Anesthesia for tracheal surgery

I. Introduction

The treatment of tracheal disease, specifically by resection and reconstruction comes from the systematic work of Grillo exploring methods of tracheal repair. It is no accident that the early surgical papers included descriptions of the anesthetic approach as well. Successful tracheal surgery requires skilled coordination between surgeon and anesthesiologist.

Much of the early need for tracheal surgery was a sequellae to the success of anesthesia and intensive care. As intubation and ventilation became a common means for supporting critically ill patients, tracheal injury from endotracheal tubes and tracheostomy tubes required treatment. In turn we now have better designed endotracheal tubes and a better understanding of the proper way to handle patients with airway appliances.

Tracheal surgery spans from simple fiberoptic exams to complex resection and reconstruction. The more complex cases should be sent to centers with extensive experience and an institutional commitment to the specialty. All anesthesiologists, however, will benefit from an understanding of the principles and practical approaches to lower airway lesions.

The American Society of Anesthesiology has promulgated a clear algorithm for the difficult airway. That algorithm is really for patients with difficult oral and facial anatomy. Tracheal anatomy is not addressed and without careful thought, using its methods in these patients may actually be harmful. We will review the special considerations for tracheal lesions, and anesthetic approaches to surgical procedures.

II. Patient considerations

A. Fixed stenosis

There are many diseases and injuries that can cause a fixed tracheal stenosis. This is characterized by a region of the trachea that is narrowed throughout the respiratory cycle, as contrasted with the dynamic obstruction caused by a weakened tracheal wall. On examination there will be limitation to flow to both inspiration and expiration, with stridor. Flow volume loops will show attenuation of both phases of the flow curve. Plain chest radiographs, and certainly tomograms will show a stenotic segment.

Patients commonly present with increasing dyspnea. They may note exacerbation with respiratory infections, and certainly decreased exercise capacity. Other presenting
symptoms may be hemoptysis, persistent bronchitis, goiter or neck masses, or superior vena cava (SVC) syndrome. Patients may also be identified after difficulty with routine intubation (an endotracheal tube would not pass), or when persistent “asthma” finally precipitates bronchoscopy or pulmonary function tests for assessment. It is distressingly common for patients with tracheal lesions to have been mistakenly treated for the much more common bronchospastic disease.

Air flow in the respiratory tract usually shows laminar characteristics – smooth flow patterns with a parabolic velocity profile. Because of the rapid branching of the tracheobronchial tree, the majority of airflow resistance is in the major conducting airways, so stenosis in this region will be clinically relevant. In laminar flow, the Hagen-Poiseille relationship holds:

\[
\text{Resistance} = \frac{\text{viscosity} \cdot \text{length}}{\text{diameter}^4}
\]

Note the profound effect of diameter, which corresponds to the clinical observation that patients note few symptoms until their stenosis reaches a certain threshold (on the order of 5-6 mm in adults) when dyspnea to exertion first appears. Once symptomatic, small changes in diameter, from secretions, infection, trauma or progression of disease can greatly exacerbate the obstruction.

Airflow does not remain laminar in severe stenosis. Irregularities in the profile of the tracheal lumen can create disturbed flow, and even flow in smoothly contoured tubes will become turbulent when the inertial forces overwhelm viscous damping. Reynold’s number is a non-dimensional parameter balancing viscous and inertial forces. Above a geometry-dependent threshold (2100 in cylindrical conduits) turbulent flow predominates. Reynold’s number is defined as:

\[
\text{Re} = \frac{\text{density} \cdot \text{diameter} \cdot \text{velocity}}{\text{viscosity}}
\]

In turbulent and orifice flow, gas density is a determinant of airway resistance. Further, airflow resistance is higher in turbulent flow than in equivalent laminar flow. Dilating the airway, reducing peak flows (by calming and sedation), and reducing gas density all can restore laminar flow. Helium is less dense, so helium/oxygen mixtures can improve flow characteristics in severely stenotic airways. Helium can be used as a temporizing measure while the patient is transported and the surgical team assembled. Anesthetic management is typically performed with high O₂ concentration and potent inhalation agent. Whether the flow advantages of added helium would offset the lowered oxygen reserve from the lowered FIO₂ is an open question.

It is helpful to know the location and cause of the stenosis before planning the anesthetic. Typical locations are midtrachea for cuff stenoses and the site of previous tracheostomy if scarring from that procedure has caused the injury.
**B. Dynamic obstruction**

Flow-dependent obstruction is caused by a weakened tracheal wall, or by an intralumenal mass that moves with respiration. Patients will have symptoms that are manifest primarily during inspiration or expiration. Position may be an important factor in their airway patency and every effort should be made to mimic their optimal position during induction.

Normal pressure relationships in the tracheobronchial tree show a gradient that directs airflow. During inspiration the pleural and alveolar pressure are subambient, the tracheal and conducting airway intermediate, and the mouth at ambient pressure. In the extrathoracic region, the tracheal lumen will be at lower pressure than the surrounding tissue, and would collapse were it not for the resiliency of the cartilage rings that nearly encircle the trachea. If the rings have been damaged or eroded, the trachea will tend to collapse on inspiration, worse when a higher gradient is attempted. Thus attempting to compensate for the increased resistance of a tracheal lesion by more respiratory effort will be counterproductive. On flow-volume loops, there will be a plateau in the inspiratory phase, where optimum flow is achieved by a balance of pressure gradient and lumen size. Positive pressure ventilation should counteract this tracheal collapse, though more complex injuries make the balance unpredictable.

On expiration, the thorax is at higher pressure than the tracheal lumen, which in turn is at higher pressure than the mouth. Intrathoracic lesions will be manifest in expiration. There will be the same plateau in the flow-volume loop, but now in the expiratory phase. Controlled ventilation should have no advantage, although the application of positive end-expiratory pressure (PEEP) may increase the intraluminal pressure. Indeed patients may use pursed lip breathing on expiration to induce this phenomenon. This suggests that the transluminal pressure seen by the trachea is not just the pulmonary pressure which would be similarly raised by PEEP.

Loss of integrity of the cartilage skeleton of the trachea is seen after trauma, tumor, and some congenital abnormalities. Any lesion in the trachea will worsen the effect by increasing the needed pressure gradients. Large external masses in the anterior mediastinum can compress and distort, and should trigger concern. To some extent, the tone of the muscles of respiration seems to play a role, with worsened obstruction seen after the administration of muscle relaxants. In these patients, positional symptoms may be very important. Mediastinal masses may also encroach on vascular structures, with SVC syndrome and airway swelling, worsening the symptoms. In experimental studies, the cardiovascular effect of an anterior mediastinal mass was right heart failure due to pulmonary vessel obstruction which was independent of mode of ventilation.

A careful history should be able to identify those patients at risk for problems with airway obstruction at induction of anesthesia. The safest approach in patients at significant risk is to maintain spontaneous ventilation until the obstruction can be assessed and the airway secured. A potent inhalation agent is employed until loss of consciousness. At this stage it is possible to attempt control of ventilation, though the
patient will not be ready for instrumentation. If it is possible to control ventilation, we
know that positive airway pressure is advantageous, and we will be able to speed the
arrival at a surgical anesthetic plane as well as consider the use of muscle relaxants. If
controlled ventilation is not possible (after suitable methods of relieving upper airway
obstruction) muscle relaxants should not be used.

It is possible to perform rigid bronchoscopy and intubation solely on deep inhalation
anesthesia with spontaneous ventilation. The onset will be slow since ventilation will
decrease as the anesthetic depth increases, especially in the presence of airway
obstruction – the drive to ventilation in the presence of a respiratory load is attenuated by
potent inhalation as well as intravenous agents. Sevoflurane is currently the best choice
for inhalation induction, it is potent and surprisingly non irritating to the respiratory
tract.\(^8\)

If ventilation can be successfully controlled, the use of neuromuscular blockers can be
considered. The advantage of relaxants is better intubating conditions and less chance of
movement during rigid bronchoscopy. The disadvantage is that spontaneous ventilation
will not be possible, and that muscle tone will be lost. Being able to recover spontaneous
ventilation can be important for diagnostic reasons, to assess if there is a dynamic
component to the tracheal obstruction, and for therapeutic reasons, to illustrate by the
movement of air where the true lumen is located in a badly diseased trachea. As the
bronchoscopy proceeds, an initially adequate airway can become bloody and swollen and
no longer safely controlled. Being able to fall back on spontaneous ventilation in this
circumstance may be essential, and cannot be assured after paralysis.\(^9\) In the end, the
point in the procedure when muscle relaxants can be safely used depends on the
experience and judgment of the anesthesiologist and surgeon. Some centers have
published good results using intravenous techniques alone.\(^10\)

C. Tracheoesophageal fistula

A fistula between trachea and esophagus (TEF) creates unique challenges to the
anesthesiologist. Until the trachea is intubated below the fistula, there is no way of
preventing refluxed gastric contents entering the lungs, or of assuring that controlled
breaths will enter the lungs instead of the GI tract. Excluding congenital abnormalities in
neonates, the common causes of TEF are postintubation fistulas, as well as traumatic
tears, and erosion from tumor, infection or radiation. In the worst cases, large holes allow
free and chronic aspiration with severe lung injury.

Aspiration risk can be minimized by elevating the head of the bed (reverse Trendelenberg
position), gastric drainage, and withholding food. Nasogastric suction or gastrostomy
tubes can be suctioned to reduce gastric contents and vent gas from mask ventilation.
Cricoid pressure will obviously be ineffective. If one lung has been more severely
affected by aspiration, that side should be dependent to prevent gastric contents from
injuring the better side.
Spontaneous ventilation has strong advantages over controlled ventilation for the unsecured airway in TEF. The descending diaphragm draws gas into the lungs. All that is required is a patent airway above the lesion, which can be obtained with standard jaw thrust, oral or nasal airways, or a laryngeal mask airway (LMA). Anesthetic induction methods that maintain spontaneous ventilation, like potent vapors, allow ventilation while the airway is assessed and secured. In contrast, controlled ventilation requires that the compliance of the lungs be lower than that of the GI tract. Even if a sufficient fraction of each delivered breath enters the lungs, there will be progressive abdominal distention since the esophageogastric junction acts as a one-way valve. Eventually the distended abdomen will compromise ventilation. Despite the advantages of spontaneous ventilation, controlled ventilation and muscle relaxation is often employed in neonates, with subsequent occlusion of the TEF by a balloon until the repair is complete.

Patients with very small fistulae present a different challenge: finding the tract. Controlled ventilation is not a problem in these patients. The fistula may be found with contrast studies in the radiology suite, or intensive bronchoscopic examination of the trachea, possibly while dye is introduced into the esophagus.

Endotracheal tubes should be positioned precisely under direct fiberoptic guidance in patients with tracheoesophageal fistulae. The tube must be distal to the fistula, and it is preferable to have the cuff distal to the lesion, so that it does not enlarge the hole. Fistulas near the carina may be better managed with double lumen tubes or endobronchial intubation.

D. Airway trauma

Anesthetic considerations in traumatic injuries to the airway revolve around identifying those patients at risk, and choosing techniques that do not cause a tenuous airway to be lost. Traumatic injuries to the airway are usually classified by their mode of injury. Penetrating injuries are the result of gunshots and knives. Blunt trauma can be from direct blows, or secondary to rapid deceleration.

1. Penetrating trauma

The presence of penetrating airway injury in the neck is usually unsubtle. An open airway, with gas exchange from the wound will be present. The optimum approach in these cases is to directly intubate the exposed distal tracheal end, perform any other resuscitative care, and then surgically address the trachea. There is the risk that placing a tube in the distal trachea will disrupt the mucosa, pushing it with the end of the tube to fold and obstruct the airway. If possible, the mucosa should be grasped with a surgical instrument and the tube gently slid in. The patency of the tube can then be assessed by conventional means as well as fiberoptic examination.

Other injuries that should be considered include trauma to the innervation of the vocal cords, pneumothorax, and injury to the major vessels. The surgical approach to the trachea can be a primary repair in auspicious circumstances. Induction of anesthesia of obviously
easy, and the tube can be switched to an orotracheal tube under controlled conditions, or with retrograde methods described later.

Penetrating injury within the chest may not initially be recognized. Pneumothorax and major vascular injury will be the initial focus. Hemoptysis, pneumomediastinum and pneumothorax can be caused by lung injury and well as tracheal injury.

2. Blunt trauma

The mechanism of blunt airway injury is still debated. Most blunt trauma is seen in motor vehicle accidents or other high impact encounters. Direct injuries to the larynx and cervical trachea are caused by a violent blow by the steering wheel in automobile drivers and by branches or chains in motorcyclists or bicyclists – “clothesline injuries.” In these cases the fractured tracheal ring can be dislocated, obstructing the trachea.\(^\text{17,18}\)

Deceleration injuries are where portions of the trachea, hilum and lungs and chest wall slow at different speeds, producing ruptures of the trachea at various levels, or disruption at the mainstem bronchi. Injuries can occur at all levels but are common midtrachea where the trachea passes behind the subclavian vessels and at the hilum, and right mainstem bronchus. Alternative hypotheses are that the acute lateral deformation of the thoracic cages causes traction injuries, or that high airway pressures from the sudden compression of the chest causes blow-out fractures of the trachea at places where the wall stresses are concentrated.

Tracheal injuries should be suspected in all patients involved in high speed motor vehicle accidents. Symptoms include hoarseness, voice change or pain. Air in the neck is a sensitive sign, and can be seen on Xray or CT scan which will be obtained in any case to evaluate the cervical spine. In grosser cases, subcutaneous emphysema will be present. Hemoptisis, stridor and respiratory distress can all be signs of airway injury, as is the dropped lung sign seen in complete disruption of a mainstem bronchus. A few patients will only be recognized later in their hospital course when tracheal stenosis is seen.\(^\text{19}\)

These patients require careful airway management. A partially disrupted trachea can be completely disrupted by the passage of an endotracheal tube. Cricoid pressure can dislocate a fractured cricoid or thyroid cartilage. Positive pressure ventilation may either put sufficient stress on a partially ruptured segment to complete the disruption, or be ineffective as gas escapes through a ruptured wall. The safest course is to maintain spontaneous ventilation, either with deep inhalation agents or topical anesthesia and fiberoptic intubation.

E. Bronchopleural fistula

Bronchial disruption can occur at any level of the tracheobronchial tree. Peripherally it usually managed conservatively. The pleural space must be vented to prevent a tension pneumothorax, and adequate ventilation must be assured. Spontaneous ventilation will work well, as long as the lung stays inflated. If controlled ventilation is required, methods
of minimizing airway pressures should be employed, including high frequency jet ventilation. Placing a double lumen tube and ventilating the two lungs independently allows the lung with the fistula to not steal all the tidal volume.

Disruption of the major airways, including lobar bronchi after lobectomy and the mainstem bronchi after pneumonectomy requires surgical intervention. Lung isolation will be required, both to allow surgical exposure, and to prevent spillage of pleural contents, blood and pus, into the open airway and to the other side. Prior to induction patients should be placed with the affected side down. A tube should be placed endobronchially on the side opposite the lesion under fiberoptic guidance.

III. Procedures

A. Rigid bronchoscopy

The rigid bronchoscope finds particular application in tracheal lesions and tracheal surgery. Unfortunately, at many institutions its use is rare because flexible bronchoscopy is more common for routine examination. The unique feature about the rigid bronchoscope to the anesthesiologist is that it takes the place of an endotracheal tube, serving as an airway as well as a surgical tool.

Rigid bronoscopes come in various sizes, but share common features: a hollow central lumen open at each end, a side opening for gasses, and some small channels along the side for light and jet ventilation. The upper end is opened to allow instruments to be passed, or closed to allow gas delivery.

In the anesthetized patient, the bronchoscope is introduced either directly, or with the assistance of a laryngoscope. Once in the trachea, the neck is extended and the bronchoscope attached to the anesthesia circuit. A variable leak will be present, worsen with proximal position and smaller bronchoscopes, and lessened with distal passage, or passage though a narrowed tracheal region.

Ventilation in the presence of a substantial leak can be problematic. First of all, end-tidal gas tension measurements are useless as all the returning gas leaks out. Second the attempted tidal volume is largely lost due to leakage, and only a small and variable fraction actually delivered to the patient. Observation of chest excursion is the best way to assess ventilation. Blood gas sampling can describe the patient’s ventilation at one point in time, but an indwelling continuous arterial gas catheter would be required to provide adequate feedback to guide therapy.

Closing the mouth and nose can lessen the leak (although gas can easily enter the stomach as well). Using high gas flows can also help, but special modifications of modern anesthesia machines is needed since most machines currently on the market do not allow O₂ flows above 12 l/min whereas flows of 30 l/min may be necessary.
Another method of ventilation with a rigid bronchoscope is to jet gas down the side port.\textsuperscript{20} This method requires an open system to prevent severe barotrauma. The gas is delivered at up to 50 psi (300 kPa) at the source and without a channel for egress that pressure would be transmitted to the entire respiratory organ.\textsuperscript{21} The effectiveness of ventilation again has to be assessed by chest excursion. Anesthetic agents must be administered by the intravenous route during jet ventilation.

The rigid bronchoscope can be used to slice off fragments of granulation tissue or tumor in the airway. The anesthesiologist must be aware of this possibility and refrain from ventilation until the loose tissue is retrieved. The anesthesiologist and the operator of the bronchoscope must also negotiate adequate time to ventilate in-between apneic periods required for instrumentation. Examination through the rigid bronchoscope is accomplished with prismatic telescopes which have superior optical properties. Ventilation is maintained in the annular space around the telescope.

The rigid bronchoscope is well suited to examination and interventions in the trachea and main bronchii. A flexible fiberoptic bronchoscope is needed for more distal work. The flexible instrument can be passed through the rigid bronchoscope allowing ventilation and distal observation.

Anesthesia can be maintained by either the inhalation or intravenous route. Neuromuscular blockade is advantageous if the airway can be secured since vigorous movement with a rigid bronchoscope in place could be dangerous. Because of the large leak with the uncuffed rigid bronchoscope inhalation agents are less desirable. The quantity of agent used will be uneconomical with the high flows required, and the contamination of the operating room environment is considerable. Level of inhalation agent in the 200 ppm range have been published, well above NIOSH guidelines of 2 ppm for potent inhalation agent used without N\textsubscript{2}O\textsuperscript{22}. Intravenous agents should be selected for their short duration of activity. Remifentanil and propofol are ideal. Awake rigid bronchoscopy in topically anesthetized patients is only of historical relevance.

The rigid bronchoscope can be used as a platform for laser surgery of the airway. The major risk is airway fire. Ventilation at low F\textsubscript{I}O\textsubscript{2} must be employed during laser segments, and N\textsubscript{2}O is not a safe diluting gas since it too supports combustion. Even though the bronchoscope is inert, and no combustible endotracheal tube is used, dessicated tissue can be ignited. The treatment for airway fire has been well described, including cessation of O\textsubscript{2}, removal of the fuel, saline quenching, reestablishing an airway, and supportive care.

**B. Flexible bronchoscopy**

Flexible bronchoscopy allows inspection of the major airways as well as several generations of the tracheobronchial tree. Snares, brushes and fine forceps can be passed through its channel to allow instrumentation of the airway. The flexible bronchoscope is well tolerated by awake patients if adequately topicalized, and so allows inspection of the extent of functional tracheal damage or recovery after surgery. The flexible bronchoscope
is also used for placement of endotracheal or endobronchial tubes, and for pulmonary toilet.

In the presence of severe tracheal stenosis, the flexible bronroscope is less useful. It is difficult to ventilate through the bronroscope (although jet ventilation from the suction channel has been described) and so the tube will further obstruct the airway. A rigid bronroscope allows ventilation through its generous internal lumen, and can be used to directly dilate stenotic regions. There is a system for using a flexible bronroscope to dilate the airway, first by passing a wire guide, then a balloon dilator. Ventilation will have to be through the stenosis until the dilation is complete. General anesthesia may not be required for balloon dilation with a flexible bronoscope (a supposed advantage).

There are several methods for managing the airway during flexible bronchoscopy. Awake patients with adequate topical anesthesia can breath around the bronroscope that is passed through the mouth or nose. Under general anesthesia, an endotracheal tube can be introduced and the bronroscope passed through the tube. Finally, an LMA will sit above the larynx, allowing a bronroscope to be passed through the LMA, the cords and into the trachea. The LMA is particulary advantageous in very proximal lesions and in cases where muscle relaxants are otherwise not needed.

C. Tracheal resection and reconstruction

a) Initial phase

At the simplest level, anesthesia for tracheal reconstruction is an exercise in sharing the airway. After evaluation, induction, and possibly bronchoscopy, the airway is secured with a tube distal to the lesion. Part of the value of the initial bronchoscopy is to assist planning the means of securing the airway. The anesthesiologist should view the airway with the surgeon, and get a sense of lumen size and course. Knowing the airway is bloody or friable will help management of sudden obstruction during the operation.

There are three good reasons to start with rigid bronchoscopy: examination of the trachea and assessing resectability, dilating tight stenoses or removing some endoluminal tumor to permit passage of an endotracheal tube, and in the worst cases, providing the airway used for the procedure. Rigid bronchoscopy is essential when the airway lumen is significantly compromised; less than 5 or 6 mm in diameter. Unless the airway is dilated, the initial operative course will feature hypoventilation with attendant hypoxia, hypercarbia and arrhythmias.

Induction can be either inhalation or intravenous depending on the underlying pathology and the experience of the practitioners. Long acting agents are unwise since the initial bronchoscopic evaluation may find resection should be postponed or canceled.

Anesthetic maintenance can be achieved several ways. Inhalational agents are inexpensive, blunt airway reflexes well, and are relatively quickly dissipated. The disadvantages are that the airway will be open intermittently during the procedure, so that
much agent will contaminate the operating room environment. Also during those periods, no anesthetic will be administered to the patient, requiring compensatory deeper levels before and after.

Total intravenous anesthesia is well suited to tracheal surgery. The processes of ventilation and anesthesia delivery are decoupled, and the operating room air is not contaminated. Remifentanil and propofol delivered by infusion are an excellent choice. Airway reflexes are well blunted, and the effects wear off quickly at the conclusion. Other intravenous regiments, such as ketamine infusions, sufentanil or alfentanil infusions and barbituates are certainly possible, but run the risk of producing lingering post-operative sedation, which we shall see is undesirable.

Regional techniques are used for simple tracheal procedures, like flexible bronchoscopy and occasionally tracheostomy. In theory cervical tracheal resection could also be performed under block, but the level of cooperation required, particularly if rigid bronchoscopy is contemplated makes it impracticable.

The monitoring required for tracheal surgery concentrates in the assessment of respiration. CO₂ measurements in the end-tidal gas and arterial blood are helpful to assess adequacy of ventilation. Oxygenation is confirmed by pulse oximetry. An arterial catheter is helpful, especially in the postoperative period. It is possible to compress the innominate artery which crosses the trachea at the sternal notch. Such compression will impair blood flow to the right arm and right carotid. Either an arterial line or pulse oximeter on the right arm will provide warning. More extensive hemodynamic monitoring should be dictated by other coexisting conditions. Intravenous access will be needed, but major volume requirements are rare.

b) Resection

The preferred position of the endotracheal tube at the start of the resection is distal to the lesion. If the tube is proximal, the surgical manipulation may provoke airway obstruction in some types of tracheal lesions. In some situations, distal intubation will not be feasible. Once the airway is secured, the patient is positioned for the tracheal resection with the neck extended to deliver the tracheal out of the thorax. Space will be tight around the patient’s head, but access must be preserved to allow the anesthesiologist to manipulate the endotracheal tube, an essential part of the procedure.

Surgical dissection is performed to expose the affected region, and the endotracheal tube is withdrawn sufficiently to allow severing the trachea. Ventilation is then accomplished with a tube placed in the surgical field into the distal trachea, attached to a circuit accessible by the anesthesiologist. If possible, the circuit should include a sampling port to allow assessment of end-tidal CO₂.

The tube placed on the field will lie in a tightly curved position, so a non-kinking flexible armored tube is preferable. The tube is also placed into a rather short distal tracheal segment, so will easily be advanced into a mainstem bronchus. For all these reasons, as well as the potential that blood and clots can run into the tracheal from the surgical field,
the anesthesiologist must maintain close vigilance over tube position and pulmonary compliance.

An alternative to distal intubation with an endotracheal tube is the use of jet ventilation with a jet catheter. The jet catheter is of smaller caliber and does not require a seal to deliver tidal volume. There are some drawbacks to jet ventilation, including more difficult assessment of the adequacy of ventilation, unless a separate distal sampling catheter is used. Barotrauma is a constant risk if the catheter is advanced into too small a segment of the pulmonary tree. Jetted gases are rarely humidified, so the respiratory tract will become dehydrated, and secretions will more difficult to mobilize. It is hard to deliver gaseous anesthetics via jet ventilation, and there is the aesthetic problem of aerosolized blood and secretions from the jetting process. Finally the jet catheter will tend to recoil from the airway so must be held in place by a member of the surgical team.

One other proposed method for oxygenation and ventilation is the use of cardiopulmonary bypass (CPB). No airway appliance would be required with this technique. There are substantial disadvantages to CPB, including the need to anticoagulation, microemboli, and more invasive access. More difficult reconstruction, where CPB might be contemplated, usually are intrathoracic, and the substantial lung manipulation required for surgical access would be damaging in the anticoagulated state. Indeed, in experienced centers, CPB is never needed unless major vascular or cardiac work is also required (e.g. vascular rings).

c) Reconstruction

The necessary resection is done and the reconstruction prepared by placing sutures loosely spanning the resected area. Intermittent removal of the endotracheal tube facilitates placement of sutures in the distal margin. When it is time to bring the two tracheal ends together, the surgical tube is withdrawn and the orotracheal tube carefully advanced into the distal trachea.

Flexion of the neck shortens the distance from trachea to carina, so the neck is now flexed to allow the tracheal ends to be reapproximated without tension. This neck flexion will be maintained for the balance of the procedure and throughout the postoperative recovery period.

In some instances the orotracheal tube will have been withdrawn entirely from the trachea during the reconstruction to allow better exposure of the subglottic larynx for repairs at that level. Direct laryngoscopy to replace it would be difficult under the surgical drapes, but fiberoptic intubation would certainly be possible. Fortunately, there is a clever alternative method of intubation. A small stiff catheter is passed retrograde from the surgical field, and fished out of the mouth. An endotracheal tube can then be sutured to the end of the catheter, and the whole assembly pulled into the trachea. This maneuver will be necessary if the orotracheal tube is pulled out, if the patient had a preexisting tracheostomy that was used initially, if the rigid bronchoscope served as the airway during the initial phase of the resection, or if the endotracheal tube was damaged when the trachea was entered. For proximal lesions where the tube will likely need to be pulled
out of the trachea, suturing a catheter to the orotracheal tube before it is fully withdrawn may simplify the reintubation.

d) Emergence

At the end of the procedure the goal is to have an extubated patient with a patent airway. There are several reasons to prefer extubation. An appliance in the trachea will irritate the tracheal anastomosis, especially if the end of the tube or the cuff is at the suture line. Positive pressure ventilation will also put strain on the suture line, and tend to push air into the tissues until the mucosa has sealed. A tracheostomy distal to the repair is possible, but will injure some of the remaining good trachea, so it is avoided. If the airway needs to be secured in the postoperative period, either because of transient swelling or injury to the innervation to the cords, a small uncuffed tube is preferred. The reintubation can be achieved either with direct laryngoscopy while maintaining strict neck flexion (a straight laryngoscope blade works best) or by fiberoptic intubation.

Neck flexion must be rigorously maintained. Even one episode of extension in the emergence period may disrupt the anastomosis. This will be a disaster, both acutely (bleeding, subcutaneous emphysema and loss of airway) and longer term (leak, scarring and restenosis). To prevent neck extension a suture is placed from the chin to the chest. This will prevent an awake patient from unconsciously extending his neck, but will not stop the movements of a partially conscious patient in the midst of emergence. A prudent anesthesiologist will keep a hand on the occiput throughout the emergence and transport process, forcing the head to follow the torso during patient movement. All other matters of organization and equipment can be delegated. To the extent possible, gentle emergence, avoiding violent coughing and movements, is preferable.

Opiates should be used sparingly. Pain is usually minor, small amounts of narcotic and non-narcotic analgesics are quite sufficient. Furthermore, we desire an awake cooperative patient who is able to maintain upper airway patency.

A large part of the art of anesthetizing patients for tracheal reconstruction occurs in the immediate postoperative period, when the adequacy of the airway must be evaluated. Good tidal volumes and a strong voice are signs of a successful outcome. If the patient does not appear to be moving air well, several alternatives must be quickly assessed. Absent or inadequate respiratory effort is a result of inadequate respiratory drive or muscle strength. Both scenarios should be treated symptomatically with support of ventilation and reversal of neuromuscular block or respiratory depression. Again, since these patients have less tolerance of respiratory compromise, a properly planned anesthetic will tend towards light levels of block and sedation.

Patients with respiratory obstruction will show vigorous effort, but inadequate air movement. Sternal and intercostal retraction, and discoordinated chest and abdominal excursion are all signs of obstruction. In the more awake patients, anxiety and air hunger will be manifest. The clinical question is then whether the obstruction is in the upper airway (above the vocal cords), or the more worrying lower airway. Upper airway obstruction can be treated by conventional methods: oral suctioning, jaw thrust, oral or
nasal airways or even a laryngeal mask airway (LMA). The only caveat is to avoid neck extension.

Lower airway obstruction can also be due to edema of the trachea or larynx. This is particularly likely if extensive manipulation was required, if the disease process affected non-resected areas, or if infection is present. Severe cases will require a stenting tube – small caliber uncuffed endotracheal tube. In less severe situations, nebulized epineprine, upright posture, and a short course of steroids will be sufficient.

Cord function can be impaired from the preexisting disease, or by the surgical dissection. Even though the nerves may be anatomically intact, stretch or trauma may cause transient spasm that adducts the cords. Fiberoptic exam or direct laryngoscopy will show tightly adducted vocal cords, and passage of a small endotracheal tube, or temporary tracheostomy will be necessary.

Finally, technical problems with the anastomosis are always possible. It is wise to inspect a problematic reconstruction fiberoptically before the end of the procedure since unanticipated problems can occur. In the extreme situation, the operation will have to be resumed, and the reconstruction revised – not an pleasant occurrence.

In the first day or two after the procedure, intensive nursing care with close observation is needed. Problems include difficulty clearing secretions and bleeding in the neck compromising the airway. Serial bronchoscopy at the bedside is common, both to assess the surgical repair and to assist with pulmonary toilet.

Patients with previous tracheal reconstruction presenting for unrelated anesthesia are not particularly difficult to manage although fiberoptic intubation or exam has some merits. The larynx may be relatively distal if the resection was extensive or the tracheal mobility limited (heavy set and older patients). A successfully reconstructed trachea should have smooth walls without stenotic segments, however even clinically satisfactory repairs can have mild narrowing at the site of the anastomosis. Furthermore, there is risk of inadvertent endobronchial placement of an endotracheal tube, since the tracheal length may be shortened after resection. Effort to be gentle in introducing the endotracheal tube and inflating the cuff is desirable. If possible, it would be better not to have the cuff sit across the anastomosis. Techniques that avoid intubation such as regional techniques, mask ventilation or the LMA also are appropriate.

It is possible that there is residual disease or stenosis at the site of the surgery that is not yet symptomatic. If the patient has not been routinely or recently evaluated, a prudent approach to these patients is to have the thoracic surgeon perform bronchoscopy prior to the surgery.

**D. Carinal resection and reconstruction**

Lesions near the carina add some new challenges to the process of the tracheal resection and reconstruction discussed above. The procedure is intrathoracic, usually
approached from a thoracotomy, and the lungs cannot be treated as a single entity. As in all thoracotomies, arterial monitoring is prudent and methods of postoperative analgesia, such as thoracic epidural catheters, are needed.

The considerations for induction of anesthesia are similar to surgery for higher lesions, although it is even more clear that surgical access to the airway in the case of complete obstruction is not an option. Some authors suggest veno-venous bypass as a fallback technique. Once the bronchoscopic examination is completed, it is time to intubate the trachea. There are several options. If the airway is not too compromised, the tube can sit above the lesion. The trachea will often be approached via thoracotomy, and the airway entered. Exposure cannot be assisted by collapse of the lung unless a blocker is passed into the surgical side. If the bronchus is already damaged, a blocker would be unwise so small tidal volumes and some effort from the surgeon’s assistants are required. Once the trachea is entered, a tube is passed on the field into the opposite mainstem bronchus and single lung ventilation employed.

Some lesions are better addressed by distal intubation from the start. Since the lesion is at or beyond the carina, the only option is endobronchial intubation. An endobronchial tube is chosen instead of a standard double lumen tube because the double lumen tube is too bulky to permit tracheal surgery. Long flexible tubes of small diameter but sufficient length (>31cm) to reach the bronchus are not currently widely available. It is possible to easily construct them by combining two tubes. An example is shown below, using a Phycon silicone armored cuffed tube with it’s integral collar*, and a length of standard PVC tubing placed in the collar with a friction fit. The lumen stays a constant diameter and the tube has the desirable properties of being more stiff in the upper portion and flexible and non-kinking in the lower portion. Note that the tip design in endobronchial tubes is important. There is not a long segment of bronchus for the cuff and distal potion to sit, so a shorter cuff to end design is preferable.Trimming the end of an endotracheal tube will make the cuff incompetent since the cuff air channel runs beyond the cuff. The endobronchial tube is positioned under fiberoptic guidance. The jury-rigged nature of these tubes, as well as the extensive surgical manipulation of the region causes frequent tube malposition. A fibroscope should be constantly at hand as the anesthesiologist will be required to make frequent corrections as the operation proceeds.

Other creative endobronchial tubes have been created by trimming the distal portion of the tracheal lumen off a double lumen (destroying the tracheal cuff). This leaves a single lumen in the distal trachea that ends in the bronchus. The endobronchial lumen is well designed for the bronchus, especially the right mainstem bronchus. The abbreviated tracheal lumen is actually quite useful, allowing introduction of fiberoptic bronchoscope, jet catheter, bronchial blocker or oxygen insufflation. This modified double lumen tube is less satisfactory, however, in greatly distorted airways, since the contour is designed for normal anatomy and has no protection against kinking once warmed and bent.

With endobronchial intubation, one lung will not be ventilated. As in all thoracotomies, the level of shunt and desaturation is variable and unpredictable. Standard maneuvers include suctioning, confirming position, increasing FIO₂ and varying the ventilatory
patterns. Unlike many thoracotomies, it is not as easy to administer ventilation to the deflated lung. While the airway is intact, deflating the endobronchial cuff, blocking the mouth and nose and delivering longer, larger tidal volumes can help. Alternatively, placing another endotracheal tube high in the trachea (yes, two endotracheal tubes, of small diameter) can allow differential ventilation or at least constant positive airway pressure (CPAP). Another approach is to place an LMA after the endobronchial tube and, if it seals sufficiently, CPAP can be administered. Finally, a jet catheter can be placed in the trachea. Indeed a technique using two jet catheters has been described. The jet catheter has the advantage of not requiring a seal, but may not be effective if there is substantial distal obstruction. In extreme circumstances, blood flow to the pulmonary artery can be restricted, lessening shunt.

Once the airway is open, CPAP cannot be administered from above. A second tube can be placed from the field into the deflated lung, or a jet catheter can be used. The jet catheter has the advantage that it is small enough to allow surgery to proceed, it does not require an entire circuit, and the length that needs to be placed in the trachea is very small. Since large tidal volumes are not needed on the surgical side the force and mess of jetting is less.

The conduct of one-lung ventilation for carinal surgery requires all the considerations given conventional pulmonary resection. Care with airway pressures and avoidance of overdistention is important. In cases where a pneumonectomy is performed, there are also the issues of thoracic volume and shift of the mediastinum, as well as the need for careful fluid management, lower FIO2, and gentle surgical manipulation.

There is little difference in the management of emergence from anesthesia in carinal surgery as opposed to tracheal surgery. Cord swelling is less likely, but obstruction from blood and secretions more common. Pain control will be a bigger factor; selection of methods that do not suppress respiratory drive is preferable.

Patients with previous carinal surgery that present for unrelated surgery should not, in general, present particular anesthetic problems. It would be prudent to avoid pushing an endotracheal tube too distal and risk injuring an anastomosis. Most anesthesiologists at centers with experience with these patients would confirm good tube position and an undamaged distal airway with bronchoscopy after intubation. If lung isolation is required for the surgical procedure, the considerations are more involved. As much as possible it is wise to avoid instrumenting and especially inflating a cuff in a repaired region. The carinal anatomy will be abnormal, with possibly shorter bronchial lengths and different angles of departure for the bronchii. The use of an endobronchial tube may be necessary. In any case, all tube positioning should be done under fiberoptic guidance to avoid the risks of malpositioning.
E. Stents

If primary removal or correction of airway lesions is not possible, other means of assuring an airway must be found. These include trachostomy tubes, T-tubes, and stents.

1. Tracheostomy

The standard tracheostomy should be familiar to all practitioners. It can be performed under topical anesthesia in impending airway obstruction, or on a patient with an endotracheal tube in place. The management is similar to reconstructive surgery, except that extubation, neck flexion and concerns about upper airway obstruction are not present.

The indications for tracheostomy include facilitating controlled ventilation, protection of the airway against aspiration and bleeding, and allowing airway access distal to an obstructed or damaged portion. Tracheostomy is also commonly performed in patients requiring prolonged intubation since it is more comfortable and less injurious to vocal cords than orotracheal or nasotracheal intubation. There has to be special consideration of gas humidification since the function of the nasopharynx is bypassed. If no humidification and cleaning is done, the tube will eventually become obstructed with secretions. Voice can be preserved via a number of tube modifications, including choosing not to use a cuff or choosing a tube with a special fenestration.

When presenting for another procedure, a patient with a tracheostomy tube can either ventilated through the existing tube, or the tracheostomy tube can be exchanged for a cuffed endotracheal tube passed through the tracheostomy stoma. It is unwise to remove a fresh tracheostomy tube, the stoma has not yet healed and the replacement tube can easily enter another tissue plane. If a tube is placed, care must be paid to the depth of insertion, since the length to the carinal bifurcation can be deceptively short. The effectiveness of ventilation will also depend on whether there is a cuff in place, or whether the inner cannula that covers the fenestration of a fenestrated tube is in place.

2. T-tube

The T-tube is an uncuffed tube that sits in the trachea, held in place by the side arm through a tracheostomy stoma. It is designed to bridge any diseased portion of the trachea, allowing full voice and mouth breathing. The tracheostomy segment is typically capped, but can be opened if there is proximal obstruction, and for suctioning.

Placement is done in an anesthetized patient, with the folded tube placed through the stoma and springing into proper position. Evaluation via flexible bronchoscopy through the side arm and rigid bronchoscopy from above will also show adjustments that need to be made. The procedure can take many iterations to find the optimal size and length for each segment. At times the tube may lie in a folded state in the distal trachea, completely obstructing the airway. The anesthesiologist needs to recognize this promptly and
provoke correction or removal. There will be extensive apneic periods during placement and manipulation requiring coordination between anesthesiologist and surgeon. In the interlude, a small endotracheal tube can be placed in the stoma, or the stoma can be covered and ventilation accomplished through the rigid bronchoscope.

At the end of the procedure the patient should be ready to resume spontaneous ventilation. Blood and secretions can precipitate acute obstruction, so close observation, suctioning, and even removal of the tube may be needed. Although the goal is to cap the side-arm, there may be enough swelling of the larynx after all this manipulation to delay capping for a few hours. Humidified oxygen applied to the stoma will be needed.

If a patient with a T-tube in place comes for unrelated surgery, there are several options. Regional techniques, where appropriate, will avoid airway manipulation. An LMA can be placed, and the sidearm left capped. The tube will then perform its function as a tracheal stent. The sidearm can be accessed by removing its cap and placing the adapter to an appropriately sized endotracheal tube. In this case, the trachea is open above, and ventilation will depend on the relative resistance of the two arms. The upper arm can be obstructed by a blocker placed via laryngoscopy of placed via the sidearm and cajoled into sitting in the proximal lumen. Finally the T-tube can be entirely removed and replaced with a tube through the tracheostomy. The choice of method should depend on the nature of the procedure and the predicted postoperative course.

3. Stent

Endoscopically placed stents can be silicone tubes or expanding wire devices. The stents are placed directly via a rigid bronchoscope, or using a flexible guidewire placed with a flexible bronchoscope. Rigid bronchoscopy allows ventilation through the bronchoscope, while flexible bronchoscopic techniques require intermittent ventilation with mask, tube, or jet catheter. The major anesthetic considerations, besides the underlying tracheal pathology, is the chance that a poorly positioned stent will completely obstruct the airway. As with T-tubes, the stent once deployed may need minor corrections to improve its function, so an anesthetic of unpredictable duration ensues. On emergence, patients tend to find the stent irritating, and can cough it out of position. The patient will need to be reinduced and the process restarted. Assessment of the adequacy air movement, and maneuvers to improve the airway, such as nebulized epinephrine and a short course of steroids may be needed.

When a patients with a stent presents for unrelated surgery, many of the considerations for patients with T-tubes pertain. Regional techniques and the LMA will avoid tracheal manipulation. If it is necessary to secure the airway, all the information available on the stent and the underlying tracheal lesion should be collected (probably a wise precaution even if intubation is not planned). The location of wire stents can be seen on Xray. If the stent is relatively distal, a tube placed in the proximal trachea may not impinge. The tube should be placed under fiberoptic guidance, and care must be taken not to allow it to move during patient positioning. While it is possible to intubate into or beyond the stent, there is the real risk of dislodging the stent, either pushing it distally and causing
obstruction, or inadvertently removing it on extubation and leaving a vulnerable trachea. With time wire stents become embedded into the trachea wall, and potentially more secure, but the extent and safety of this is not yet known.

**IV. Conclusion**

The anesthetic management of patients is entwined with the surgical management in tracheal surgery. Anesthesia cannot be planned in isolation. Nevertheless, deep understanding of the anatomy of the lesions, and the physics of airflow in the airways guides our approach. The art of anesthetic management is knowing when spontaneous versus controlled ventilation is preferable and recognizing and responding to an obstructed airway. The focus is much more on ventilation, with hemodynamics, fluid management and pain control secondary.

What will the future bring? Some changes in anesthetic agents, surely. Fast acting narcotics and sedatives are here; we now need a muscle relaxant with sufficiently transient action to allow recovery of spontaneous respiration when control is unsuccessful. New surgical techniques are also inevitable. We can look forward to continued improvements in diagnostic imaging techniques, stents and fiberoptic instruments. Perhaps tracheal replacement will be possible. The anesthetic management will need to evolve in step.


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