepithelium present in the vestibule because transmitted heat will dissipate on the footplate surface or in the perilymph.

Lasers used in ear surgery are particularly helpful in revision procedures. In these instances, they are useful in cutting adhesions bloodlessly without exerting force or manipulating middle ear structures and thus riskin inadvertent damage to the inner ear as in instances of vestibular fibrosis.

Oral Cavity

In the oral cavity, the laser is mainly used as a hemostatic cutting knife, and for this purpose the CO_2 is the laser of choice. It is used with a handpiece (Fig. 113-9) or with a micromanipulator to delineate and resect small tumors of the tongue, the floor of the mouth, and the mucosa of the cheek. The KTP/532 laser, with its flexible fiberoptic delivery system, may also be used for the excision of benign and malignant lesions of the oral cavity; however, its soft tissue interaction is not as precise as that of the CO_2 laser. The Nd:YAG laser in the noncontact mode is a poor cutting tool, but it can be used to coagulate selected low-flow vascular tumors of the oral cavity. It can also be used occasionally to coagulate tongue varicosities. When used in the contact mode with specialized contact tips, the Nd:YAG laser approaches the CO_2 laser in its precise cutting ability with hemostasis of capillary-sized blood vessels.

The advantages of a CO_2 laser include good hemostasis, precise cutting when coupled to an operating microscope, uncomplicated healing, and less pain than is associated with the electrocautery. The electrocautery should be available for all laser excisions of the oral cavity. Although capillary hemostasis is satisfactory, ligation of large blood vessels (> 5 mm) is occasionally required, particularly in the base of the tongue.

Early (T1) carcinomas of the tongue are excised by retracting the lesions using a silk suture on either side (Fig. 113-10). This process will also permit orientation of the lesion after removal. Adequate exposure can be obtained with the usual mouth gags and retractors, exposing upper and lower alveolar ridges, floor of the mouth, buccal mucosa, tongue, palate, and tonsils. Toluidine blue (2% solution) is useful to point out areas of multicentric carcinoma in situ or early invasive carcinoma. An adequate surgical margin should be obtained and examined by frozen section to ensure complete excision, and the specimen should be oriented properly for histologic examination.

The CO_2 laser beam can be delivered using a handpiece or a micromanipulator attached to a microscope. The advantages of the operating microscope are that it permits magnification with better appreciation of the laser effects on tissue and enables joystick precision. The microscope is preferred for stationary targets, such as the floor of the mouth, palate, immobile tongue, and retromolar area. The handpiece is preferred for mobile areas, such as the mobile part of the tongue and cheeks. The surgical defect is not sutured or grafted but is left to heal by secondary intention.

Vascular Lesions

Laser treatment of vascular malformations, particularly with the CO_2 and argon lasers for excision and coagulation, has been reported by Dibartolomeo (1983), Healy et al (1984), and Apfelberg et al (1985). The argon laser has been useful for the treatment of patients with port-wine stains and superficial telangiectasias; however, it does not appear to be beneficial for the treatment of deeper vascular lesions, such as venous malformations. The CO_2 laser hase been used as a surgical tool to excise small localized hemangiomas and to vaporize capillary subglottic hemangiomas. Reports by Dixon et al (1986), Rosenfeld and Sherman

(1986), and Shapshay et al (1987) pointed to the excellent results achieved with the Nd:YAG laser in the treatment of patients with vascular lesions of the oral cavity, particularly low-flow venous malformations. Because of its greater depth of penetration and scatter into the soft tissue leading to better photocoagulation, the Nd:YAG laser is more effective in the treatment of patients with deep vascular lesions.

Vascular tumors often present in the head and neck. In a review of 32 patients treated at the Lahey Clinic (Rebeiz et al, 1991), the most common site of involvement was the tongue, followed by the buccal mucosa, lip, and nose. Most of the patients presented with more than one lesion involving different parts of the head and neck. The larynx was involved in five patients who were seen because of breathing difficulty or hoarseness.

Treatment should be planned in several stages, depending on the character, location, size of the lesion, and age of the patient because the majority of capillary hemangiomas will involute by the time the patient reaches the age of 7 years. The risk of necrosis and scarring of the surrounding normal tissue is higher when the laser energy use is excessive (> 40 W at continuous exposure). When dealing with an extensive venous malformation, it is better to undertreat a lesion and plant treatment in several stages. The treatment plan is modified according to the response obtained rather than risk damage to healthy tissue, resulting in necrosis and scarring, particularly for lesions of the oral commissure, pharynx, and, most important, the larynx.

The Nd:YAG laser power used is 20 to 30 w at 0.5- to 1-second pulse duration in a punctate nonoverlapping technique to treat low-flow venous malformations. A fiberoptic delivery system (2.1 mm quartz fiber) is used without a focusing lens and is held with a malleable suction tip 1 to 2 cm away from the tissue while the surgeon observes shrinkage of the lesion. All procedures are performed under general endotracheal anesthesia. For some patients with lesions of the oral cavity or tongue, nasotracheal intubation is preferred. The procedure lasts from 15 to 30 minutes depending on the size and location of the lesion.

For larger or thicker venous malformations of the cavernous type, a glass slide is used to compress the lesion when possible (for example, with lesions of the tongue and cheek) (Fig. 113-11), reducing its thickness to 1 cm. Steroids are routinely administered intravenously immediately before operation to diminish postoperative edema.

A challenging aspect of venous malformations of the head and neck occurs when the larynx is involved. Lesions of the larynx may be solitary or, more commonly, associated with other pharyngeal or oral lesions. The only alternative treatment of laryngeal lesions is laryngofissure and excision, but this treatment carries a risk of bleeding, swelling, and obstruction of the airway and changes in the voice. The Nd:YAG laser, with its fiberoptic delivery system, can be inserted easily through the laryngoscope and used to coagulate the lesion under direct vision.

Pain is usually absent or minimal in most patients, even when swelling and necrosis are severe. The reason for this finding is not well understood, but it may be that the sensory nerve endings are either destroyed, as in third-degree burns, or are unaffected by the Nd:YAG laser wavelength because of their color and poor absorption.

The patient must be aware of the treatment plan and warned not to expect excellent results from the first procedure. A useful technique for large malformations is to compress the tissue under a glass slide to a 1-cm thickness. This compression permits better penetration of the laser beam into the tissue, affecting the full thickness of the lesion and using less total energy.

Venous malformations present a therapeutic challenge. Surgical treatment often results in high morbidity, cosmetic and functional deformities, surgical risk of bleeding, and injury to vital structures, such as nerves and blood vessels. Cure is rarely achieved, and treatment is usually palliative. The Nd:YAG laser is a perfect tool for the treatment of patients with these lesions because of its coagulation properties, and its beam is well absorbed by vascular tissue. Most patients require several procedures, often planned preoperatively, with an interval of 4 to 6 months between treatments. In the series of patients treated at the Lahey Clinic (Rebeiz et al, 1991), excellent results were obtained in the majority of patients, with minimal cosmetic and functional deformities.

Laser Bronchoscopy

The role of laser technology in the management of airway obstruction is well established. Malignant obstruction is palliated more effectively with the Nd:YAG laser, which has distinct advantages over other lasers with regard to hemostasis. Benign stenotic lesions of the trachea and proximal main bronchi are treated more effectively with the CO_2 laser.

Subglottic and tracheal stenosis

Treatment of patients with benign subglottic stenosis with the CO_2 laser is one of its earliest endoscopic laser applications, and CO_2 laser therapy is still well accepted as the first approach to the problem of benign stenosis of the upper airway. Benign subglottic and tracheal stenoses are caused by previous tracheal intubation, tracheostomy, tracheal trauma, inflammatory diseases, and idiopathic stenosis.

Since its introduction into medical practice in the early 1970s, laser technology has provided the precision and hemostasis necessary for the endoscopic management of obstructing airway lesions. Therapeutic bronchoscopy using different types of laser energy can now be used to treat various benign and malignant lesions that previously required open operation.

The CO_2 laser still has an important role in tracheobronchial laser therapy and remains and ideal therapy for patients with benign stenosis and tracheobronchial papillomatosis (Shapshay and Simpson, 1983). The excellent cutting and vaporization qualities of the CO_2 laser energy permit discrete resection of benign stenosis with minimal damage to the airway wall. Central airway papillomas can undergo vaporization with the CO_2 laser with minimal bleeding (see Fig. 113-5).

The CO_2 laser is associated with precise and predictable soft tissue interaction, minimal damage to surrounding normal tissue, and minimal formation of char. These characteristics make the CO_2 laser ideal for the treatment of patients with benign tracheal stenosis. The use of a rigid bronchoscope is necessary for the CO_2 laser bronchoscopy because the CO_2 laser energy cannot be transmitted through a flexible fiber. In standard rigid bronchoscopy with the CO_2 laser, an articulating mirror system is used for the transmission of laser energy, and the laser beam must be channeled down the barrel of the bronchoscope. Because the laser is coupled to the proximal end of the bronchoscope, precise aiming is somewhat difficult. If the laser energy could be released closer to the lesion to be treated at the distal tip of the bronchoscope, precision would be increased and telescopic optics could be used.

No flexible fiber is yet available that is suitable for transmission of the CO_2 laser. However, delivery systems for the CO_2 laser are being developed in an attempt to provide safe, efficient, and convenient application in the tracheobronchial tree. A new semirigid metallic CO_2 laser waveguide, InfraGuide (Heraeus LaserSonics, Inc, Milipitas, Calif), has recently become available, which can be positioned within the bronchoscope along with a telescope and suction catheter.

Healey et al (1974) reported successful management of 177 pediatric patients with benign tracheal stenosis, tracheal granuloma, and papilloma. They recommended a trial of endoscopic laser therapy in patients with acquired tracheal stenosis before performing an open procedure, which is often associated with higher morbidity. Endoscopic laser radial incision followed by dilation of the stenosis should be considered as the first line of management in patients with cicatricial or weblike benign tracheal stenosis.

Technical limitations in the delivery systems have been evident since the early application of the CO_2 laser in the trachea and bronchi. The main problem has always been the inability of the CO_2 laser beam to pass through commonly available quartz fibers because of its long wavelength (10.6 microm) in contrast to the Nd:YAG and argon lasers with much shorter wavelengths (1.06 and 0.5 microm respectively), which can be delivered through these dibers. The first CO_2 laser delivery system used by Strong and Jako (1972) included a micromanipulator (Americal Optical Corporation, Southbridge, Mass) that coupled the CO_2 laser to the operating microscope and permitted precise application on the vocal cords. Two years later, the same system was used with a coupler attached to a modified rigid bronchoscope for CO_2 laser treatment of the lower airway. Several improvements have been made to this original system. Shapshay and Simpson (1983) reported on the use of an early version of a bronchoscopic coupler attached to a modified rigid bronchoscope in the management of tracheal lesions. Ossoff and Karlan (1982) further advanced the coupling of this laser to rigid bronchoscopes.

A hollow semirigid waveguide (Heraeus LaserSonics, Inc) has been developed to transmit the CO_2 laser beam. The principal advatage of the waveguide system is the ability to position the laser beam accurately on the target tissue. An open rigid bronchoscope system can be used with suction catheters and telescopic optics.

Technique

General intravenous anesthesia with muscle relaxation is used in most patients. Adequate ventilation is achieved by a manually driven Venturi jet attached to the side arm of a ventilating bronchoscope. In some instances, topical anesthesia with intravenous sedation is used, permitting spontaneous ventilation.

The CO_2 laser is used at an average power setting of 10 to 12 W with 0.5 secon exposure. Two lengths of the waveguide are available, 30 and 45 cm, with an outer diameter of 3 mm that ensures that the waveguide will fit into adult-sized rigid bronchoscope. The energy transmission of the waveguide is greater than 70% for the CO_2 wavelength and approximately 20% for the helium-neon laser wavelength.

Patients are intubated with the open tube rigid bronchoscope after induction of general intravenous anesthesia and institution of Venturi jet ventilation. The stenotic trachea is incised using the technique of laser radial incision and dilation described by Shapshay et al (1987) (Fig. 113-12). This method is effective in opening the cicatricial scar formation without causing a circumferential defect. Gradual gentle dilation of the trachea is performed by increasing the size of the rigid ventilating bronchoscope. This technique permits retention of epithelial areas between incisions and promotes rapid reepithelialization of the area (Fig. 113-13). Patients are usually extubated in the operating room and transferred to a recovery room for observation.

The CO_2 laser has definite advantages for the treatment of patients with benign tracheal stenosis because of its excellent cutting abilities and shallow, predictable tissue penetration. The CO_2 laser waveguide delivery system has provided short-term and long-term results similar to those of existing bronchoscope delivery systems but permits simultaneous use of better optics and more precise delivery of high-power density CO_2 laser energy.

Obstructing endobronchial lesions

The application of laser technology to the endoscopic treatment of patients with tracheobronchial disorders began in 1973 with the use of the CO_2 laser to ablate benign tumors, such as respiratory papillomas (Strong et al, 1974). Since then, several types of lasers have proved to be precise, powerful, and relatively safe tools for endoscopic management of lesions obstructing the airway (Shapshay et al, 1983; Toty et al, 1980). The effectiveness and safety of laser application in bronchology were enhanced after the introduction of the Nd:YAG laser in 1980 (Dumon et al, 1982, 1984; Hetzel et al, 1983; McDougall and Cortese, 1983). The special hemostatic qualities of this laser energy make it the most suitable laser for endoscopic removal of malignant tracheobronchial lesions with a propensity for hemorrhage into the airway.

The epidemic incidence of carcinoma of the lung during the last two decades has resulted in a considerable number of patients presenting with malignant lesions obstructing the central airways. These patients are often extremely symptomatic with profound dyspnea, uncontrolled hemoptysis, or postobstructive sepsis. The majority of patients presenting with lesions obstructing the central airways have tumors that are inoperable because of mediastinal or lymph node involvement or lesions that are too central for surgical resection. Chemotherapy has proved inadequate for the treatment of such patients.

Traditionally, most patients have been referred for external beam radiotherapy for control of endobronchial disease. However, some studies (Chetty et al, 1989; Saunders et al, 1984) have suggested that external beam radiotherapy is inadequate treatment for patients with bulky endobronchial tumors. Saunders et al (1984) demonstrated that 95% of patients treated with radiotherapy had evidence of persistent or recurrent tumor at the primary site at the time of autopsy. Chetty et al (1989) also noted a high incidence of persistent endobronchial disease in patients treated with external beam radiotherapy for lesions obstructing the large airways. These authors (Chetty et al, 1989; Saunders et al, 1984) suggested that local therapy might better relieve endobronchial obstruction while producing less toxicity.

The introduction of laser technology in bronchology is an important addition to the management of patients with endobronchial obstruction. Unlike ionizing radiotherapy, laser therapy may be used repeatedly for the palliation of malignant tracheobronchial obstruction. Classic papers by Toty et al (1981) and Dumon et al (1982) described the technique of Nd:YAG laser therapy for patients with malignant endobronchial obstruction and attested to the safety and effectiveness of this therapy. Brutinel et al (1987), in a series of 116 patients with 176 laser applications, indicated that the quality and duration of life were improved in patients with obstructing carcinoma who were treated with laser bronchoscopy. Although the CO_2 laser was the initial laser used for tracheobronchial laser therapy (Shapshay et al, 1983), its use in the treatment of patients with malignant obstruction has severe limitations because of the poor hemostatic properties of this laser wavelength. The hypervascularity of many malignant endobronchial neoplasms is best treated with the Nd:YAG laser because of its excellent coagulation properties (Fischer, 1987).

Our philosophy regarding indications and techniques of therapy is similar to that outlined by Dumon (1985). Central lesions are treated because they produce severe symptoms that warrant therapy despite the inherent risks of the procedure. We use the rigid bronchoscope in the majority of procedures because this instrument offers a number of advantages over the flexible bronchoscope (Duckett et al, 1985), including better control of hemorrhage because of the use of large suction catheters, assurance of ventilation with the Venturi jet, excellent visualization because of the high-quality optics of the telescope, and rapid removal of tumor through the open tube with large biopsy forceps (Fig. 113-14, A-C).

The flexible bronchoscope is often a helpful tool when used through the rigid bronchoscope for treatment of more distal or upper lobe tumors (Fig. 113-14, D) and tracheobronchial toilet; however, it is not adequate for the treatment of patients with highly vascular and bulky tumors. It is also useful in the outpatient bronchoscopy suite for the treatment of patients with small, noncritically obstructing tumors requiring photocoagulation for control of hemoptysis or for benign lesions, such as granulation tissue.

The anesthetic management of patients who require laser bronchoscopy can be challenging to the anesthesiologist and the endoscopist. Multiple anesthetic techniques are available for use with rigid bronchoscopy. Our technique is similar to that of Duckett et al (1985). In high-risk or elderly patients, the procedure is carried out with topical lidocaine, intravenous sedation, and assisted ventilation. With the topical technique, however, control of cough is often difficult, especially when applying the laser near the carina.

Mean operative times for patients with malignant lesions range between 30 and 40 minutes in contrast to operative times lasting several hours that have been reported when the flexible bronchoscopic technique is used (Brutinel et al, 1987). They noted a favorable survival rate in patients treated with Nd:YAG laser bronchoscopy compared with a group of historical controls at the Mayo Clinic.

Our experience in treating 269 patients with 400 bronchoscopy procedures using the Nd:YAG and the CO_2 lasers revealed the unique capabilities of these lasers in providing palliation for patients with obstruction of the central airway resulting from malignant tumors and for patients with selected benign stenoses (Beamis et al, 1990). Of 16 patients who were in respiratory failure and intubated at presentation, 40% could be extubated after laser bronchoscopy. The intraoperative mortality rare was 0.3%, which attests to the safety of this procedure. We believe that both the Nd:YAG and the CO_2 lasers should be applied through the rigid bronchoscopes when treating obstruction of the central airway.

Dermatology

Rhinophyma

Rhinophyma is an inflammatory disorder of the skin characterized by benign hypertrophy of adnexal sebaceous glands. It affects middle-aged men predominantly. The skin of the nose undergoes nodular enlargement characterized by hypertrophy of the sebaceous glands, with debris and sebaceous material collecting inside the dilated ducts and acini.

The nasal lesion causes disfigurement, and a foul odor is associated with the sebum. Loss of self-esteem caused by the cosmetic deformity is the main indication for treatment. As with tuberous sclerosis, many different treatment have been offered. Pastorek (1972) has advocated complete excision of the skin and sebaceous glands followed by skin grafting or partial excision of the dilated glands, leaving some glands and skin for reepithelialization, the standard treatment before laser surgery. It is not always possible to determine the level of excision precisely because of persistent bleeding.

Bohigian et al (1988) reported on the use of the CO_2 laser coupled to an operating microscope for the treatment of patients with rhinophyma. The CO_2 laser provided excellent hemostasis, which improved visualization and permitted accurate excision of the hypertrophied glands. Using the microscope for magnification permits layer-by-layer excision with preservation of the epithelial glandular remnants as a source for reepithelialization. The adequacy of the treatment is assessed during the procedure by squeezing the skin, trying to force out sebum. Failure to express sebum indicates that a good level of excision has been reached, that is, the epithelial elements of the sebaceous glands. The handpiece delivery system is used for larger rhinophymas and for "feathering" the edges of the excision at the end of the procedure.

Use of the CO_2 laser to excise rhinophyma is preferable to use of the electrocautery because it permits precise tissue removal, causes minimal scarring, and is associated with uncomplicated healing and minimal discomfort (Fig. 113-15).

Tuberous sclerosis

Tuberous sclerosis is an autosomal dominant progressive neurologic disease characterized by mental retardation, seizures, and skin angiofibromas. Facial angiofibromas occur in approximately 90% of patients with tuberous sclerosis and cause considerable disfigurement and emotional distress. Occasionally, angiofibromas may grow and cause obstruction of vision, and they may hemorrhage when manipulated. Often symmetric, they are located in the nasolabial groove and over the nose, cheeks, chin, forehead, and scalp.

Many treatment methods have been tried, including dermabrasion, fulguration, electrolysis, and excision with skin grafting. The CO_2 laser is an ideal instrument for treating these lesions (Bellack and Shapshay, 1984) (Fig. 113-16). When coupled to an operating microscope, the laser can precisely abltate the small lesions after the bulk has been vaporized using the handpiece. The micromanipulator is used with a 250 to 300 mm lens, a spot size of 0.3 mm, and laser power between 5 and 7 W. The depth of excision can be controlled easily and extends into the basal layer of the epidermis without damaging the underlying dermis. Postoperative wound care consists of hydrogen peroxide washes and application of an antibiotic ointment. Epithelialization is usually completed in 2 to 3 weeks.

Port-wine stains

Port-wine stains are often isolated or present as part of syndromes that involve blood vessels in other organs. Affected areas are the forehead, face, and neck. As opposed to other vascular lesions, port-wine stains do not disappear with time and persist into childhood and adult life. The main abnormality is an increase in the number of vessels and ectasia. The spectrum of colors of these lesions varies from pink to red to purple - an important consideration when choosing the appropriate laser wavelength for treatment.

Many laser wavelengths have been described for the treatment of this condition, including the KTP/532, Nd:YAG, CO_2, argon, and pulsed dye lasers. The CO_2 laser can achieve good results because its wavelength can seal vessels up to 0.5 mm in diameter. In addition, this wavelength causes little scatter and localized tissue damage and thus less scarring. The aim is to vaporize the cutaneou surface and to seal off the vascular channels below the surface. Scarring is still the main concern and the most common complication. Most clinicians agree that the pulsed dye laser is ideal for the treatment of port-wine stains because of its superficial effect and its good interaction with pigmented tissue and hemoglobin.

Treatment of port-wine stains with pulsed dye lasers and argon laser can be performed under local anesthesia on an ambulatory basis. The argon laser fiber is held 4 to 5 cm from the skin, and the minimum power required to achieve an effect is usually 1 to 1.5 W, with a pulse duration of 0.2 second (Noe, 1983; Silver, 1986).

Bailin (1983) reported a success rate of 57% in 37 patients treated for port-wine stains with the CO_2 laser. He used a pulse duration of 0.05 second, a power density of 498 to 796 W/cm^2, and a spot size of 2 mm.

A report on the flash-lamp tunable dye laser in the treatment of port-wine stains shows promising results (Morelli et al, 1986). The advantage of the tunable dye laser is that a wide variety of laser dyes can be used, depending on the desired wavelength. The dye selected for tretment of port-wine stains emits enery at 577 nanom, theretically ideal for selective absorption by hemoglobin and poor absorption by melanin, thus decreasing the risk of damage to normal skin and scar formation. This laser is used to treat both adults and children with good results. Tan et al (1989) reoprted excellent results in 33 of 35 children aged 3 months to 14 years who were treated with the flash-lamp tunable dye laser.

Experimental Lasers

Photodynamic therapy

Photodynamic therapy consists of administering a chemical agent to sensitize living tissue so that it can be activated by a light source at a given wavelength, which results in its cellular destruction. It is based on selective tissue absorption and retention of hematoporphyrin derivative. It had been known that porphyrins cause fluorescence of tumors, but Lipson et al (1960) were the first to describe the photodynamic properties of hematoporphyrin derivative.

Several investigators have demonstrated the use of hematoporphyrin derivative in photodynamic therapy for the treatment of carcinoma of the lung, obstructing tumors of the tracheobronchial tree (Balchum et al, 1984; Cortese and Kinsey, 1982), bladder tumors (Benson et al, 1983), gastrointestinal tumors (Hayata et al, 1985), and head and neck tumors (Gluckman, 1991; Keller et al, 1985). Although benign, respiratory papillomatosis has been treated on an experimental basis with photodynamic therapy (Abramson et al, 1988). Because the dye is absorbed by rapidly multiplying cells, it is picked up preferentially by the papillomas. When the laser light is aimed at the lesions, the tumor cells are destroyed.

Because of the severe skin photosensitization resulting from hematoporphyrin derivative, many clinicians consider photodynamic therapy an aggressive mode of treatment and limit its used to the palliation of malignant tumors. Hematoporphyrin derivative causes rapid necrosis of living cells when they are activated by light. The exact mechanism of cellular destruction is not known, but it is believed to be caused by the production of a singlet oxygen, which is highly destructive to the structure of the cell (Weishaupt et al, 1976).

The indications for the use of photodynamic therapy in the tracheobronchial tree differ among investigators. Cortese and Kinsey (1982) noted that hematoporphyrin derivative photodynamic therapy is useful only for the control of small superficial squamous cell carcinomas (carcinom in situ) of the tracheobronchial tree that are within the reach of the flexible fiberoptic bronchoscope. To define the role of photodynamic therapy as an endoscopic treatment of tumors of the tracheobronchial tree, a controlled multi-institutional study is under way in which a random sample of patients with partially obstructing carcinoma of the lung are treated with photodynamic therapy and radiation and are compared with a control group treated with radiotherapy alone.

The use of hematoporphyrin derivate in photodynamic therapy is limited because it is absorbed by inflammed and traumatized tissue to some extent as well as by tumors. Therefore it is not specific for tumors as one would desire. More distressing are complications related to dye toxicity, including severe skin photosensitivity for several weeks. The patient should be protected against sunlight with clothing and sunscreens or risk severe sunburn, especially when the procedure is performed in summer. These side effects, which may persist for more than 30 days, remain a major limiting factor for the application of hematoporphyrin derivative photodynamic therapy.

Rhodamine-123, another photosensitizing agent, has been the subject of an increasing number of recent investigations (Castro et al, 1987, 1991). It localizes selectively in the mitochondria of living tissue and is taken up and retained by many types of carcinoma cells, causing selective tumor toxicity at certain doses and significant normal tissue toxicity at high doses. Castro et al (1987) achieved better results by combining this photosensitizer with a visible light (argon laser) to perform photoradiation toxicity of tumors. They observed the death of tumor cells at temperatures as low as 40°C when performing photoradiation in vitro. They concluded that Rhodamine-123 at nontoxic doses of 1 micrg/mL enhances the tumoricidal effects of the argon laser at reduced temperatures. Rhodamine-123 does not cause the skin photosensitization seen with hematoporphyrin derivative, and it can be used at low nontoxic doses, both of which make its clinical application more attractive. Human trials have not yet begun.

New laser wavelengths

Holmium:YAG laser

The holmium:yttrium aluminium garnet (Ho:YAG) laser is a new solid-state laser operating at a wavelength of 2.1 microm. It is a pulsed laser with a 250 microsec pulse duration that is transmitted through small quartz fibers. It has the unique ability to ablate and cut bone and cartilage with a precision not seen with the commonly available continuous wave lasers (Shapshay et al, 1991a).

It has been used experimentally in endoscopic sinus surgery at the Lahey Clinic Medical Center (Shapshay et al, 1991b) and at Johns Hopkins Medical Center (Kennedy, 1991). The laser was used mainly to coagulate and shrink polyps, to incise and ablate ethmoid sinus bone and middle turbinate bone, to enlarge the maxillary and frontal sinus ostia, and to achieve hemostasis. It was helpful in making precise incisions in the middle turbinate, uncinate process, and bulla ethmoidalis, which permitted precise removal of these structures without avulsion. The pulse energy used was 0.5 to 1.5 Joules, and the repetition rate was 2 to 6 Hz.

In a series of 20 patients treated at the Lahey Clinic, no complications related to the use of the laser developed (Shapshay et al, 1991b). The average blood loss was 75 mL (range, 5o to 250 mL), and the mean operative time for bilateral sphenoethmoidectomy was 2 hours, which is comparable to the standard technique of endoscopic sinus surgery. The amount of postoperative crusting and synechia was moderate and similar to that seen after a conventional procedure. Healing was satisfactory in all patients.

The Ho:YAG laser is a safe and useful tool in endoscopic sinus surgery. Its application in nasal surgery could be extended to other procedures, such as endoscopic dacryocystorhinostomy, transsphenoidal surgery, optic nerve decompression, and interstitial photocoagulation.

Erbium:YAG laser

The erbium:YAG laser is a solid-state pulsed laser that emits radiation with a wavelength of 2.94 microm. This wavelength is well absorbed by water, with an absorption co-efficient of 7700 cm^{-1}. Because of the high water absorption, which is even greater than with the CO_2 laser, and its high pulse energy, the erbium:YAG laser can easily ablate soft tissue and, in particular, bone; it causes minimal damage to adjacent tissues. The high peak power produced in each pulse causes a rapid increase in tissue temperature, leading to microexplosion and ejection of microscopic fragments of tissue.

The use of this laser wavelength is still experimental, and several laboratory studies have shown its effects on soft tissue and bone (Nelson et al, 1989; Walsh et al, 1989). Because of its excellent bone and soft tissue interaction, future applications of this laser when coupled to an operating microscope may be in laryngeal surgery, sinus surgery, and otology. More studies are needed, however, to determine the extent of damage to the vocal cords, inner ear, and nerve tissue. Like the CO_2 laser wavelength, the erbium:YAG laser wavelength cannot be transmitted through flexible fibers; it can be used only with a handpiece or coupled to an operating microscope, which limits its application in the tracheobronchial tree.

Free electron laser

The term *free electron laser* was coined by Madey, who headed the group that developed this laser in 1976 (Houston, 1989). The new generation of free electron lasers is more efficient and operates at higher power (Houston, 1989).

The free electron laser provides continuous, tunable, coherent, and monochromatic electromagnetic radiation that extends from the ultraviolet to the far infrared spectrum. This laser consists of a high-energy electron beam that passes through a periodically alternating static transverse magnetic field that is made up of a series of magnets, which are lined up so that their polarity alternates. The magnetic field thus created forces the electrons in the beam to oscillate in a transverse direction and to emit a laser beam in a forward direction.

The free electron laser is still under experimental investigation. It is expected to stimulate more medical applications because it provides a wide variety of wavelengths from which to choose. A long-needed characteristic of a laser has been the simultaneous delivery or bleding of several wavelengths in the range of the CO_2, argon, and Nd:YAG lasers that would offer the advantage of both cutting and coagulating. With the free electron laser, this application is theoretically possible using one machine with the same optical system. The major limitation is its delivery system (fiberoptic transmission). The availability of new wavelengths will also lead to the development of dyes less toxic that the ones now available, thus improving photodynamic therapy.

The goal of providing less invasive endoscopic surgery on an outpatient basis may best be met with future developments and innovations in lasers and fiberoptics. Laser-assisted video endoscopic surgery is a relatively new concept for achieving cost-effective therapy and potentially eliminates more morbid open procedures.