Anesthesia for Bronchoscopy

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Abstract: Bronchoscopic procedures are at times intricate and the patients often very ill. These factors and an airway shared with the pulmonologist present a clear challenge to anesthesiologists. The key to success lies in the understanding of both the underlying pathology and procedure being performed combined with frequent two-way communication between the anesthesiologist and the pulmonologist. Above all, vigilance and preparedness are paramount.

Topics discussed in this review include anesthesia for advanced diagnostic procedures as well as for interventional/therapeutic procedures. The latter includes bronchoscopic tracheal balloon dilation, tracheobronchial stenting, endobronchial electrocautery, bronchoscopic cryotherapy and other techniques. Special situations, such as tracheoesophageal fistula and mediastinal masses, are also considered.

Keywords: Airway management, airway lasers, anesthesia, bronchoscopic surgery, EBUS, ENB, metallic stents, silicone stents, bronchoscopy.

INTRODUCTION

There has been a recent proliferation in bronchoscopic interventional procedures leading to an increasing demand for anesthesia services for these often challenging procedures [1]. A number of thoracic surgery procedures such as mediastinal staging, that were traditionally performed in the operating room with an inpatient stay can now be done on an outpatient basis using minimally invasive bronchoscopic methods[2]. As a result, a number of facilities have constructed specially equipped interventional pulmonology suites independent from the ORs. A development of which are the “Hybrid ORs”, capable of accommodating both advanced diagnostic, interventional, and minimally invasive procedures as well as classic open procedures. The intent is to establish centers of excellence for these highly specialized procedures, using standardized protocols that nevertheless allow for individualized approaches that match clinical conditions.

Patients presenting for interventional pulmonology procedures often carry high anesthetic risk.[3] Anesthesia providers frequently have to deal with the combination of severe lung pathology with additional multisystem comorbidities such as obesity, diabetes and coronary heart disease. During bronchoscopic surgery anesthesiologists and pulmonologists must share the airway occasionally with conflicting clinical objectives. (For instance, the pulmonologists may require a motionless operating field, whereas the anesthesiologist requires lung movement to maintain oxygenation and ventilation.) A clear method of communicating clinical needs in a respectful environment is essential.

Finally, the challenge of contemporaneous record keeping exists due to the dynamic nature of bronchoscopic interventional procedures. Changing airway conditions and anesthetic requirements may leave little time for documentation. This may require an automated anesthesia Information Management System (AIMS) or a second individual focused on this task.

As a result of these special requirements, it is essential for the anesthesiologist to be conversant with all these procedures, familiar with the commonly used anesthetic techniques, and skilled in the various airway management options for these often challenging patients.

FREQUENTLY PERFORMED PROCEDURES
Diagnostic Bronchoscopy, Including Brushings, Washings, and Biopsies

Bronchoscopic examination of the airway allows visual inspection (look for lesions, areas of compression etc.) and diagnostic procedures (brushings, washings, and biopsies of tracheal and/or bronchial lesions). These are accomplished through either a flexible bronchoscope or (less commonly) a rigid bronchoscope.

To obtain bronchial brushings a brush is advanced to the lesion via the bronchoscope channel either using either direct visualization or (for distant peripheral lesions) fluoroscopy. The lesion is then gently brushed, the brush withdrawn, and the brushings transferred onto glass slides for cytological review. Sometimes a special brush sealed in a protective catheter is employed to obtain “protected brushings” for microbiologic studies.

To obtain bronchial washings, the bronchoscope is passed in the usual manner while isotonic saline (0.9%) is instilled through the bronchoscopic channel into the target area. Fluid is then aspirated into a trap attached to the suction tubing, followed by cytological or other analysis.

Finally, bronchoalveolar lavage (BAL) is commonly performed for diagnostic/therapeutic purposes. In BAL aliquots of approxi- mately 20 mL - 40 mL of isotonic saline are administered via the bronchoscope and then suctioned. An important therapeutic variation of BAL is therapeutic whole-lung lavage, which is usually done for pulmonary alveolar proteinosis (PAP) [4]. Whole-lung lavage is usually performed using a left-sided double-lumen endotracheal tube so as to allow lung isolation in order to allow ventilation of one lung while lavaging the other. Compared to BAL, the infused volumes are enormous - up to 50 L of isotonic saline are sometimes used. Typically, done on a sequential manner, one lung is lavaged on a single day followed by the other lung a few days later, although at the authors’ institution, bilateral therapeutic whole lung lavage is often performed in the same setting, on the same day.
To obtain endobronchial biopsies, the bronchoscope is passed in the usual manner into the vicinity of the suspicious area. Biopsy forceps are then passed down through the bronchoscope channel, its jaws are opened and closed on the tissue, and the forceps are removed. The obtained tissue is then transferred into a formalin-containing container for fixation. For large tissue samples that cannot pass through the bronchoscope channel, continuous suction is applied to hold the sample in place at the tip of the bronchoscope while the entire bronchoscope is then withdrawn with the tissue sample held at the bronchoscope tip by suction. Attempting transbronchial biopsies involves a higher risk of bleeding and pneumothorax since the lung parenchyma near the pleural surface is typically the target for diagnosing diffuse lung disease while tumors typically have increased vascular supply and may be closer to bronchial artery branches. The appropriate position of a bronchoscope in these types of procedures is wedged in an airway to serve as a barrier to any bleeding and to tamponade the otherwise non-compressible biopsy site.

**Tracheobronchial Balloon Dilation**

The most common cause of subglottic or tracheal stenosis is prolonged tracheal intubation, it can also occur after relatively short periods of intubation. This may be, as a result of traumatic intubation, or from other causes (e.g., inhalational injury, previous laryngeal surgery, or as a complication of cervical spine trauma). Wegener's granulomatosis and sarcoidosis are rare conditions causing tracheal and bronchial stenosis that may be encountered in tertiary care centers. In addition, lower airway stenosis related to lung transplantation is not uncommon. In the idiopathic causation is illustrated in a series by Rahman et al. [5], of 115 patients presenting with benign tracheal stenosis, 106 were the result of intubation/mechanical ventilation, while only nine were from other etiologies (of which four were idiopathic).

The procedure for tracheal or bronchial balloon dilation can be performed in a number of ways, for instance using a guide wire and fluoroscopy, or via the bronchoscope’s working channel [6, 7], (Fig. 1). In one method using a flexible fiberoptic bronchoscope, a balloon catheter is threaded over a guidewire and positioned across the stenotic area. Under bronchoscopic visualization, the balloon is then inflated to several atmospheres pressure for 30 to 120 seconds, the specifics depending on the manufacturer’s recommendations. Repeat inflation-deflation cycles are performed to achieve the desired result. Apnoea is required during the periods of balloon inflation (when treating tracheal and not bronchial stenosis) and some desaturation may occur. Limiting the inflation time. The duration of apnea until this occurs depends upon age, severity of underlying lung disease, comorbidity, and body habitus. Not infrequently, the procedure is used in conjunction with other techniques (dilation using a rigid bronchoscope, cryotherapy, Nd: Yag laser ablation, stent placement).

Potential procedure complications include bleeding, perforation, wall injury or rupture (often resulting in pneumomediastinum), pneumothorax, mediastinitis, chest pain, bronchospasm, and atelectasis.

**Tracheobronchial Stenting**

In the last two decades, considerable progress has been made in the endoscopic management of central airway obstruction. In particular, the use of new types of self-expanding metallic stents (SEMS) and hybrid stents placed bronchoscopically has provided new clinical options [8]. Metal, hybrid and silicone stents (Fig. 2) are frequently used to support and maintain the tracheal lumen, restore integrity of a disrupted airway, and support an airway wall from a compressing mediastinal mass. These can be placed under direct vision with the use of rigid bronchoscope (Fig. 3) or with the assistance of a guide wire using fluoroscopic guidance and a flexible bronchoscope.
Endobronchial Electrocautery

This technique is equally effective and less expensive than Nd: YAG laser therapy for intraluminal airway obstruction [10, 11]. It is thought to produce less airway scarring and subepithelial fibrosis compared with the use of Nd: YAG laser [12]. Moreover, there are also several instruments used with this technique like snares, blades, probes and hot forceps to address several technical issues not fully addressed by simple laser technique.

Bronchoscopic Cryotherapy

This procedure is an alternative to using a laser that entails the therapeutic application of extreme cold for local destruction of tissue by freezing-induced coagulation necrosis. Nitrous oxide is used as a cryogen by virtue of the cooling of gas on expansion (Joule-Thomson effect). The technique uses special probes applied via a flexible bronchoscope. Lacking the risk of fire, tissue perforation or Thomson effect). The technique uses special probes applied via a flexible bronchoscope. Lacking the risk of fire, tissue perforation or

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Endobronchial Ultrasound-guided Transbronchial Needle Aspiration (EBUS-TBNA)

An EBUS bronchoscope is a flexible bronchoscope containing both conventional bronchoscopic optics and a linear array ultrasound probe. This combination allows the operator to perform directed needle aspiration of abnormal mediastinal structures instead of "blind" transbronchial needle aspirations. It is an accurate, safe and cost-effective technique that facilitates the biopsy of mediastinal lymph nodes and peribronchial lesions [21, 22].

Complete Mediastinal Staging Using EBUS-TBNA

EBUS-TBNA has proven to be valuable for mediastinal lymph node staging of lung cancer [23] with the ability to sample lesions even beyond the reach of standard mediastinoscopy. These procedures can be fairly lengthy as all lymph nodes found to be over 5mm in size sampled, working from higher nodal stations (N3) through lower stage nodal stations (N1) during a systematic mediastinal staging procedure.

Electromagnetic Navigational Bronchoscopy (ENB)

ENB is designed to enable the operator to biopsy lesions within the periphery of the lung, beyond the reach of the bronchoscope. This is a catheter-based system used through the working channel of a bronchoscope. It is comprised of the following [9]:
1. a sensor probe able to navigate the bronchial tree and communicate real-time information concerning its position;
2. an electromagnetic location board;
3. an extended working channel;
4. a computer system that converts CT scans into multiplanar images with 3-D virtual lung reconstruction.

The use of such a system will require certain requirements including specialized non-magnetic procedure (OR) bed, and if needed a non-magnetic breathing circuit holder (Fig. 4). This set-up allows navigational guidance within the lungs to endobronchially invisible targets beyond the limits that the standard bronchoscope can reach, followed by a tissue biopsy, in a manner similar to stereotactic brain biopsies. Both moderate (conscious) sedation and general anesthesia techniques are used in this setting.

Removal of Foreign Bodies

The removal of foreign bodies was one early use of bronchoscopy. This may be accomplished with either a flexible or rigid bronchoscope depending on the nature of the foreign body and the clinical status of the patient. A wide range of tools have been designed for this purpose including wire baskets, forceps and other grasping instruments, endoscopic magnets, cryotherapy probes etc.

Lung Transplant Airway Dehiscence Restoration

Airway dehiscence is a potentially fatal complication typically arising in the early postoperative period (days to several months) following lung transplantation [17]. In most cases temporary metallic airway stenting can be used to provide airway support while infection treatment and healing may occur [18, 19]. Long term management is often an important challenge in these patients.

Endobronchial Treatment of Inflammatory Airway Diseases

Benign airway diseases such as Wegener’s granulomatosis, sarcoidosis, and strictures related to mycobacterial or fungal disease may be treated with combination of endobronchial steroid injection, cryotherapy, balloon dilation, dilation using a rigid bronchoscope and application of topical mitomycin-c [20].

ADVANCED DIAGNOSTIC PROCEDURES

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Fiducial Implantation

Stereotactic radiosurgery is a treatment possibility for inoperable lung tumors. Fiducial markers are placed in or near the target tumor to facilitate precise tumor ablation. For peripheral lung lesions, ENB may offer an attractive alternative to CT-guided placement of these fiducials [24] with less risk of pneumothorax.

Pleural Dye Marking

In cases where a small lesion may not be palpable during video assisted thoracotomy (VATS) or thoracotomy, ENB can be used for guidance to inject a small amount of indigo carmine dye close to the target lesion and at the pleural surface as a guide for surgical resection.

Fig. (4). A non-metallic breathing circuit holder for use with navigational bronchoscopy (SuperDimension®). This is used instead of the usual metal design in order to avoid interference with the electromagnetic imaging system. (Circuit holder design courtesy of Ken Barclay, Cleveland Clinic) Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.
Endoscopic High dose Rate Brachytherapy

In cases where malignant airway obstruction is recalcitrant to maximum dose external beam radiation therapy and where palliative techniques like stenting or laser resection continue to be limited by extrinsic compression and tumor in-growth, additional radiation can be delivered by placing a catheter through which a radiation source may be used to give additional radiation therapy. Bronchoscopy is used to precisely place this catheter, which is typically placed under conscious sedation [25].

Bronchoscopic Lung Volume Reduction (BLVR)

This is still an experimental technique, with several variations, used to treat severe emphysema. The goal is to replace open lung volume reduction surgery with its associated morbidity and mortality with a minimally invasive option. Technologies like valves, thrombin glue, airway bypass techniques, coils and steam ablation etc. are not yet approved for use in the US but the Spiration® IBV system and the PneumRX coils have the CE mark and are currently approved for use in treating severe emphysema elsewhere. These patients have end-stage chronic obstructive pulmonary disease and can present challenges with both oxygenation and ventilation.

Bronchoscopic Valve Implantation for Persistent Bronchopleural Fistula

In exceptional circumstances air leaks from the lung parenchyma may persist following thoracic surgery. In those with an intractable leak, under a human device exemption (HDE) the FDA has approved the use of the Spiration IBV valves to treat prolonged air-leak after thoracic surgery [26].

Bronchial Thermoplasty

Bronchial thermoplasty is a bronchoscopic procedure in which controlled heat is applied endobronchially to reduce the mass of the airway smooth muscle as a treatment for severe high-dose inhaled steroid dependent asthma [27]. This procedure is performed over three bronchoscopic sessions, each session treating different parts of the lungs. The procedure recently has been FDA approved and has been shown to reduce asthma symptoms and trips to ER as well as lost days of work [28, 29]. These procedures are done with conscious sedation with asthma premedication and several assessments of asthma control prior to and after the procedure.

MODERN BRONCHOSCOPY SUITES

Today's modern bronchoscopy suites (Fig. 5) are sometimes actually "hybrid" ORs that allow surgeons and pulmonologists to perform combined open, minimally invasive, and image guided procedures in the same operative setting. These interdisciplinary, multifunctional rooms employ cutting edge technology with the goal of improving patient outcomes.

ANESTHETIC CARE

Pre-operative Evaluation

The extent of preoperative evaluation depends on several considerations, such as whether the procedure is elective, urgent or emergent, and how stable or critical the airway is. In elective cases, pre-operative assessment is usually conducted in the customary fashion with special attention to the following:

- The nature and extent of the proposed procedure.
- Common associated conditions and co-morbidities: heavy tobacco smoking coronary artery disease and chronic obstructive/restrictive pulmonary disease, chronic alcoholism, malnutrition and aspiration pneumonitis.
- Airway evaluation and review of possible symptoms of airway compromise, such as hoarseness, stridor, use of accessory muscles of respiration, dysphagia, or orthopnea.
- A review of the clinical notes concerning the size of the lesion, its location and extent, especially relative to vital structures. A computerized tomographic scan of the neck and chest will help rule out airway abnormalities or mediastinal masses.
- A history of type and duration of chemotherapy and its possible effects on vital organs (especially the heart and lungs).

Interventional Pulmonology Procedures and the Difficult Airway

Patients undergoing bronchoscopic procedures are potentially difficult airway cases, although in the majority of these cases the problem is that of lower airway pathology and so does not impact significantly on intubation. Even in patients with critical tracheal stenosis, ventilation is usually very possible, and intubation is usually achieved with a small endotracheal tube.

Pre-medication

Pre-medication with sedatives and anxiolytics should be considered only for very anxious patients, because the pulmonary status of many bronchoscopy patients is poor, and because some of the medications used in these patients may have respiratory depressant effects. Nevertheless, when it is considered necessary to use them, judicious care should be exercised, with small titrated doses. Once medicated, these patients should not be left alone without monitoring. As an added safety precaution, supplemental oxygen should be provided before sedation is administered. Premedication with atropine was once popular to counteract possible bradycardia and manage secretions; however the routine use of atropine as a premedication is no longer recommended [30].

Monitored Anesthesia Care

Monitored anesthesia care is a commonly used technique, especially outside the OR. The majority of uncomplicated and routine diagnostic as well as some simple therapeutic bronchoscopic procedures can be performed under moderate sedation, at least in selected patients undergoing selected procedures. However, in more complex cases, such as when the lung is compromised, or when a patient becomes unable to tolerate the respiratory depressant effects of many of the commonly used sedatives, ventilation support may become necessary. It should also be noted that because of their detailed understanding of the lung pathology and their special knowledge of the respiratory status of a patient, pulmonologists are able to make very accurate judgments in determining which patient would be a good candidate for moderate (conscious) sedation provided by a sedation nurse while supervised by the pulmonologist, versus those cases requiring deep sedation/monitored anesthesia care (MAC) or general anesthesia by an anesthesiologist. In the latter situation, many sedatives have been successfully employed, including midazolam, fentanyl, morphine, remifentanil, alfentanil, and propofol. More recently dexmedetomidine and fospropofol have been added to the list of drug options [31-33]. The required

Fig. (5). Modern bronchoscopy suite with anesthesia machine and automated record keeping system, along with C-arm, and electromagnetic navigation equipment. Photo courtesy of Cleveland Clinic. bronchoscopy Suite. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.
depth and technique of anesthesia to safely facilitate these procedures will have implications for the qualifications of the provider; for example, in Ohio sedation nurses are limited to monitoring moderate (conscious) sedation under the supervision of the pulmonologist and may not ordinarily be involved in providing deep anesthesia.

General Anesthesia

A total intravenous anesthetic technique (TIVA), typically an infusion of pure propofol administered at between 50 and 150 mcg/kg/min, is usually preferred over an inhalational anesthetic technique. This is for several reasons. First, it ensures continuous delivery of anesthesia compared to an inhalation technique where ventilation leaks occur around the rigid bronchoscope [34], or with the flexible bronchoscope being inserted into and removed from the airway, or with the insertion of instruments like balloons, forceps, and cautery, or with techniques such as intermittent apnea or jet ventilation in addition to the intermittent airway suctioning performed by the pulmonologists for optimal visualization. Secondly, TIVA avoids pollution of the operating room by inhalational anesthetic agents. Third, it avoids the risk of exposing operating room personnel to anesthetic vapors. Finally, it should be noted that with TIVA, the integrity and functionality of the intravenous line should be monitored throughout the procedure. In addition, the Bispectral index monitor (BIS Monitor™) (Covidien, Dublin, Ireland) can be used to help monitor the depth of anesthesia and avoid intraoperative recall [35].

The Utility of Muscle Relaxation

Muscle relaxation facilitates both SGA and ETT insertion. Relaxation of the jaw muscles makes easier insertion of a rigid laryngoscope for suspension laryngoscopy, as well as insertion of rigid bronchoscopy more easier and safer. Muscle relaxation also improves overall lung compliance by eliminating the chest wall component. Finally, by the virtue of providing a motionless patient, it is advantageous in situations where unexpected patient movement might result in serious consequences. For example, during laser-based procedures a motionless patient drastically decreases the risk of unwanted misdirection of the laser beam that might result in damage to normal airway tissues, to major vessels or to the esophagus. A motionless patient will also help increase precision in biopsying small paratracheal nodes decreasing the number of sampling attempts and shortens the procedure. In cases where a SGA is used muscle relaxation also helps minimizing trauma to the vocal cords caused by the frequent insertion and removal of the bronchoscope against contracted cords—which often happens when muscle relaxants are not used.

Fluid Management in Bronchoscopic Surgery

It is prudent to restrict intravenous fluid administration to the minimum volume required, as many have limited lung reserve and are at risk of pulmonary congestion or even frank pulmonary edema, especially if they have concomitant cardiac disease, such as left-sided or right-sided heart failure, which may have been a complication of their long standing lung pathophysiology (cor pulmonale).

The use of Corticosteroids in Bronchoscopic Surgery

Many anesthesiologists and surgeons use corticosteroids, in particular dexamethasone, as a prophylactic measure to decrease airway edema after airway surgery. Steroids might be useful to reduce post-operative vocal cord edema when the flexible fiberoptic bronchoscope (alone or through an SGA and in the absence of ETT) has been inserted into and removed from the airway several times, rubbing against the vocal cords in the process, or alternatively when a rigid bronchoscope has been used for a prolonged duration. Steroids are also used in cases where extensive tracheobronchial tissue trauma has been done during a prolonged procedure. The clinical utility of steroids in this context is controversial. Evidence supporting the use of steroids includes its efficacy prior to certain maxillofacial procedures due to their proven benefit in reducing the degree of postoperative edema and inflammation [36-38]. On the other hand, Hughes et al have shown that steroids are ineffective in reducing airway edema following carotid endarterectomy [39]. Additionally, steroids are also beneficial as an anti-nausea medication (vide infra) [40]. Finally, many bronchoscopic surgery patients with underlying lung conditions (e.g. Wegener’s granulomatosis) that require chronic steroid therapy are treated by many clinicians with 100 mg of hydrocortisone (the so-called “stress dose” steroids) to avoid adrenocortical insufficiency in the face of chronically suppressed suprarenal gland by the exogenously administered steroid. However, again the efficacy of this treatment has not been scientifically demonstrated [41].

Anti-nausea Prophylaxis

Nausea and vomiting and a likely increased risk of aspiration could be detrimental to some bronchoscopy patients because of limited pulmonary reserve. Also, since an ETT is used only in a limited number of these patients, the majority of the procedures are done with techniques that do not fully protect against aspiration—such as use of a rigid bronchoscope, a SGA or no artificial airway whatsoever (natural airway). The use of maximum anti-nausea prophylaxis, especially in patients with risk factors for complications, is therefore justified. In such cases, the use of propofol TIVA is helpful, as is the avoidance of inhalation anesthetics and of nitrous oxide. Dexamethasone in dosages of 4-10 mg IV of commonly used [40] as well as other agents.

Management of the FiO2

Administrating 100 % fraction of inspired oxygen (FiO2) in bronchoscopy procedures is very common. However, it is usually necessary to maintain oxygen concentrations at the lowest tolerable level, below 40%, during thermal treatment with Nd: YAG lasers as well as with other procedures where an airway fire could occur. Periods of extended apnea and complete airway obstruction can be expected during some especially challenging cases. Complete airway occlusion frequently occurs during the critical phase of removing the stent or stent fragments or when inflated balloon dilators are used for tracheobronchial dilation. Therefore, it is always advisable to return to ventilation with 100% oxygen before extraction of the stent, prior to exchange of airways, and prior to extubation. Finally, if during thermal treatment patients cannot tolerate lower oxygen levels, it may become necessary to defer treatment temporarily, and ventilate with higher oxygen concentrations and consider using therapy such as debulking via a rigid bronchoscope or via cryoablation, where oxygen concentrations may be maintained at higher levels.

AIRWAY MANAGEMENT CHOICES FOR BRONCHOSCOPIC PROCEDURES

• Natural Airway

This is a popular technique, especially when relatively short procedures are performed in a remote bronchoscopy suite where an anesthesia machine is unavailable. A moderate (conscious) sedation technique is appealing for these procedures as spontaneous ventilation can be maintained. Special emphasis should be placed on good airway topical anesthesia to allow the patient to tolerate the bronchoscope without the need for deep planes of sedation and their associated risks. Bronchoscopy may be performed in this setting either trans-nasally or trans-orally using a bite block or other airway designed for FOB use.

• Endotracheal Tube (ETT)

When a standard 5.9 mm diagnostic bronchoscope is used, a size 7.5 ETT may be used but when using a 6.7 mm therapeutic
bronchoscope the 8.0 ETT is the smallest preferred tube. Obviously the larger the endotracheal tube the less likely that the bronchoscope will get stuck or that high airway pressures will be an issue. Most commonly size 8.5 or 9.0 mm ID ETT are used for these procedures to allow for enough room around the operating bronchoscope for easy and adequate ventilation.

There are several types of bronchoscopy adaptors (Fig. 6) that incorporate diaphragms to reduce the air-leak, although higher gas flows are generally needed to continue to deliver adequate ventilation to compensate for the remaining leak.

The ETT can and should be cut short (preferably after intubation, to facilitate navigation of the fiberoptic bronchoscope (Fig. 6). However if there is a significant risk of bleeding it may be advisable to leave the tube long enough to enable potential need for endobronchial intubation and one lung ventilation to isolate a potentially asphyxiating bleed. Intubating patients with a tracheal stent, whether a SEMS stent or a silicone stent, requires special caution, as it risks distorting or dislodging the stent distally that may occlude the airway. A shortened large-bore ETT can be used via an existing tracheotomy using flexible bronchoscopic instruments (Fig. 7). As a general principle, ETT provides a secure airway, which is helpful in patients with severe gastroesophageal reflux disease, hiatal hernia, post esophagectomy with stomach pull through operation, and/or there is a need to insert the EBUS scope esophageally to obtain transesophageal biopsies of nodes and lesions that are closer to the esophagus than the tracheo-bronchial tree (Fig. 8). Of note that ETT will also provide protection to the vocal cords against repeated trauma and friction with the bronchoscope in long procedures that would require multiple insertions and retractions of the bronchoscope.

**Rigid Bronchoscope (Fig. 3)**

A rigid bronchoscope is preferred for major airway interventions such as:

1. The insertion and removal of silicone stents because of their size and their noncompressible material,
2. For removal of large broncholiths and granulation tissue.

**Fig. (6).** A large diameter endotracheal tube (ETT) is used for a bronchoscopic procedure, please note the blue Portex swivel adapter, that facilitates simultaneous spontaneous ventilation during diagnostic and therapeutic bronchoscopy. Here the ETT was cut short to facilitate decrease resistance to bronchoscope going in an out of the ETT, as well improve its maneuverability. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.

**Fig. (7).** This patient had a remote laryngectomy for cancer, and later developed tracheal stenosis just below the stoma. Later on he also developed tumor invasion at the level of the carina. Here we see an 8.0 mm ID endotracheal tube used as a conduit for the bronchoscope. Only the tip of the tube could be accommodated in the stenotic trachea; the tube cuff functioned as an external seal. This improvised arrangement allowed positive pressure ventilation while also allowing for dilation the trachea using the flexible bronchoscope. This allowed the use of a small diameter rigid bronchoscope to deploy a silicone stent to the carina. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.

**Fig. (8).** An EBUS bronchoscope is inserted esophageally next to an existing ETT for biopsying lesions that are closer to the esophagus than the trachea. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.

3. For coring out a large tumors invading the tracheo-bronchial tree,
4. To maintain airway patency in the face of a large mediastinal mass causing airway compression.

When the rigid bronchoscope is used, ventilation can be achieved either by attaching the anesthetic circuit to the bronchoscope side port for conventional ventilation [42], or via jet ventilation, where the jetting device is attached to the bronchoscope side port through a special adaptor. Leaks around the rigid bronchoscope are common, but are easily remedied by increasing the fresh gas flow, and packing the mouth with saline-soaked gauze. Special
attention should be given to protecting the lips and teeth. In addition care should be taken at the end of the case when removing the gauze so as to avoid subsequent airway obstruction from retained gauze pieces when the bronchoscope is removed.

• **Supraglottic Airway**

In cases where the tracheal lesion is subglottic, a supraglottic airway (SGA) can be used to advantage [43, 44], as it does not enter the glottis (Fig. 9 and Fig. 10A and B). This arrangement allows access to the subglottic lesion by providing a conduit for a flexible bronchoscope, as well as providing a means of ventilation (Fig. 11A and B). However, since it is a less definitive airway, it does not guarantee protection against aspiration.

The techniques described above require clear communication between the anesthesiologist and the pulmonologist. Use of a fiberoptic swivel connector adapter will allow continuous ventilation (Fig. 11B), thereby avoiding circuit disconnection during flexible bronchoscopy, in a manner similar to use of an ETT.

• **The use of Airway Exchange Catheters in Bronchoscopic Surgery**

Airway exchange devices can be useful during bronchoscopic procedures because of the dynamic nature of the procedures that might require different forms of airway during the same procedure and because one may encounter situations in which the airway is expected to be difficult to intubate. Accordingly it is advisable to start with awake intubation, with a relatively small-sized ETT, preferably a Parker Flex-Tip™ Tracheal Tube. Compared to the standard tube, use of the Parker tube has reduced from 89% to 29% (P < 0.0001) the need to reposition the tube during insertion into the trachea [45]. Then an airway exchange catheter can be used to replace it with a larger tube to facilitate the flexible bronchoscopic procedure. If a rigid bronchoscope is required, the exchange catheter could be used for access to the airway until the laryngeal inlet is visualized through the rigid bronchoscope and the scope is secured in position. The same principle can be applied again after finishing with the rigid bronchoscope; here, the exchange catheter is introduced through the rigid bronchoscope and used to insert an ETT after removing the rigid bronchoscope. An exchange catheter can also be effective for intubation through an LMA but it is possible that the exchange catheter may slip behind the glottis and result in esophageal intubation, so standard methods of assessing tube position must still be used [46].

**Fig. (9).** Illustration of a balloon dilator being passed through a bronchoscope for the treatment of subglottic stenosis. The i-gel SGA as shown above allows access to treat subglottic lesions while allowing positive pressure ventilation. Fig. (1) shows how the balloon is inflated. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.

**Fig. (10).** Left (A): Illustration showing the use of an EBUS equipped bronchoscope for the ultrasonic imaging of paratracheal nodes via an endotracheal tube. Notice how the presence of the tube limits the region that the EBUS probe can scan and also provides for suboptimal probe alignment. Right (B): These two limitations are overcome by the use of a supraglottic airway – in this case an i-gel. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.
POSTOPERATIVE CARE

Most of the procedures described above are performed as outpatient procedures, where patients are discharged the same day. However, extremely ill patients with borderline function may benefit from overnight admission. This compares favorably with invasive thoracic surgery, which requires post-operative ICU admission and a prolonged hospital stay.

MANAGEMENT OF UNIQUE AIRWAY CASES

Long Term Management of Post Airway Fire Complications

Survivors of extensive airway fires often present periodically to tertiary and quaternary care facilities for long term management of their complex airway pathology; developed as a result of the airway fire or subsequent complex tracheal repair. Such patients tend to suffer from recurrent tracheal stenosis due to recurring scar build up. When the tracheal lumen becomes significantly narrowed, the symptoms of stridor, shortness of breath and limited functionality capacity require management.

Treatment consists of balloon dilation, electrocautery or laser- ing of the scars with or without mitomycin application. This treatment sequence may require a variety of airway interventions depending on the severity and extent of the stenosis, and stage of the procedure. The procedure generally begins with bag mask ventilation, then passage of a supraglottic airway through which an operating bronchoscope may be introduced. Some degree of dilatation is accomplished with balloon dilation, laser cautery, etc. This may be followed by either the passage of an ETT or rigid bronchoscope by the interventional pulmonologist. In extreme cases where there is very tight continually recurring stenosis of a short tracheal segment, an ENT or a thoracic surgeon performs an operative tracheal resection and re-anastomosis.

Management of Anterior Mediastinal Mass (AMM)

The presence of an anterior mediastinal mass can predispose patients to severe respiratory or cardiovascular complications, during anesthesia. These may include airway obstruction, compression of the cardiac chambers, and compression of the pulmonary artery [47]. Therefore, particular caution is required in managing these patients.

Spontaneous ventilation has been highly recommended in the anesthetic management of AMM patients, because muscle relaxants are not used and negative intrapleural pressure is maintained [48]. Several conservative anesthetic plans have been proposed for managing AMM [49]. Some propose that the patient should be intubated awake after being topicalized and sedated while positioned in the least symptomatic position. The use of dexmedetomidine, a selective α₂ agonist with sedative, analgesic, amnestic [50], and antisialagogue properties [51] has been suggested as having particular utility as a sedative adjunct in this regard. This drug maintains spontaneous respiration with minimal respiratory depression and has been used in the management of AMMs [52]. Patients under dexmedetomidine sedation are generally easy to arouse [53], a property that has been exploited during awake fiberoptic-assisted intubation [31]. However, this advantage, may not hold under higher doses (off label). An anesthetic induction using inhalational agents while maintaining spontaneous respiration is another potential course of action. This would seem of particular utility in uncooperative patients.

Severe cases that include the management of patients with larger AMMs (causing > 50% reduction in airway diameter as seen on a computed tomography scan) should not be treated outside of the OR. Some authorities recommend that cardiopulmonary bypass
be available on stand-by and that femoral vessel cannulation should be secured prior to induction [49, 54]. As a precaution against catastrophic loss of the airway after induction.

**Tracheoesophageal Fistulas (TEF)**

Although tracheoesophageal fistulas (TEF) are best known to medical students in the context of congenital anomalies involving the embryology of the trachea and esophagus, more commonly they may occur as a result of malignant disease or following radiation treatment for such disease.

A malignant tracheoesophageal fistula is a pre terminal condition in esophageal cancer and is associated with significant suffering; in particular, regurgitation into the trachea via the fistula is a continuing concern. The general consensus concerning management is to use stents to cover the fistula.

Stent placement is often accomplished under general endotracheal anesthesia. In such cases, the ETT tip should be placed distal to the site of the TEF to avoid blowing gases into the fistula with positive pressure ventilation. However, this is not always possible. Awake fiberoptic intubation methods usually work best in such a setting, as well as the maintenance of spontaneous ventilation prevents gas loss through the fistula. While this can be accomplished utilizing inhalational anesthetics, concerns include operating room contamination from leaking anesthetic gases with the risk of inadequate anesthesia for patients, and contamination of the operating room staff with anesthetic agent. An alternative would be a very careful titration of intravenously administered anesthetic, like propofol, and/or dexmedetomidine.

**COMPLICATIONS**

**Potential Complications of Bronchoscopic Procedures**

Potential complications of bronchoscopic procedures are numerous, and range from hypercarbia, hypoxemia and cough to major bleeding, loss of airway integrity, endobronchial fire damage, pneumothorax formation, and injury to glottic structures. The use of jet ventilation can be complicated by pulmonary barotrauma. Laser air (CO2) cooled or Argon plasma related cerebral or cardiac emboli have been reported as well [55]. Other disease specific risks may include acute carcinoid syndrome and acute bronchospasm.

**High Risk Procedures**

**Metallic stent removal** has a high associated risk of complications. Potential complications include retention of stent pieces, mucosal tears with bleeding, re-obstruction, the need for postoperative mechanical ventilation pneumothorax, damage to the pulmonary artery, and death [56]. When the stent is fractured during removal, unwanted fragments may remain permanently embedded in the tissue. In one report, critical airway obstruction occurred during removal of a tracheal stent using a rigid bronchoscope under general anesthesia, and cardiopulmonary bypass had to be instituted urgently; the stent was eventually removed by directly opening the trachea [57].

**Airway Fire Associated with Laser Surgery**

One particularly devastating complication is the occurrence of an airway fire. Management is summarized as follows:

**Steps to Take in Case of Airway Fire Include**

1. Discontinue laser and turn off O2 (as well as N2O if it was mistakenly used.)
2. Remove the burning endotracheal tube and drop it in a bucket of water.
3. Flush area with water or normal saline.
4. Re-intubate immediately and resume ventilation with 100% O2.
5. When the condition has stabilized, assess the damage with a ventilating rigid bronchoscope; remove any debris and foreign bodies.
6. Consider the use of IV steroids; however, their efficacy is not proven.
7. Use antibiotics.
8. Implement supportive therapy, including ventilation, and extubate when clinically indicated.
9. Perform tracheotomy if necessary.

**Tracheal Rupture**

Tracheal rupture or loss of tracheal integrity may complicate any of the above-mentioned procedures. However, they occur more frequently with traumatic intubation, tracheostomy, rigid bronchoscopic dilation, balloon dilation, or complicated metallic stent removal. Reported risk factors for tracheal rupture include advanced age, chronic obstructive pulmonary disease, weakened tracheal walls, (usually secondary to chronic airway inflammation), previous procedures, infection, and steroid therapy [58-61].

The signs and symptoms of tracheal rupture are non-specific, but a combination of such non-specific symptoms and signs in the clinical setting should lead to a high degree of suspicion. Dyspnea and a dry cough are sometimes the only signs evident in an awake patient. Cyanosis and tachycardia may also be evident. Other signs include hemoptysis, persistent air leak, subcutaneous emphysema, pneumomediastinum, and pneumothorax [62-64].

Bronchoscopy is the gold standard for the diagnosis of tracheal rupture. It is also critical in assessing the extent of the tear. Routine chest radiographs and bronchoscopy are usually sufficient for diagnosis in most cases.

The management of a tracheal tear can be observational (conservative) or surgical (Fig. 12), depending on the extent of the injury, the presenting signs and symptoms, and the general condition of the patient. In general, small, shallow tears that do not lead to severe compromise in ventilation and oxygenation can be treated conservatively [65, 66]. If the patient is dependent upon positive pressure-assisted ventilation, however, surgical treatment is needed. Regardless of the choice of management, the status of the trachea should be monitored with frequently repeated tracheoscopy.

Ventilatory management consists of adequate oxygenation and ventilation of the patient, and the prevention of worsening subcutaneous emphysema, pneumomediastinum, or pneumothorax. This can be achieved by positioning the ETT so that the cuff is distal to the level of the injury (Fig. 12), and by close monitoring of the airway pressure, keeping it at the lowest possible level. A higher FiO2 and respiratory rate may be required. Selective or bilateral bronchial intubation can be performed in tears located above or near the carina. It is important to note that standard direct intubation is potentially hazardous, because a false passage can be easily created. Fiberoptic-guided intubation may be safer.

Other possible management options include high frequency oscillating ventilation or hyperbaric oxygen therapy [67, 68]. In rare situations, cardiopulmonary bypass or percutaneous cardiopulmonary support systems have been used [69, 70]. Pneumothoraces should be treated with chest tubes, pain should be managed, and hemodynamics should be monitored and supported where needed.

**SUMMARY**

Interventional pulmonology is a fast-growing field. These procedures are at times complex, and the patient population is very sick. Many of these surgeries are performed out of the operating rooms. Anesthesiologists need to stay abreast of the advances in this field, and of the anesthetic challenges that might come with it. The key to favorable outcomes lies in deep understanding of the underlying lung pathology, open two-way communication between
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the anesthesiologist and pulmonologist, understanding the nature of the procedure, and above all, extreme vigilance and preparedness.

CONFLICT OF INTEREST

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