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LASER BRONCHOSCOPY

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Laser bronchoscopy developed in the early 1980s. This presentation is the result of 20 years of everyday experience with the technique and numerous discussions at meetings and courses throughout the world.

BIOMEDICAL LASERS

What is a LASER? Each laser emits a beam corresponding to a specific part of the electromagnetic spectrum. In order of decreasing wavelength and increasing frequency, electromagnetic radiation ranges from radiowaves to gamma rays. Visible light is a narrow band from 400 to 700 nanometers (nm) between infrared and ultraviolet radiation. The wavelength of a laser depends mainly on the nature of the active material that is stimulated. An excimer laser emits in the ultraviolet range above 400 nm. Argon and KTP lasers emit in the green spectrum at 488 nm and 532 nm. Dye lasers emit yellow or red light between 580 and 630 nm respectively. YAG laser emits in the Infrared at 1064 nm and CO2 laser in the extreme Infrared at 10600 nm. YAP Laser emits in the Infrared at 1340 nm.
Laser light has three unique characteristics, i.e., monochromaticity, coherence and collimation. Monochromaticity means that all light in the laser beam is of one wavelength. Coherence means that all waves in the beam are in step in time and space. Collimation means that the waves are traveling along parallel ray directions.
Regarding collimation, it is important to note that laser light loses this characteristic when delivered through bare fibers which have an irregular tip cross-section. As a result, aiming and control of power density become problematic.
Fibers with metallic tips should be used and all the following discussion is contingent upon this prerequisite.

Effects of YAG laser light on living tissue: The effects of a laser on living tissue depend on the wavelength of the beam and the physical principles of light propagation. As already stated wavelength depends on the nature of the active material. The principles of light propagation can be summed up as follows. Light can be:

- transmitted, i.e. pass unaltered through an obstacle;
- absorbed, i.e. be converted into other forms of energy chiefly heat;
- diffused, i.e. be spread over a certain circumference and depth;
- reflected, i.e. bounce off the surface like a mirror.

Reflection depends solely on the reflective power of the surface on which the light impinges. Shiny and damp tissue are reflective. Metallic instruments are highly reflective. While reflection is not a major factor in YAG laser treatment, it can constitute a danger not only for tissues surrounding the operative site but also for the surgeon's unprotected eye.
Transmission of YAG laser light is greater in pale tissues. If the impact zone is white, the beam may be completely transmitted. This is important because underlying dark tissue can be damaged.
Absorption is a function of power density and color of the tissue. The basic rules can be summed up as follows:

- the darker the tissue and the higher the power density, the greater the absorption. Tissue color depends mainly on tissue vascularization and on the laser charring;
- power density depends on the power setting of the laser and the distance of the tip of the optical fiber from the tissue.

Power density = The duration of emission also determines energy density which is the product of power density and time.
Energy density = Setting the laser in the discontinuous mode allows exact dosage of the amount of energy delivered to the treatment zone at each impact.
Diffusion is the opposite of absorption in that the paler the tissue is, the lower the power density and the greater the diffusion is.

Bronchoscopic lasers: Although the $C0_2$ device was the first laser to be used in the airways, the articulated arm delivery system limited widespread endoscopic application. Only lasers that can be delivered through an optical fiber, i.e. the KTP, argon, dye, and YAG, are suitable for routine laser bronchoscopy. The YAG is currently the best laser for airway resection because of its effects on living tissue. The reliability of the YAG laser is also a major factor in its success. The KTP laser which is obtained by doubling the frequency of the YAG laser using a KTP crystal is also useful. At high power (10-12 watts), the green KTP beam achieves intense vaporization. At low power (2-3 watts), it is absorbed by red tissue and thus can be used to devascularize angiomas.

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The power of an argon laser is only a few watts. Its effects are similar to those of the KTP beam at low power. Dye lasers also provide a very weak beams and are used only after photosensitization with hematoporphyrine.

Operating mode of YAG lasers: Another factor determining the effects of a YAG laser on living tissue is the operating mode. The most frequent operating mode is the continuous wave mode. In the continuous wave mode, the active material is continuously stimulated although the beam is usually delivered discontinuously in successive impacts at intervals determined either by the endoscopist or by a built-in timer.

Another operating mode is the superpulsed mode. In this mode, the laser emits very high-powered bursts in rapid succession resulting in a similar mean power which is delivered discontinuously by the endoscopist. By favorizing surface effects, the superpulsed mode transforms the laser into a veritable optical scalpel.

LASER RESECTION IN THE AIRWAYS

Anatomical relationships: The topography of the tracheobronchial tree which consists of a succession of subdividing bronchi is familiar to pulmonologists. However, it is useful to recall the anatomical relations of the tracheobronchial tree.

The trachea is easily accessible and its anatomical relationships are well known. In the back the esophagus is in permanent contact with the trachea. In front the innominate artery crosses the lower third of the trachea. The aortic arch and the recurrent nerve are in contact with the left edge of the end of the trachea. The right main stem bronchus is in contact with the pulmonary artery in the front. The left main stem bronchus is surrounded by the esophagus in the back, the aortic arch above and the pulmonary artery in the front.

Laser resection in the right and left upper lobe bronchi is difficult. This is true even with a flexible fiber optic bronchoscope because the rigidity of the laser fiber prevents angulation of the tip of the fiber optic bronchoscope. Another danger in the upper lobe bronchi is close contact with the pulmonary artery especially on the left. For these reasons indications for resection in the upper lobes are limited.

Access to the right lower and middle lobe bronchi and the left lower lobe bronchi is relatively easy. The main anatomic relations are the organs of the mediastinum in particular the heart and pulmonary veins.

Physiologic considerations: The volume of the tracheobronchial tree is only 150 cc (Anatomical dead space). Thus even a minimal accumulation of blood or secretion can cause major hypoxia leading to dreaded cardiovascular risks: myocardial ischemia, arrhythmia, bradycardia and even cardiac arrest.

Maintaining a free airway and efficient ventilation at all times are essential to the prevention of complications. However, proper precaution should be taken when using oxygen in the presence of inflammable materials such as a fiber optic bronchoscope.

INDICATIONS AND CONTRAINDICATIONS OF LASER BRONCHOSCOPY

Indications: Obstructive lesions in the main airway, i.e. the trachea and/or the right and left stem bronchi, are indications for endoscopic resection. For malignant lesions, surgery is the method of choice. Only patients ineligible for surgery should undergo endoscopic treatment. Laser resection can be associated with radiation therapy or chemotherapy but it should be performed first.

Among tumors of uncertain prognosis, adenoid cystic carcinomas are rarely surgical indications. Carcinoid tumors that are atypical in histology or have an extrabronchial extension are always surgical indications, but strictly endobronchial carcinoids of typical histology are indications for laser resection.

Benign tumors such as hamartoma, chondroma, leiomyoma, and papilloma can easily be removed endoscopically.

Management of iatrogenic cicatricial stenosis of the trachea or main stem bronchi is more difficult and requires a carefully planned association of resection and medical treatment. Mechanical dilatation and stenting are essential components in endoscopic treatment. Surgery is rarely indicated as the primary therapy.

Small peripheral lesions and lesions that do not compromise ventilation are theoretically not indications for laser resection but under certain circumstances exceptions may be made (e.g. small benign tumors or inoperable peripheral tumors).

Contraindications: The main contraindication for laser resection is extrinsic compression of the trachea or the main stem bronchi. However even these cases can now be treated using indwelling stents.

ENDOSCOPIC TECHNIQUES OF LASER RESECTION

Basic principles of endoscopic resection: Safe endoscopic resection depends on maintaining ventilation, preventing hemorrhage, and minimizing laser exposure. To ensure ventilation the physician must not hesitate to interrupt resection to inspect the peripheral airways and perform aspiration whenever necessary.

To prevent hemorrhage it is important to coagulate the lesion before resection. In this regard it is essential to remember that at a given power setting, the closer the tip of the laser is to the target, the smaller the spot illuminated and thus the greater the power density.

In other words, power density can be changed simply by moving the tip of the laser closer or farther from the surface. This rule constitutes one of the basic principles of laser resection.

Practically speaking, at a power setting of 30 to 45 watts with a emission duration of 1 second, the bronchoscopist can obtain

- tissue shrinkage and therefore devascularlzatlon by holding the fiber about 1 cm from the target;
- charring and vaporization by holding the fiber about 3 mm from the target.

For highly vascularized tumors or tumors of uncertain hemorrhagic potential, a low-power density should be used to favorize coagulation.

Once a tumor has been coagulated or in order to avoid heating beneath the surface (e,g. for cicatricial tracheal stenosis), a high-power density can be used to favorize rapid vaporization.

Laser exposure can and should be minimized using mechanical resection whenever possible.

Laser Resection using the Rigid Bronchoscope: Since rigid bronchoscopy requires general anesthesia, it must be performed in a surgical setting with a nearby recovery room.

The endoscopist and anesthetist must cooperate fully in order to ensure ventilation.

A surgical bronchoscope allowing simultaneous ventilation and treatment (aspiration, lasing, and debulking) must be used.

Peripheral endobronchial lesions especially when located in the upper lobes are not good indications for resection using a rigid bronchoscope. If the patient requires general anesthesia, the open tube can be used as a conduit for the fiberscope.

Lesions in the main stem bronchi can be treated according to the coagulation/vaporization principle. A suction catheter should always be in place at the site of treatment in order to keep the operating field clear by continuous suction of blood, secretions and smoke. Mechanical debulking with the tip of the bronchoscope shortens procedure time and limits laser exposure. The axis of the bronchus can be located by tactile feedback from the bronchoscope in contact with bronchial cartilage. To prevent hypoxia, the healthy main stem bronchus should be inspected regularly to ensure that it is free.

In case of bilateral lesions it is advisable to begin on the less obstructed side in order to establish a reliable airway as soon as possible.

Tracheal lesions are easier to treat but reopening must be achieved rapidly in order to avoid complications. The best way to establish an airway rapidly is simply to push the bronchoscope slowly but forcibly through the stenosis.

For iatrogenic cicatricial stenosis, the laser is only used to make 3 or 4 radial incisions. Mechanical dilatation using progressively larger tubes plays an essential role.

Laser Fiberscopy: Most practitioners in the world perform endoscopic laser resection using a rigid bronchoscope (Toty, Vergnon, and Dumon in France; Cavaliere in Italy; Diaz in Spain; Frietag in Germany; Beamis, Shapshay, Harrell, Edell, and Colt in the USA). However, some American teams have reported excellent results using a flexible fiberoptic bronchoscope (Unger and Mehta).

Laser fiberscopy requires strict cooperation on the part of the patient who must be able to support the discomfort.

Local anesthesia must be thorough. It may be necessary to renew local anesthesia if the procedure is prolonged.

Continuous aspiration is necessary to remove smoke. Blood oxygen should be monitored using an oxymeter and care should be exercised when administering oxygen due to the risk of ignition of the fiber optic bronchoscope. The working channel must be clean (no trace of blood) when the laser fiber is inserted Small peripheral lesions are easy to treat under local anesthesia. After thorough coagulation, debulking with biopsy forceps can greatly shorten the procedure. When debulking, it is important to push the fragment down rather than to pull it forcibly up. Large pieces can always be detached. Fragments can be removed using accessories such as a Dormia basket or a Fogarthy balloon.

Lesions in the main stem bronchi require great care. The patient should be turned on the obstructed side so that in case of hemorrhage ventilation of the healthy side can continue.

Lesions in the trachea or in pneumonectomized patients are very delicate to treat. The major potential complications are hemorrhage and hypoxia which are very difficult to control using the fiber optic bronchoscope.

Treatment of tracheal lesions confronts the endoscopist with the dilemma of choosing between vaporization to open the airway quickly and coagulation which is needed to prevent excessive bleeding during removal. In cases involving subtotal obstruction of the trachea, the fiber optic bronchoscope should not be used

ADVANTAGES AND DISADVANTAGES OF THE FLEXIBLE FIBEROPTIC BRONCHOSCOPE

Advantages:

- Since flexible fiberscopy is the most widely used technique, it has been dubiously argued that many lung physicians a reluctance to learn another technique.
- Fiberscopy is an ambulatory procedure that can be performed under local anesthesia thus avoiding the dangers of general anesthesia particularly in a high-risk patients.
- Fiberscopy is less cost-intensive since it does not require an operating room and can be done by a smaller staff.

Disadvantages:

- Treatment is long and difficult for the patients and time-consuming for the physician.
- Permanent exposure to smoke is hazardous for the staff.
- The inability to perform mechanical resection and dilatation results in less complete disobstruction and, more importantly, makes it necessary to use more laser energy to vaporize the lesions.
- Because the working channel of the fiber optic bronchoscope is small, instruments (laser fiber, suction tubes, forceps, etc.) cannot be used at the same time and must be inserted one after the other.
- Bleeding is difficult to control.
- Fiber optic bronchoscopes and accessories are expensive.
- Fiber optic bronchoscopes are inflammable.
- Stent placement is difficult under local anesthesia without previous dilatation

ADVANTAGES AND DISADVANTAGES OF RIGID BRONCHOSCOPY

Advantages:

- General anesthesia is more comfortable for the patient and the physician.
- Using an open tube it is possible to use a laser fiber, suction catheters, and forceps simultaneously.
- Complications can be more easily controlled.
- Use of the bronchoscope to perform dilatation and mechanical resection shortens procedure time, diminishes the amount of laser exposure, and allows more complete disobstruction.
- When necessary, stent placement is simple.
- The equipment is inexpensive and indestructible.

Disadvantages:

- Rigid bronchoscopy requires an experienced staff, a skillful endoscopist, a courageous anesthetist, and trained instrumentists.
- The procedure must be performed in an operating room with a nearby recovery room.
- The need for hospitalization increases the cost.

RISKS AND BENEFITS OF ENDOSCOPIC LASER RESECTION

The risks of endoscopic laser resection are well known: hypoxia, hemorrhage, perforation, and fire. However, in accordance with the old adage "an ounce of prevention is worth a pound of cure", endoscopic laser resection is relatively safe if the following rules are respected:

- avoid hypoxia by keeping peripheral airways free at all times;
- avoid hemorrhage by coagulating lesions thoroughly before resection;
- be mindful of the anatomical dangers and the biological effects of the laser;
- prefer mechanical debulking to laser resection in order to limit iatrogenic complications;
- use the laser in the discontinuous mode at a moderate power setting (40 to 45 watts)
- do not lase when ventilating the patient with pure oxygen (we advise a limit of 50%).

Like any technique, endoscopic laser resection has limitations. However, it can be indispensable in well selected indications. In emergency cases, therapeutic endoscopy has provided a solution for problems that had been impossible to solve until now. Treatment of subtotal obstruction of the main airway and of cicatricial tracheal stenosis has been radically transformed. Laser resection also represents a very effective modality for benign tracheobronchial tumors and certain tumors of uncertain prognosis.