



# Tracheal Resection and Reconstruction

# 13

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## Key Points

- The tracheal imaging (CT scan and/or MRI) must be examined by the anesthesiologist to plan the anesthetic management.
- Patients with tracheal stenosis may not become symptomatic until the tracheal diameter is narrowed to <50% of normal.
- Initial surgical management for tracheal stenosis will commonly involve rigid bronchoscopy and dilation.
- The two major methods of distal airway management for resection of tracheal stenosis are cross-field ventilation with an endotracheal tube or jet ventilation with a tracheal catheter.
- Maintenance of anesthesia during the period of tracheal resection is commonly managed with intravenous anesthesia techniques.

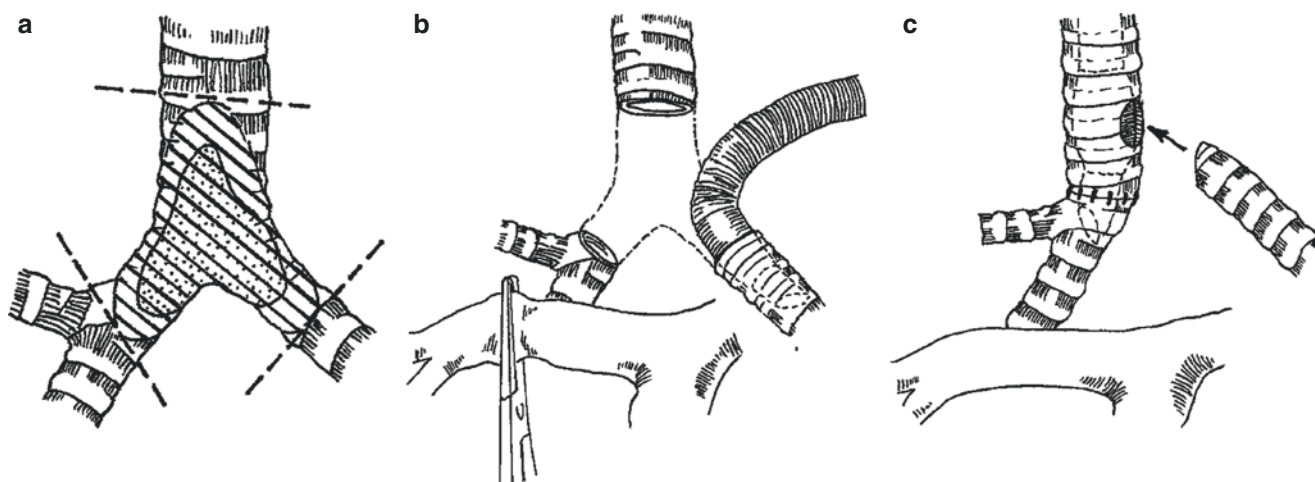
## Historical Note

Surgery of the conducting airway requires diagnostic and therapeutic manipulation of the respiratory tree despite ongoing ventilation. From the very beginning of tracheal surgery, the greatest challenge facing the anesthesiologist has been how to ventilate the patient adequately before and during airway resection. Close collaboration between anesthesia and surgical colleagues was required. Early reports of tracheal tumor resection by Belsey [1] described reconstruction of the mid-trachea after the intratracheal tube was advanced by the surgeon beyond the tracheal defect. A wire coil was

constructed over the cuff of the intratracheal tube, a free graft of fascia covered the wire skeleton, and the intratracheal tube was withdrawn. In 1957 Barclay [2] reported the resection of the carina for a low tracheal tumor with deliberate endobronchial intubation of the left side by the surgeon across the surgical field. The right main stem bronchus was sutured to the remaining trachea, while the left lung was ventilated. Ventilation was then resumed via the orotracheal tube, and the left bronchial was sutured to the right bronchus intermedium during intermittent periods of apnea. In 1963 Grillo and Bendixen [3] described the performance of a similar procedure under critical circumstances, in a patient whose tracheal obstruction had progressed to severe dyspnea and pulmonary hyperinflation. During cross-field ventilation of the left lung, the right pulmonary artery was lightly clamped so that the unventilated lung was not perfused (Fig. 13.1). Elimination of shunt maintained “the best possible tissue oxygenation” permitting an unhurried reconstruction. “The operative requirement for complete anesthetic control during all phases of tracheal surgery is met by the technic of transitory physiologic pneumonectomy.” The same group in 1969 reported the anesthetic management of 31 patients who underwent tracheal resection and reconstruction [4]. The problems of anesthetic induction and control of the airway were fully described in a paper first presented at the International Anesthesia Research Society in March 1969. The upper and lower airway management strategies used during a pivotal period of the development of tracheal resection and reconstruction at the Massachusetts General Hospital were elegantly presented. The discussion of the paper at the meeting reveals the increasing appreciation of the etiology of post-intubation stenoses and the clinical dilemmas these injuries presented.

Prolonged incision and complex reconstruction of the airway in patients with compromised pulmonary function have demanded further innovation on the part of anesthesiologists and surgeons. A spectrum of ventilation strategies has been used, not only to maintaining ventilation but to optimize

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**Fig. 13.1** Cross-field ventilation for carinal resection. (a) The tumor is at the carina; the patient is intubated with an orotracheal tube (not shown). (b) A sterile endobronchial tube is placed across the surgical field after the left main stem bronchus is incised. (c) After anastomosis of the right main stem bronchus to the remaining trachea, the cross-field endobronchial tube is removed; the orotracheal tube is advanced into a

right endobronchial position, during anastomosis of the left main stem bronchus to the trachea. Early descriptions of this technique included snaring of the right pulmonary artery during (b) to minimize shunt during one-lung ventilation (as shown here); this was later deemed unnecessary in most cases. (Adapted from Ref. [3])

operating conditions. Evidence of the success of this evolving collaboration lies in the large series of successful procedures reported.

## Etiology of Tracheal Lesions

The trachea, carina, and major bronchi may be affected by a variety of conditions that are amenable to surgical resection and reconstruction. Airway lesions can be a result of benign or malignant etiologies (Table 13.1) and may or may not result in significant stenosis. Congenital stenosis is typically resected during infancy, after presentation in the first few months of life. In adults many cases of subglottic stenosis are idiopathic; frequently patients have increasing respiratory symptoms for many years, often incorrectly attributed to asthma. Post-intubation injury is the most common cause of benign tracheal stenosis despite the widespread use of high-volume, low-pressure cuffs. Posterior glottic stenosis and circumferential subglottic stenosis are the result of direct trauma from the tube and the cuff, respectively. This results in mucosal ulceration; subsequently the exposed tracheal cartilage is devitalized and disappears, followed by replacement of the tracheal wall with scar tissue [5]. Mucosal injury leading to ulceration has been observed after as little as 2–3 h of intubation with a high-volume low-pressure cuff in a subgroup of patients who received standard anesthesia care [6]. After extubation most lesions heal as a fibrous scar; however some lesions develop malacic components. Post-intubation strictures typically show concentric narrowing, whereas post-tracheotomy stomal strictures tend to result in more side-to-side rather than

**Table 13.1** Etiology of tracheal lesions amenable to resection and reconstruction

Benign lesions
Congenital
Tracheal atresia
Congenital stenosis
Congenital chondromalacia
Vascular rings
Idiopathic
Post-intubation or post-tracheotomy injury
Posterior glottic stenosis
Subglottic stenosis (including cuff injuries)
Tracheoinnominate artery fistula (anterior trachea)
Tracheoesophageal fistula (posterior trachea)
Stomal stenosis (from tracheotomy)
Trauma
Inflammatory
Wegener's granulomatosis
Postinfection (after treatment)
Tuberculosis
Syphilis
Diphtheria
Typhoid
Malignant lesions
Primary malignancies
Squamous cell carcinoma
Adenoid cystic carcinoma (cylindroma)
Mucoepidermoid carcinoma
Carcinoid adenoma
Sarcoma
Mesenchymal tumors
Secondary malignancies
Bronchogenic carcinoma
Thyroid carcinoma
Laryngeal carcinoma
Esophageal carcinoma

anteroposterior narrowing. Penetrating or blunt trauma may cause life-threatening tracheal disruption or, if less severe and unrecognized, may present later as stenosis [7]. A variety of inflammatory diseases can cause airway stenosis; however due to widespread involvement of the airway, few are considered suitable for surgical resection. Most inflammatory lesions are therefore treated with chronic tracheostomy, intermittent dilation, or stenting. A notable exception is Wegener's granulomatosis, which can produce focal stenosis amenable to resection. Postinfectious stenotic lesions may be resected after treatment of the underlying infection. Tracheal resection is performed for primary malignancies unless metastases preclude curative surgery; secondary neoplasms invading the trachea typically arise from the adjacent structures and are less often amenable to surgical resection. When curative resection is not possible, many patients are treated with palliative endoscopic debridement. Similarly, endoluminal metastases which are the result of hematogenous spread from distant malignancies (including breast, colon and renal cell carcinomas, and melanoma) are typically debrided or stented.

## Planning Tracheal Surgery

Planning is essential in these challenging and varied procedures and should be clearly outlined in the preoperative interdisciplinary checklist (Table 13.2). A number of elements are required, starting with a clear understanding of the patient's tracheal anatomy and the resection proposed. A detailed plan for ventilation throughout induction, during the period of open airway and on emergence, must be clear to the anesthesia and surgical teams. Appropriate airway equipment should be assembled and tested to ensure that it is in good working order including rigid bronchoscopes of a variety of diameters and a way of ventilation through a bronchoscope. A supraglottic airway device usually a laryngeal mask airway (LMA) should be available, as well as endotracheal tubes in a range of sizes to be placed orotracheally or into the distal airway by the surgeon. If cross-

field intubation is anticipated, sterile endotracheal tubes and a sterile breathing circuit are needed.

Fundamental questions in planning a case include whether there is airway stenosis, where it lies within the airway, and how small is the residual airway. Glottic and subglottic lesions almost always require dilation by the surgeon at the beginning of the procedure usually with rigid bronchoscopes of increased diameter, although some centers use smooth round dilators. An endotracheal tube may be then be placed, although often of a smaller size than would usually be used. If the lesion is in the mid-trachea or lower, and the lumen is adequate, an endotracheal tube may be placed above the lesion, without prior dilatation. The anesthetic technique has influenced the chosen mode of ventilation. Anesthetic agents with rapid onset and short duration permit a deep plane of general anesthesia with prompt recovery and resumption of spontaneous ventilation necessary to successful extubation of patients with compromised airway anatomy. A crucial decision is when it is appropriate to suppress the patient's spontaneous breathing and conversion to controlled techniques. In some centers it is preferred to secure the airway each time with an inhalational induction, maintenance of spontaneous ventilation, and avoidance of muscle relaxants until the initial airway is established. Most airway resections are performed in centers with experienced surgical and anesthesia teams. In many circumstances it is suitable to induce general anesthesia with intravenous agents and give muscle relaxant prior to rigid bronchoscopy, dilation, or laser resection of the airway in preparation for definitive resection. This is particularly true of patients who have had a recent, uneventful rigid bronchoscopy as part of their preoperative care.

Many experienced clinical groups recommend a staged approach which starts with cautious fiberoptic bronchoscopy, after airway topicalization in the awake, spontaneously breathing patient. This permits evaluation of vocal cord function and for any malacic segments. This is often followed by rigid bronchoscopy under general anesthesia to dilate stenosis or debride obstructing tumor from the airway. The rigid bronchoscope is also the best tool to measure the position and length of the lesion in the trachea. The following measurements are made relative to the patient's upper incisors: the carina, the distal and proximal ends of the lesion, and the vocal cords. This permits an estimate of both the length of the lesion and the remaining trachea available for reconstruction. The airway can be temporarily improved in the vast majority of patients allowing patient optimization for the definitive resection, to ensure that any bronchospasm and pulmonary infections are reversed, and weaning of steroids if needed.

Excellent analgesia is required to optimize the chances of prompt extubation and is planned according to the incision required by the resection. Postoperative positive pressure ventilation is undesirable as pressure on new anastomoses increase the risk of airway dehiscence.

**Table 13.2** Planning for tracheal surgery

Tracheal anatomy, resection proposed
Incision required and patient position
Preoperative assessment
Patient monitoring
Ventilation
Transition from spontaneous to controlled ventilation
Apparatus required for ventilation
Mode of ventilation
Anesthetic drug regimen
Analgesia
Emergence, airway configuration at the end of the case

## Tracheal Anatomy and Surgical Management

The position of the lesion within the trachea will determine the site of incision and the extent of trachea requiring resection. This is often described by the number of tracheal rings removed. Using cadaver studies, Grillo investigated how much of the trachea could be removed with end-to-end reconstruction without causing undue tension or compromise of the blood supply. He determined that a median length of 4.5 cm was achievable, equivalent to seven rings [8]. The blood supply to the upper trachea is predominantly from the inferior thyroid artery, whereas the lower trachea and carina are supplied by the bronchial arteries [9]. The blood supply enters the walls of the trachea laterally in a segmental fashion; therefore the trachea is best mobilized with anterior and posterior dissection to prevent devascularization.

Knowledge of the location of the tracheal lesion and the proposed extent of airway resection are essential for planning the induction of anesthesia and the maintenance of oxygenation and ventilation. Additionally, the position of the lesion will determine the incision required and the patient position.

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### The Subglottis and Upper Trachea

Resection of the subglottis and upper third of the trachea may be accomplished via a collar (cervical) incision with the neck fully extended and a bolster placed behind the scapulae. The subglottic airway extends from just below the vocal cords to the lower border of the cricoid cartilage. Post-intubation stenosis is the most common cause of subglottic stenosis. Complete transection of the subglottic airway will divide the recurrent laryngeal nerves; resection is therefore modified to preserve the posterior shell of the cricoid cartilage in order to protect the entry point of these nerves [10]. Most post-intubation strictures involve relatively short segments, between 1 and 4 cm, and can be managed by segmental resection and reconstruction with a primary anastomosis. Malignancies may require more extensive resection including concomitant laryngectomy.

Prolonged trans-laryngeal intubation frequently results in synchronous laryngotracheal injury. The most common glottic injury is a posterior inter-arytenoid stenosis, which restricts vocal cord movement. These combined injuries require simultaneous high tracheal resection and laryngofissure, with excision of the inter-arytenoid scar. When the subglottic anastomosis lies within a few millimeters of the vocal cords, there is significant risk of glottic edema. A Montgomery T-tube (Fig. 13.2) is placed to support the airway and left in place several months to minimize restenosis. The T-tube is a cylindrical silicone stent with a perpendicular limb which is positioned in a small tracheostomy which makes it unlikely

to become dislodged or migrate [11]. Following laryngotracheoplasty the upper limb of the silicone stent lies 0.5–1.0 cm above the cords. In cases of stenotic or malacic segments of the cervical trachea without laryngeal injury, a T-tube may be left in place with the upper limb of the T-tube that is positioned below the cords, allowing for voice preservation.

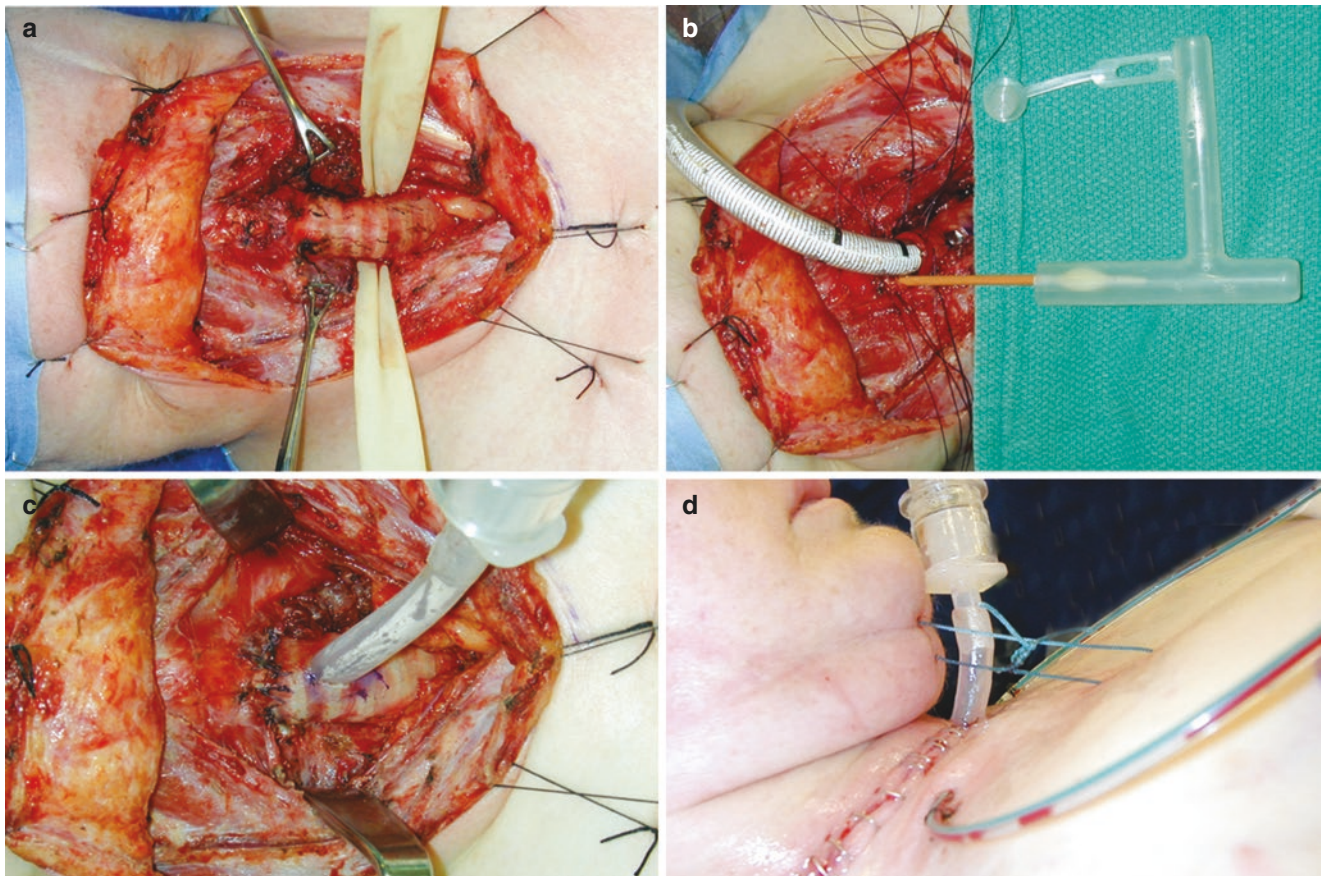
Head flexion during primary anastomosis delivers the cervical trachea into the mediastinum to facilitate reapproximation of the edges of the trachea, and if the anastomosis appears to be at risk of being under tension, a guardian stitch is placed after skin closure, between the skin of the chin and the anterior chest and maintained for approximately a week (Fig. 13.2).

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### Mid-Trachea

A cervico-mediastinal incision is used for tumors of the mid-trachea (Fig. 13.3) and most benign lesions throughout the trachea. The upper trachea is explored through a cervical incision, which is extended via a partial sternotomy to just below the sternal angle, and separated with a pediatric chest spreader. Through this incision the anterior carina and the right and left tracheobronchial angles can be exposed without sacrifice of the innominate vein, artery, or other great vessels. The trachea is then mobilized and incised and distal ventilation is secured. Many surgeons will request for the patient's neck to temporarily be flexed to test the ease with which the tracheal ends will come together. The length of trachea that can be safely incised is influenced by the patient's age, body habitus, pathology, and prior treatment. If it is clear that the anastomosis will be under excessive tension, or a long segment of trachea requires resection, a release maneuver is performed, most often a suprahyoid release. Muscle attachments to superior surface of the hyoid bone and the hyoid bone itself are divided allowing the larynx to drop, adding between 1 and 2 cm of additional mobility to the trachea [12].

The resection of long segments of trachea which cannot be repaired with a primary anastomosis presents a formidable problem and underscores the fact that the trachea is not simply a tube but is an armored structure capable of sustaining cyclical intrathoracic pressures. Historically, prosthetic grafts fail in the long term due to the formation of granulation tissue and fistulas, and while devascularized aortic grafts have been used, they tend to develop malacic components. More promising reconstructive techniques include fasciocutaneous forearm flaps stiffened with C-shaped segments of rib cartilage [13]. Reports of decellularized tracheal allograft repopulated with the recipient's own chondrocytes and airway epithelial cells were recently used to replace the trachea in a small number of patients, by a single lead surgeon [14].



**Fig. 13.2** Airway management for high tracheal resection. (a) Mobilization of the trachea, the patient's head is to the left of the photograph. (b) A sterile cross-field endotracheal tube has been placed in the distal trachea. A Montgomery T-tube will be placed; the balloon of a Fogarty catheter will be inflated to obstruct the proximal limb, to allow ventilation via the distal limb. The Fogarty catheter is passed retrograde through the patient's mouth. (c) Ventilation via the Montgomery

T-tube external limb during closure of the incision. A standard endotracheal tube connector has been inserted into the external limb of the T-tube. (d) Head flexion and the guardian ("chin") stitch. The Fogarty catheter is deflated and removed when spontaneous ventilation is reestablished. The guardian stitch is removed after a week. (Photos courtesy of Dr. Andrew Pierre, Division of Thoracic Surgery, Department of Surgery, Toronto General Hospital)

This clinical experience that has been recently heavily criticized for incomplete reporting of poor long-term outcomes must be considered experimental at this time.

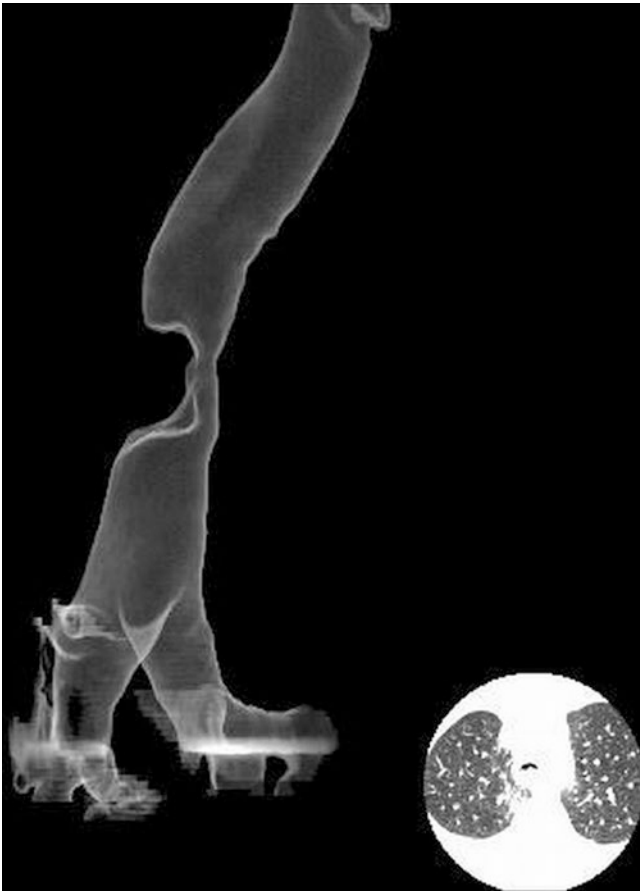
## Carinal Resection

The incision depends on the type of carinal resection. Carinal resection without pulmonary parenchymal resection is approached through a full sternotomy. The pericardium is opened anteriorly, and the exposure is facilitated by mobilization of the aorta and both main pulmonary arteries (Fig. 13.4). Tracheal resection is usually limited to less than 4 cm at the carinal level. When there is anastomotic tension, a hilar release is performed with a U-shaped incision of the pericardium, which allows hilar structures to advance by about 2 cm. Laryngeal release is not deemed helpful for carinal resection and a chin stitch is not routinely used. Resection of the carina may be combined with a right or left pneumo-

nectomy or right upper lobe bronchial sleeve resection. Left carinal pneumonectomy may be performed via a sternotomy, a left posterolateral thoracotomy, or clamshell incisions. When all or part of the right lung requires resection, a right posterolateral approach is used. Careful patient selection and optimization are essential to the success of these technically demanding and high-risk surgeries [15].

## Patient Characteristics

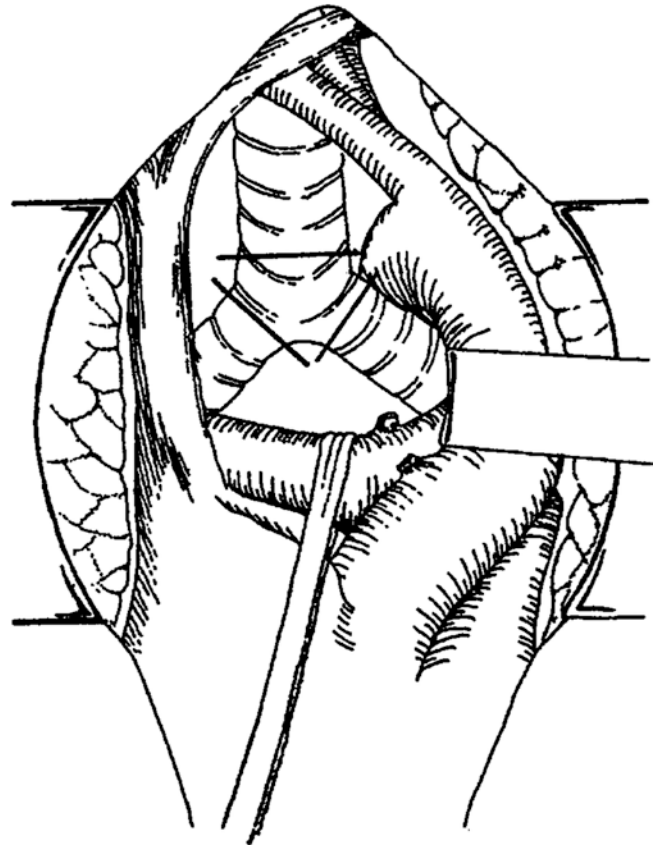
Idiopathic tracheal stenosis is a diagnosis almost exclusively in females often presenting for resection in their fifth decade of life; many have had progressive symptoms for up to 10 years. At least one third report clinically significant reflux, and at least as many are obese which may be due to their exercise limitation. Patients with post-intubation and post-tracheotomy stenoses have a mean age in their 40s at the time of presentation and not infrequently have diabetes



**Fig. 13.3** A three-dimensional CT reconstruction of a mid-tracheal tumor. This patient was managed with rigid bronchoscopy and debriement prior to tracheal resection

mellitus, cardiovascular disease, asthma, or chronic obstructive pulmonary disease, all conditions that may have required prior intubation. These comorbidities increase the likelihood of perioperative complications. Patients with tracheal tumors tend to be a decade older, tend less to be diabetic or obese, and are more likely to smoke, with the associated risk of vascular disease. It must be noted that some primary tracheal tumors are not associated with smoking and can present at any age [16].

Most patients are symptomatic, the most common being dyspnea on exertion, but a careful history may reveal orthopnea, a brassy cough, difficulty clearing secretions, and wheezing. Malignant tumors may produce hemoptysis. Patients should be examined for evidence of airway obstruction and the use of accessory muscles or stridor. In adults narrowing of the lumen to less than 50% of its normal cross section results in dyspnea with significant exertion, and narrowing to less than 25% of its normal cross section will usually produce dyspnea and stridor at rest. Stridor is a sign of significant airway obstruction; likely the tracheal diameter is 6 mm or less [17]. These patients are at risk of acute airway



**Fig. 13.4** Exposure of the carina via a sternotomy

obstruction with a mucus plug. Stridor is classically more pronounced in inspiration when stenosis is extra-thoracic; if the lesion is intrathoracic, the stridor may be predominant in expiration, particularly if there is significant malacia. In addition to auscultation of the lungs and trachea, patient's neck mobility should be evaluated.

### Preoperative Assessment

The anesthesiologist should review all available information delineating the patient's airway pathology. The chest X-ray may be deceptively normal. A CT scan of the neck and thorax will have typically been performed, with thin cuts along the entire airway. Increasingly three-dimensional images are being constructed from helical CT data. This imaging is helpful in defining the relationship of the lesion to the vocal cords and carina and, as a complement to prior endoscopy, helps in planning airway management.

Pulmonary function tests, including spirometry and flow-volume loops, are usually performed unless the patient is at risk of imminent airway obstruction. Fixed airway stenoses cause limitation of both inspiratory and expiratory flow at similar flowrates. A variable extra-thoracic airway obstruction

limits inspiration much more than exhalation. Conversely, with a variable intrathoracic lesion, the patient is able to inhale reasonably well, but expiratory flow limitation is produced. It should be noted that the quality of flow-volume loops is very much dependent on patient effort. The characteristic findings of expiratory flow limitation may be obscured by small airways disease such as asthma or COPD [18]. The absence of classic spirometric patterns does not predict the absence of pathology, and the presence of findings does not reliably indicate the degree of obstruction. Imaging of the airway is far more useful in planning surgery.

Manipulation of airway and mediastinal structures intraoperatively may provoke a significant sympathoadrenal stress response [19]. Increases in heart rate and both systemic and pulmonary artery pressures are seen and may be prolonged. Myocardial oxygen consumption rises and dysrhythmias may occur. The incidence of myocardial ischemia in older smokers during and after rigid bronchoscopy alone may be as high as 10–15% of patients [20]. Preoperative ECG should be obtained in all patients to assess cardiac rhythm. Patients over 40 with symptoms or significant risk factors for coronary artery disease should be investigated with echocardiography, Persantine-thallium stress testing, and coronary angiography if indicated. Risk stratification is then possible, with appropriate institution of treatment. Cardiac assessment is recommended when carinal resection is required especially when combined with pneumonectomy. If significant coronary artery lesions are identified, the decision to proceed with definitive surgery rather than palliation should be decided on a case-by-case basis. Quantitative ventilation and perfusion scans may be warranted when the resection of considerable lung parenchymal is anticipated [21]. In all patients considered for tracheal resection, the identification and treatment of reversible pulmonary disease are important. Repeated airway dilation or stenting may permit a period of medical optimization of the patient [22]. Smoking cessation is vital, particularly as patients who have undergone airway resection often struggle to mobilize secretions. Postoperative mechanical ventilation is undesirable: the presence of an endotracheal tube may predispose new suture lines to necrosis and dehiscence. Severe respiratory compromise due to parenchymal lung disease or neuromuscular disorder is a serious concern and may preclude tracheal resection [23].

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## Patient Monitoring

In addition to secure peripheral intravenous access and standard anesthetic monitors, an arterial catheter is placed for continuous blood pressure measurement. When an intrathoracic approach to the trachea is used, many anesthesiologists choose the left side for the radial arterial line; the innominate

artery lies anterior to the trachea, and compression or division of this vessel will render inaccurate arterial measurement in the right arm. Arterial cannulation also provides immediate access to blood gas analysis essential during interrupted ventilation, during ventilation with techniques that preclude capnography, and in the event of postoperative respiratory distress. Central venous cannulation may be used if indicated by the proposed surgery (i.e., including a major pulmonary resection) and cardiopulmonary status of the patient. Avoidance of the area of incision must be considered in catheter placement; jugular, subclavian, or antecubital approach may be used. A urinary catheter is placed, even if a simple resection is accomplished quickly; the patient's mobility is often reduced for several days due to postoperative neck flexion. The patient's temperature is monitored and normothermia should be maintained. In the rare instance of cervical exenteration, where elective division of the innominate artery is contemplated, placement of EEG monitoring has been recommended [7].

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## Ventilation Strategies

Surgical intervention in the airway presents unique ventilation difficulties. Clinicians have devised creative solutions for these challenges, and there has been a proliferation of ventilation techniques applied to the open airway (Table 13.3). Overarching consideration includes adequate gas exchange while minimizing airway occupancy, movement and the spraying of blood, and secretions.

### Distal Tracheal Intubation, Intermittent Positive Pressure Ventilation (IPPV)

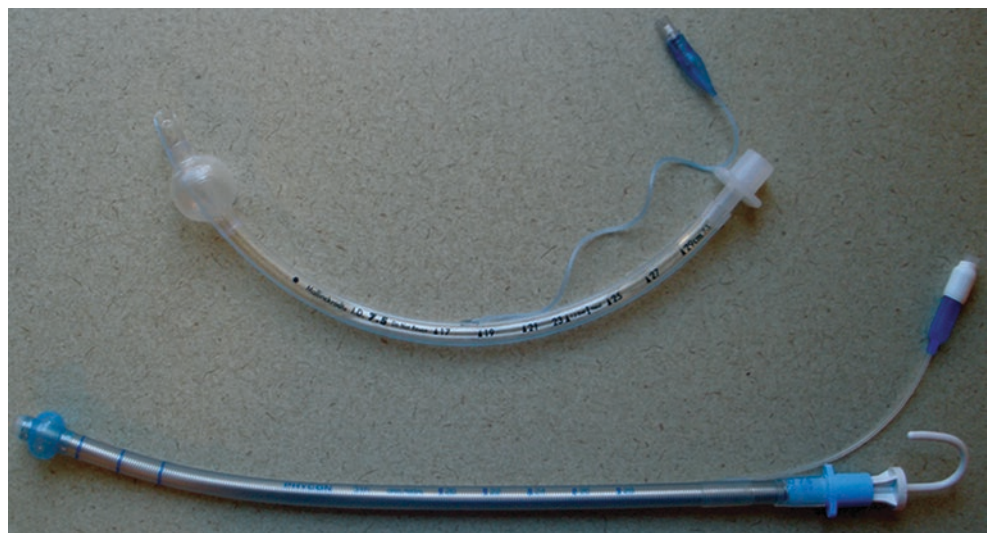
Early reports of tracheal tumor resection described reconstruction of the trachea after an intratracheal tube was advanced by the surgeon beyond the tracheal defect [1]. Advancement of a full-sized orotracheal tube across the surgical field into the distal trachea or bronchus is an option currently seldom used, as the large diameter obstructs access to the surgical field. Endobronchial tubes are long tubes of reduced diameter, with a small volume and shorter cuff positioned close to the tip. They are favored by some clinicians for certain tracheal resections. They can be positioned in the trachea beyond the lesion under bronchoscopic guidance past a mid-tracheal lesion or placed in the contralateral bronchus when a thoracotomy is required for carinal resection or carinal pneumonectomy. The endobronchial tube's slender profile allows much of the surgery to be accomplished while the tube remains within the tracheal lumen, and distal ventilation is maintained. Alternatively, these tubes can be withdrawn when the airway is opened and distal ventilation

**Table 13.3** Characteristics of modes of ventilation during airway surgery

	Able to ventilate open airway	Immobility of operative field	Specialized equipment required	Airway pressure – pressure/monitoring	Potential for barotrauma	Gas entrainment	Airway gas composition
IPPV	No	No	No	Pressure is dependent on ventilator settings/reliable	Minor	No	Stable, accurate monitoring
LFJV	Yes	No	No	Intermittently high/difficult	Yes, high	Yes	Variable, difficult to monitor
HFJV	Yes	Yes	Yes	Can be high, gas trapping common/difficult, especially around jet nozzle	Yes	Yes	Variable, difficult to monitor
HFPPV	Yes	Yes	Yes	Low peak and mean transpulmonary pressure/difficult	Yes	Minor	Stable, accurate monitoring

*IPPV* intermediate positive pressure ventilation, *LFJV* low-frequency jet ventilation, *HFJV* high-frequency jet ventilation, *HFPPV* high-frequency positive pressure ventilation

**Fig. 13.5** A 7.5 mm ID Phycon endobronchial tube (lower tube) (Fuji Systems, Tokyo, Japan) as compared to a 7.5 mm ID standard endotracheal tube (above). The standard tube is 32 cm long; the armored endobronchial tube is 40 cm and is also available in 5.5 and 6.5 mm ID sizes. Note the small endobronchial cuff size, the lack of both bevel and Murphy eye on the distal end of the endobronchial tube



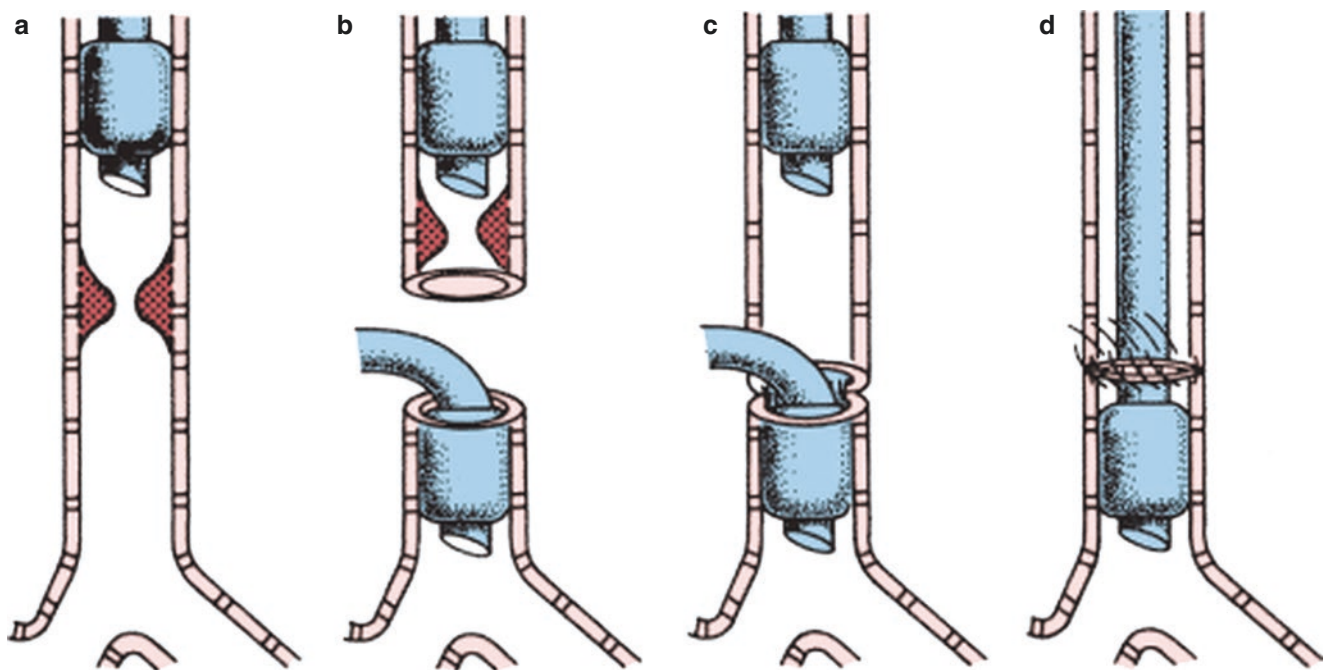
provided on the surgical field. Drawbacks of these tubes include the frequent air leak that occurs when an endobronchial tube is positioned in the trachea, as the balloon has a relatively small volume.

The cuffs are prone to being ruptured when the trachea is being repaired around its circumference, requiring replacement [24]. A variety of endobronchial cuffs have been described although many are no longer available [25]. In our institution, the Phycon endobronchial tube (Fuji Systems, Tokyo, Japan) is used (Fig. 13.5). The ideal endotracheal tube for tracheal reconstruction has been described as a long, flexible, reinforced tube with a short, low-pressure, high-volume cuff and a short segment beyond the cuff, to allow the ventilation of both lungs through a short tracheal stump without encroachment on the operative site; unfortunately no such endotracheal tube is currently manufactured [26].

The use of cross-field intubation and ventilation of the distal airway was first described for the resection of a low tracheal tumor; the left bronchus was cannulated on the field by the surgeon, while the right main stem bronchus

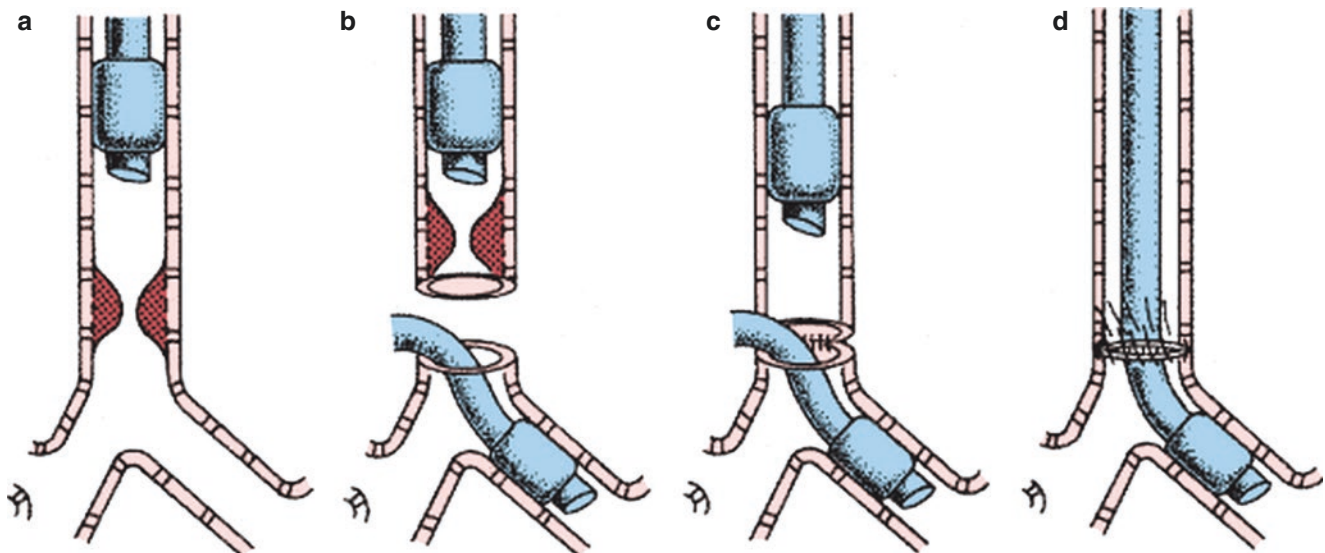
was sutured to the remaining trachea. Ventilation was then resumed via the endotracheal tube and left bronchial anastomosis was performed [2]. Geffin fully described the variations of cross-field ventilation to be used for high and low tracheal lesions [4]. An orotracheal tube is placed, above the lesion. As the airway is divided, the surgeon advances a second, sterile endotracheal tube across the field into the distal trachea (Fig. 13.6). In our institution, when subglottic resection is performed, a sterile reinforced endotracheal tube is inserted in the distal trachea, and the proximal end of the tube is passed by the patient's cheek, under the sterile drapes to be connected to the anesthetic circuit. Resection of the mid- or lower trachea necessitates the use of a second, sterile anesthetic circuit originating from the surgical field, passed over the drapes. Typically, a relatively small endotracheal tube is placed in the distal airway to permit the placement of posterior sutures, while the tube remains in the distal airway, held anterior by the surgeons. After reanastomosis of the posterior trachea, the distal tube is withdrawn; the orotracheal tube is readvanced and is used





**Fig. 13.6** Airway management for resection of a high tracheal lesion. (a) Orotracheal intubation above the lesion. (b) With tracheal incision, a sterile cross-field endotracheal tube is placed distal to the lesion. (c) The posterior wall of the anastomosis is sutured. (d) The

cross-field endotracheal tube is removed, the orotracheal tube is advanced across the anastomosis, and the anterior anastomosis is completed. (With permission from the Society for Thoracic Surgeons, previously published in [84])



**Fig. 13.7** Airway management for resection of a low tracheal lesion. (a) Orotracheal intubation above the lesion. (b) A sterile cross-field endotracheal tube is placed in the left main stem bronchus. (c) The posterior wall of the anastomosis is sutured. (d) The cross-field endotra-

cheal tube is removed, the orotracheal tube is advanced across the anastomosis into an endobronchial position, and the anterior anastomosis is completed. (With permission of the Society for Thoracic Surgeons, previously published in [84])

for ventilation. Lower tracheal and carinal resection requires some modification of the technique (Fig. 13.7). The distal tube is advanced into the left main stem bronchus below the lesion. The resected trachea and the right main stem bronchus are anastomosed, the orotracheal tube is advanced through the suture line, and one-lung ventila-

tion to the right side is accomplished, while the left main stem bronchus is anastomosed to the side of the trachea. The orotracheal tube is withdrawn above both suture lines until extubation. This technique necessitates intermittent periods of apnea as surgeons withdraw the distal tracheal tube for better exposure and placement of sutures. Increased

oxygen concentration is used when ventilating (>70%) in order to delay desaturation. Periods of moderate hypercapnia are inevitable but are usually well tolerated. Independent distal cannulation of both bronchi has been described; a variety of endotracheal tubes of different sizes should be available for distal cannulation [27].

### Low-Frequency Jet Ventilation (LFJV)

Jet ventilation releases high gas flow through a small orifice, permitting ventilation via laryngoscopes, bronchoscopes, and the open airway with minimal obstruction of the surgical field. Low-frequency jet ventilation (LFJV) is accomplished by the release of gas under high-pressure (50–60 psi) through an orifice (~1 mm) as described by Sanders [28]. A pressure regulator is required to maintain constant flow, and a handheld on-off valve is released intermittently; jet pulses are delivered at a rate of 10–20/min. A distinct advantage of this approach is its simplicity and lack of specialized equipment. The use of lengthy catheters of small caliber, advanced through the orotracheal tube, permits ventilation of distal airways. Physiologic tidal volumes are generated and chest or lung movement is clearly visible.

LFJV with intermittent apnea was first described in tracheal resection in the 1970s [29, 30], and a variation of this technique is still favored by some groups [31]. The use of a narrow lengthy catheter permits ventilation of the distal airway using a device well away from the surgical field; their diameter is unlikely to obstruct surgical access to the airway. The ultimate catheter position varies with the procedure performed. A high tracheal stenosis may not admit a regular size endotracheal tube; jet ventilation via a long small orotracheal tube has been used throughout resection [32]. More often an orotracheal tube is placed above the tracheal lesion, and the narrow ventilation catheter is advanced into the distal airway after incision of the trachea. The use of independent, simultaneous catheter ventilation of each bronchus has been described in carinal resection [33]. Unpredictable tidal volumes are generated using LFJV; they are however sufficiently large to cause disruption of the surgical field, and intermittent apnea is usually required. When high driving pressure (50–60 psi) is used through a narrow catheter, a high flow jet is produced (up to 100 l/min) entraining air, blood, and debris from the field into the distal airway. Blood may spray from the surgical field. When larger ventilation catheters are used, high flows can be maintained with lower driving pressure; air entrainment is reduced, permitting less dilution of the oxygen jet as demonstrated by the high arterial oxygen tensions that can be achieved; longer periods of apnea are therefore possible [30].

### High-Frequency Jet Ventilation

High-frequency jet ventilation (HFJV) resembles its low-frequency counterpart in that gas is delivered from a high-pressure gas source via a stiff, small-bore catheter positioned in the airway. Rather than a handheld switch, the jet stream is cut by a high-frequency pneumatic or electronically controlled flow interrupter. As the high-velocity gas jet enters the airway, additional gas is entrained at the jet nozzle, contributing to the delivered tidal volumes which remain small compared to conventional ventilation considerably less than airways dead space [34]. Variables that can be regulated during HFJV include driving pressure, frequency, and inspiratory time, usually set at 20–30% of the cycle. Ventilation rates span 100–400 breaths/min; tidal volumes delivered are 2–5 ml/kg. The mechanical effects of the use of high frequencies are crucial to the understanding of gas transfer in high-frequency ventilation. Increasing the respiratory rate decreases the emptying time of the lung, moderate gas trapping occurs, and the lung is held in a distended state. Peripheral airway pressures have been shown to be continuously positive using all high-frequency techniques with low mean and peak pressures maintained [34–37]. An obvious advantage when ventilating the open airway is that lower peak pressures are generated as compared to conventional ventilation optimizing lung recruitment with much less air leak. The use of low tidal volumes at high respiratory rates produces minimal movement of the operative field, and interruption of ventilation is not required during many procedures. The slender catheters used minimally obstruct the surgical field.

HFJV has been studied in experimental tracheal airway disruption; the gas driving pressure and size of the jet nozzle were shown to be crucial. When a constant driving pressure was used, increased nozzle size was required to maintain gas exchange with increasing air leak; however a larger nozzle used with a smaller air leak resulted in lung overdistension and systemic hypotension [38]. Clinically, increased driving pressure and inspiratory time can result in impedance in expiratory gas flow, gas trapping, development of auto-PEEP, and impaired CO<sub>2</sub> elimination [39].

When HFJV is used in the intensive care unit, the ventilating catheter is advanced through an orotracheal tube; however the optimum position of the catheter tip is the subject of considerable debate [40]. During airway surgery, the ventilating catheter is advanced across a stenosis or surgically created defect; catheter position is therefore dictated by the nature of the procedure. The use of HFJV via a catheter placed through an LMA has been described for the resection of a high tracheal stenosis either with [41] or without addition cross-field IPPV [32]. Catheters may be advanced through an orotracheal tube into the mid- or distal trachea for



**Fig. 13.8** The basket tip of the Hunsaker MonJet ventilation catheter. The collapsible basket is designed to center the catheter in the airway and to reduce catheter-whip injuries to the walls of the airway during jet

resection of tracheal segments [42, 43], into the distal bronchus for carinal or sleeve resection [42], and bilateral bronchial catheters have been reported in carinal resection in a patient with limited respiratory reserve, when desaturation occurred during HFJV of one lung [44]. These reports emphasize that ventilator frequency and driving pressure must be adjusted to the patient's respiratory compliance and the proportion of lung segments being ventilated at the time.

“Whip motion” of the distal catheter tip possibly causing tracheal laceration and pneumothorax is a concern with all jet catheter ventilation techniques. The Hunsaker jet ventilation catheter (MonJet, Medtronic Xomed, Jacksonville FL) has a distal, collapsible basket-like support to maintain the jet port tip in the center of the airway and reduce whip injuries. It has been used extensively for endoscopic laryngeal surgery and has been used in some centers for airway resection [32] (see Fig. 13.8). A recent review describes commercially available high-frequency ventilators and catheters [45].

### High-Frequency Positive Pressure Ventilation (HFPPV)

High-frequency positive pressure ventilation (HFPPV) of small tidal volumes (3–5 ml/kg breaths at 60 breaths/min) may be delivered using a conventional ventilator of low internal volume and negligible internal compliance; known volumes and gas mixtures are delivered. External PEEP may be added and there is little hemodynamic derangement described. HFPPV is applied via an insufflation catheter placed at the tip of an endotracheal tube. An injection catheter with multiple side holes is recommended to both increase turbulence, thereby reducing airway injury from the jet of gas, and to minimize gas entrainment [36]. Eriksson [46] first described tracheal resection using HFPPV with gas delivery via a rigid bronchoscope during examination of the lesion and via a 5 mm diameter insufflation catheter threaded into the distal trachea during resection and anastomosis. El-Baz [47] described the use of HFPPV during complex tracheal reconstruction using a 2 mm insufflation catheter via a Montgomery T-tube. The same type of catheter inserted down the endotracheal tube and across the resected airway for HFPPV during sleeve resection and carinal resection was further reported

ventilation. The catheter had a second lumen for monitoring distal airway pressure and presence of CO<sub>2</sub>

[48, 49]. Excellent surgical conditions with minimal motion of the field and uninterrupted access to the circumference of the anastomosis were described; continuous outflow of gas through the open bronchus was felt to minimize soiling with blood. Placement of a sterile ventilation catheter in the distal airway across the surgical field has also been used to deliver HFPPV [17]. It should be noted that the use of the high-frequency oscillation ventilation, which is used in intensive care units to treat hypoxia, is not useful for airway surgery due to excessive movement of the airways produced by this modality [37].

Disadvantages of the use of high-frequency techniques include requirement for specialized ventilator equipment and technical difficulty in monitoring ventilation parameters. The variable positioning of ventilation catheters during airway surgery precludes the use of optimal sites for airway pressure monitoring. Peripheral airway pressures may be markedly different from those in the large airways due to gas trapping inherent to the use of high respiratory rates, short expiratory times, and expiratory flow limitation. Delivered breath volumes are nearly impossible to quantify with an open airway; therefore serial blood gas analysis is essential to detect hypoventilation. Provision for humidification of gases must be made for longer procedures to avoid drying of the airway mucosa and desiccation of secretions; this is a particular problem when jet techniques are used. All modes of high-frequency ventilation require that the delivery circuit have minimal compliance. Review of the HFV literature is notable for the variation in devices used in different clinical reports. Many ventilators and breathing circuits are institution specific, having been built in a hospital laboratory. A description of operating conditions is often lacking. Many devices are in fact hybrids, superimposing a high-frequency mode on conventional IPPV or displaying features of two forms of high-frequency ventilation [40]. Similarly, many catheters used for the delivery of high-frequency jet ventilation are either institution specific or intended for other purposes such as urethral catheters or airway suction catheters, for example. There is inherent risk in the use of high flow, high-pressure gas pulses in the airway, even more so when delivered at rapid rates. Catheter position and alignment within the tracheobronchial tree must be known at all times and are made more difficult by

manipulation of the airway during surgery. Free egress of expired gas and adequate expiratory time must be maintained in order to avoid inadvertent hyperinflation and barotrauma. Whereas continuous positive airway pressure is expected in HFV and is beneficial in maintaining lung recruitment, the use of higher ventilation rates and higher volumes may result in occult PEEP [35]. The resulting lung hyperinflation can lead to impedance of venous return and hemodynamic compromise, particularly if the chest is closed. Barotrauma and volutrauma in the form of pneumothorax, pneumomediastinum, and subcutaneous emphysema have been reported with all forms of high-frequency ventilation and with LFJV. The use of not only distal airway pressure monitoring but automatic shut-off mechanisms to prevent further gas flow into the lungs in the event of high airway pressure is recommended [40].

While there are many reports of the adaptation of volatile agent vaporizers for use with high-frequency ventilation [46, 50], this is unnecessary as current practice offers ideal total intravenous anesthetic regimens. The use of short-acting volatile agent using the high flows required of HFV would be wasteful and difficult to scavenge.

## Extraordinary Ventilation Strategies

### Cardiopulmonary Bypass (CPB) and Extracorporeal Oxygenation (ECMO)

Cardiopulmonary bypass without circulatory arrest was first used for resection of a carinal tumor in 1959 followed by reports of small series in both adults and children [51]. Then as now, systemic anticoagulation required for CPB may introduce formidable problems, notably intrapulmonary hemorrhage [4]. Currently, CPB is considered only under specific circumstances: tracheoplasty of long segments in small children in whom small airway caliber precludes other options [52], combined cardiac and pulmonary procedures for malignant disease in adults [53], the repair of complex tracheobronchial injuries [54], or when tracheal occlusion is imminent from a lesion unlikely to be bypassed by tracheotomy or rigid bronchoscopy [55]. Recently, reports of tracheal reconstruction in pediatric [56] and adult patients [56, 57] using extracorporeal membrane oxygenation (ECMO) have emphasized that this form of lung assist is amenable to peripheral rather than central vascular cannulation and reduced levels of anticoagulation (see also Chap. 27). The practice of performing particularly complex tracheal reconstruction only in centers where extracorporeal support is available can be justified.

### Spontaneous Ventilation

A departure from the use of neuromuscular relaxants and positive pressure ventilation are case reports of a small number of patients allowed to breathe spontaneously throughout

tracheal resection [58] and tracheoesophageal fistula repair [59]. Total intravenous anesthesia was provided with endotracheal oxygen insufflation. Some aspiration of blood and debris from the surgical field was noted. The reported patients were well oxygenated and stable despite moderate respiratory acidosis; however it is unlikely that patients with significant limitation of pulmonary reserve would tolerate this approach. A pilot study in 20 patients of the feasibility performing upper tracheal resection awake using cervical epidural anesthesia and remifentanyl sedation reported that surgical conditions were facilitated by the absence of any tube or catheters within the airway and the opportunity to assess vocal cord motion. The authors did not discuss what they would have done if a patient has suffered complete airway obstruction [60]. Since that time there have been single cases described of upper tracheal resection under cervical plexus block, and VATS assisted mid-tracheal and carinal resection under thoracic epidural block supplemented by vagus nerve block to suppress coughing. All patients received intravenous anesthesia (propofol, remifentanyl +/- dexmedetomidine) and had an LMA placed to secure the supraglottic airway, spontaneous breathing oxygen-enriched air. Anesthetic infusions were titrated to electroencephalogram bispectral index. These cases were reported by a multidisciplinary group with an interest and expertise in non-intubated thoracic surgery; they suggest that their approach leads to accelerated recovery. They have developed exclusion criteria for patients unsuitable for the technique. Contingency plans for rescue tracheal intubation were described but not required [61, 62, 63].

### Hyperbaric Oxygenation

The use of hyperbaric oxygenation has been reported to supplement differential lung ventilation by conventional and HFV modes when these methods failed in the repair of a large tracheal tear [64]. Hyperbaric conditions enhance oxygen delivery via increased oxygen dissolved in the plasma. This approach requires the performance of surgery within a hyperbaric chamber with compression of the entire surgical team and must be considered experimental.

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## Anesthesia Induction and Maintenance

Careful questioning of the patient will reveal position-dependent increase in airway obstruction, particularly intolerance to lying supine. Anesthetic induction may be performed in a sitting or semi-sitting position. Any difficulty encountered at previous intubation or bronchoscopy should be known to the team. All team members should be present. A clear, coordinated plan is required and ongoing communication is essential. All equipment anticipated for airway management should be ready and confirmed to be working.

When there is little or no tracheal obstruction, the induction of anesthesia, neuromuscular relaxation, and intubation is performed as per the anesthesiologist's usual practice. In the presence of significant airway obstruction or stenosis, induction is followed by rigid bronchoscopy, dilation of tracheal stenosis, or debridement of tumor prior to placement of an orotracheal tube. A variety of anesthetic strategies have been described including airway topicalization and awake intubation, inhalational induction with volatile anesthetics, and intravenous induction agents with and without the use of neuromuscular relaxants [23]. Awake intubation is of questionable value in this circumstance; in patients with high stenosis, endotracheal tube placement is not possible, and in those with lower lesions, the tube must shortly be removed for rigid bronchoscopy after the induction of general anesthesia. When an inhalation induction is chosen, currently sevoflurane is most often used. Complete preoxygenation/denitrogenation will take more than the usual time, often more than 5 min, due to restriction of tidal volumes. In the setting of airway compromise, inhalation induction with a slowly increasing concentration of a volatile anesthetic in 100% oxygen will also take increased time. Patients often require some ongoing continuous positive airway pressure via the anesthetic circuit to maintain even modest tidal volumes. When a deep plane of anesthesia is achieved, a local anesthetic (often lidocaine) is applied to the vocal cords and upper airway prior to instrumentation. While this approach attempts to maintain the ability to turn off the anesthetic and to wake up the patient if difficulties are encountered, it is not without drawbacks. The decision to attempt airway dilation without the use of relaxant may make placement of the rigid bronchoscope considerably more difficult. Coughing can result in profound desaturation. If the patient forcefully breathes against a nearly obstructed airway as a very small bronchoscope fills the remaining lumen, the patient is put at risk of negative-pressure pulmonary edema. Another option after inhalation induction is to use a rapid-acting muscle relaxant (such as succinylcholine) to facilitate the introduction of the bronchoscope. Intravenous induction of anesthesia, with the use of short- or intermediate-acting muscle relaxant to facilitate rigid bronchoscopy, is described in many reports and is particularly appropriate when prior rigid bronchoscopy has been uneventful. This is the approach most often used in the author's center. Spirometric studies before and after the induction of anesthesia in patients undergoing upper tracheal reconstruction surgery showed that intravenous induction of anesthesia with muscle relaxation, placement of a LMA, and initiation of IPPV resulted in improvement in airflow across even severe intraluminal, extra-thoracic stenosis as compared to the patients' awake spontaneous efforts [65]. However it is clear that the decision of what induction agent to use and when to give muscle relaxant and control the patient's ventilation must be made

by the anesthesiologist and surgeon based on their assessment of the patient and their level of experience.

The sympathetic response to airway instrumentation may be reduced by the use of intravenous lidocaine (1–1.5 mg/kg) bolus prior to induction. The intravenous induction may be with propofol or a combination of propofol and an opioid; fentanyl or remifentanyl infusion is frequently used. Another choice of induction agent is ketamine, an *N*-methyl-D-aspartate receptor antagonist that produces dissociative anesthesia. Ketamine depresses ventilation less than many other sedative or general anesthetic drugs. It has the additional advantage of having bronchodilator and sympathomimetic effects and may contribute to the prevention of post-incisional pain. After induction patient may be mask ventilated until the introduction of the rigid bronchoscope, or a laryngeal mask airway may be placed. When the tracheal obstruction is relieved, the trachea is intubated and positive pressure ventilation usually instituted, a dose of an intermediate-acting muscle relaxant is usually given, and provision is made for ventilation during the period of open airway.

Anesthesia may be maintained with an inhalational agent while the trachea is intact, but during cross-field ventilation, where there are frequent periods where the endotracheal tube is out of the airway and the inhaled anesthetic is not delivered to the patient. Many anesthesiologists will convert to a total intravenous technique with propofol and an opioid, often a remifentanyl infusion. Similarly, intravenous anesthesia is used when high-frequency jet ventilation techniques are required. The  $\alpha$ -2 adrenergic agonist dexmedetomidine has several desirable properties for sedation while securing a critically compromised airway including anxiolysis, analgesia, and amnesia with minimal respiratory depression [66]. It is likely the sole intravenous agent that can replace inhalational induction when a spontaneous breathing technique is chosen for airway manipulation and may prove to be particularly useful in obese patients [67]. Dexmedetomidine may facilitate controlled emergence and has been used as a prolonged infusion for patients requiring a few days of mechanical support following tracheal reconstruction [68].

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## Reconstruction of the Airway

When the airway is open, the surgeon is able to manipulate the endotracheal tube within the trachea. During distal cross-field ventilation, in order to easily retrieve the distal tip of the orotracheal tube, the surgeon may affix a suture to the Murphy eye which remains in the surgical field and can be used to reposition the orotracheal tube. If the orotracheal tube is damaged, specifically if the cuff is ruptured, it may be replaced if the trachea is still open. After removal of the connector of the new tube, the surgeon can insert the pilot balloon within the lumen tube and pass the tube retrograde up

the trachea into the oropharynx where it is retrieved by the anesthesiologist. During airway reconstruction, the use of uncut endotracheal tubes is recommended, as positioning distal to surgical anastomoses is frequently required. When the airway is closed, conventional positive pressure ventilation through the orotracheal tube is resumed.

When a Montgomery T-tube is left in the trachea, there are several ways to maintain ventilation. An inflated Fogarty catheter can remain in the proximal limb, while positive pressure ventilation is provided by the tracheotomy limb. This can be facilitated by the use of a multiport ventilation of the type used for insertion of a bronchial blocker. The multiport adaptor is connected to the tracheal limb of the T-tube via an endotracheal tube connector (from a 5.0 or 6.0 endotracheal tube), and the Fogarty catheter is placed in the proximal limb of the Montgomery T-tube via the side port [69]. Alternately, the surgeon will fit a small (usually 6.0 mm) endotracheal tube into the proximal limb. This press fit permits positive pressure ventilation via the proximal limb with the tracheotomy limb corked. With spontaneous ventilation reestablished, the endotracheal tube is removed by steady traction while the surgeon maintains the position of the T-tube with a clamp.

In upper and mid-tracheal resections, the head is flexed as the anastomosis is created to reduce anastomotic tension. The guardian stitch is placed after skin closure, between the skin of the chin and the anterior chest (Fig. 13.2d). Patients should be warned of this positioning that their head will be flexed at the time of emergence, and all efforts should be made to maintain the flexed position during the postoperative period to avoid traction on the new repair.

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## Emergence After Airway Surgery

The resumption of sustained spontaneous ventilation is highly desirable. Prompt extubation is a priority after airway reconstruction to avoid positive pressure or endotracheal tube cuff trauma to the new anastomosis, which might predispose to dehiscence. Most patients breathe more comfortably in a sitting position, removing the weight of abdominal contents from the diaphragm and increasing the patient's functional lung capacity. The oropharynx is thoroughly suctioned, neuromuscular blockade is fully reversed, and the patient is extubated when awake, able to maintain patency of their upper airway and to mobilize secretions. Intravenous anesthesia by infusion for the final stages of the procedure is useful, which permits rapid emergence to a wakeful state without agitation in most cases. It is important to avoid abrupt neck extension with possible traction injury to the anastomosis. The patient should be warned in advance of the need to maintain head flexion and the presence of the guardian stitch. Alternatively, the tracheal may be extubated when

the patient is still anesthetized, breathing spontaneously, and a laryngeal mask placed. This permits fiber-optic bronchoscopy and assessment of both the anastomosis and vocal cord function. Emergence with the LMA in place provokes minimal airway irritation and coughing; the patient will often atraumatically remove the device themselves. A drawback of this approach is that the laryngeal mask is not always easily seated in the supraglottis; this technique is best reserved for patients who were easy to bag-mask ventilate.

Maintenance of normothermia is important; shivering increases oxygen consumption, which is particularly problematic if the patient's airway is compromised. Humidification of inhaled gases minimizes the inspissated airway secretions.

Re-intubation after tracheal reconstruction may be difficult. After subglottic resection the patient's neck may be positioned in extreme flexion, the airway may be edematous and bloody, and there is potential for mechanical injury to new anastomosis. If required, endotracheal tube repositioning is best accomplished under direct vision with a fiber-optic bronchoscope. When an airway stent is left in place, the trachea should not be blindly intubated from above. Telescoping of a small endotracheal tube into the stent may be possible using a bronchoscope. This technique should be applied with great care when a self-expanding metal stent has been placed for airway stenosis; the stents require several hours to completely expand. Insertion of an endotracheal tube may distort or dislodge the stent, especially if the balloon cuff becomes snagged. An LMA may be positioned above the stented airway, particularly if a short period of ventilatory assistance is required, to facilitate emergence from anesthesia. The airway with a Montgomery T-tube can be ventilated in several ways. The side arm protruding via a tracheal stoma will accommodate an endotracheal tube connector (from a 5.0 to 6.0 mm ETT), permitting connection to standard ventilation circuits. If positive pressure is required, the open upper limb must be obstructed to prevent loss of ventilating gas. The patient's mouth and nose may be manually held shut, packing may be placed in the pharynx, or a bronchial blocker or an embolectomy catheter (Fogarty #14) may be directed into to upper limb via the side arm of the stent and the balloon inflated [70]. Low-frequency jet ventilation may also be initiated via the side arm [71].

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## Immediate Postoperative Complications Specific to Airway Surgery

In all surgical patients, residual anesthetics, analgesics, and neuromuscular blockade may contribute to hypoventilation, atelectasis, and poor mobilization of secretions, leading to postoperative respiratory compromise. Additional pulmonary complications may be a direct result of surgery to the

airway. Airway obstruction should be suspected if the patient is in respiratory distress particularly if stridor is evident. Prior to emergence the tracheobronchial tree should be examined and any residual blood in the airway should be carefully removed; despite this, bleeding may be ongoing, or old clot may be mobilized from the lung periphery. Airway caliber may be further compromised by edema. Diuresis and steroids are used empirically; however controlled studies of their use in airway surgery are entirely lacking. Dexamethasone is frequently chosen for its long duration of action; however several hours may be required after dosing (4–10 mg intravenously) for edema to subside. For many years, nebulized racemic epinephrine has been recommended for treatment of post-intubation edema. The racemic form which is an equal mixture of the dextro- and levo-isomers of epinephrine is increasingly unavailable. The more commonly available 1% levo-epinephrine is proposed to be equally effective. In our institution, 5 ml of 1:1000 epinephrine is administered by nebulizer unless limited by tachycardia. Helium and oxygen mixtures provided by non-rebreathing facemask may permit increased ventilation in patients with narrowed conducting airway and are useful as a supportive measure while definitive therapy is pursued. Breathing with airway obstruction may be viewed as breathing through an orifice, which creates turbulent flow. Under turbulent conditions, gas flow varies with inverse square root of density. The low density of helium permits a 1.5 fold increase in relative flow of the commercially available heliox (70% helium/30% oxygen) over air and oxygen mixtures [72]. The high helium fraction required to significantly reduce the work of breathing precludes a high delivered oxygen concentrations which may be undesirable if the patient has low oxygen saturation. When airway compromise is refractory to medical therapy, reintubation may be required.

Pulmonary parenchymal injury may occur. In a review of cases of pulmonary edema associated with airway obstruction after surgery, more than 20% of cases were in adults that were being treated for airway tumor [73]. Spontaneous inspiratory efforts against an obstructed upper airway result in marked negative intrapleural and transpulmonary pressures, causing edema formation, usually within minutes. Laryngospasm is a frequent precursor. Bronchoscopic findings include pink frothy secretions and punctate hemorrhagic lesions throughout tracheobronchial tree [74]. Treatment is supportive and includes re-establishment of airway patency, oxygen supplementation, and diuresis; 85% of patients require reintubation, usually of short duration [73].

Pulmonary aspiration of acidic stomach contents is a particular concern during and after airway surgery where the trachea is not consistently protected by an endotracheal tube. Aspiration may occur at the time of airway manipulation or after completion of the airway procedure. Patients with newly placed T-tubes may have difficulty closing their glot-

tis. Laryngeal dysfunction can occur after suprahyoid release but is less common than after previously used thyrohyoid release procedures [74]. Swallowing dysfunction usually improves after a few days. Recurrent laryngeal nerve paralysis is possible after tracheal surgery [16]. Chemoprophylaxis with antacids, H2 blockers, and gastric propulsants remains unproven in the prevention of the secondary lung injury of acid aspiration. Once aspiration has occurred treatment is supportive: bronchoscopy for removal of particulate matter and ventilation with positive end-expiratory pressure if indicated.

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## Tracheal Procedures with Specific Considerations

Two clinical scenarios present the challenge of a pre-existing defect in the trachea prior to the induction of anesthesia: traumatic injury to the airway and tracheoesophageal fistula.

### Airway Trauma

Iatrogenic airway injury may occur during airway instrumentation, most often the posterior membranous portion of the trachea. This may occur during intubation with a single-lumen endotracheal tube or advancement of a bougie, bronchoscope, or other inflexible devices. Injury during placement of a double-lumen tube is most frequently located in the membranous trachea near the carina. If not noted intraoperatively, most injuries become apparent immediately after extubation. While small tears may be managed conservatively, urgent repair is required when significant clinical manifestations hemoptysis, dyspnea, or pneumomediastinum or if bronchoscopic examination reveals gaping of the edges of the tear during respiratory flow. Repair of injuries in the upper trachea may be possible via an extended cervicotomy, whereas thoracotomy is required for tears that extend lower in the airway [75]. Preoperative assessment is limited by the urgency of the procedure. Pulmonary function testing with spirometry is contraindicated as positive airway pressure will increase subcutaneous emphysema. Intubation of the patient for surgery is best accomplished under bronchoscopic guidance while the patient is breathing spontaneously, either awake with upper airway topicalization or after inhalation induction, until the lesion is bypassed. When a transtracheal approach is used, the surgeon will make an anterior tracheotomy and pass a small endotracheal tube distally to be used intermittently for ventilation. The repair is performed during periods of apnea when the cross-field tube is withdrawn. Repairs via thoracotomy may be repaired with a small diameter single-lumen endobronchial tube guided under direct vision to the side contralateral to the tear.

A double-lumen tube may be used but has a larger diameter which may make placement more difficult and may impede the surgical repair.

Injury to the conducting airways may be a result of blunt or penetrating trauma; often other injuries are present. Respiratory distress and subcutaneous emphysema are the most common physical findings [76]. Approximately 6% of penetrating neck injuries involve tracheal trauma as compared to less than 1% of patients with penetrating chest injuries. Most patients with blunt trauma severe enough to cause a tracheal tear do not survive long enough to present to the hospital. But in those who do, cervical spine injury is common and must be considered in securing the airway. The disruption of the trachea is most likely to occur within 2 cm of the carina. Airway control beyond the injury is required, and intubation with the aid of fiber-optic bronchoscopy in the spontaneously ventilating awake patient is recommended both to inspect the injury and to secure ventilation. When lower airway injury is identified, endobronchial intubation of side contralateral to the injury may be desirable. Trauma cases are particularly fraught with technical difficulties, patient agitation, and competing medical concerns. If the initial plan for securing the airway fails, an alternate plan should be identified. A surgical tracheostomy is useful in injuries of the cervical trachea, but if the tear is intrathoracic, then it is of no value. Cardiopulmonary bypass via femoral cannula has been described to provide lifesaving oxygenation and ventilation in such scenarios but is certainly not available in all trauma centers and has the significant drawback of the requirement for full anticoagulation of a polytrauma patient [77]. ECMO has been described for multiday support for both conservative treatment of airway trauma and for surgical repair [78] (see also Chap. 27).

### Tracheoesophageal Fistula

Congenital TE fistula is recognized in the neonatal period; adults may acquire such a lesion from trauma, neoplasia, or radiotherapy of the trachea. In cases of TE fistula, contamination of the airway with gastric contents and pre-existing pulmonary injury likely will have occurred, resulting in preoperative pneumonitis. Positive pressure ventilation is avoided prior to securing the airway as gastric insufflation may result in increased intrathoracic pressure, difficult ventilation, and impaired venous return [79]. Placement of an endotracheal tube beyond the fistula while maintaining spontaneous ventilation is recommended. A novel variation of this strategy was described in an adult who presented for resection of a large carinal tracheoesophageal fistula. To independently isolate each lung, two 5.0 mm microlaryngoscopy endotracheal tubes were placed sequentially in each bronchus following inhalation induction of anesthesia using sevoflurane. Conventional IPPV was then initiated [80].

## Pediatrics

Congenital tracheal stenosis in infants and children typically occur in the presence of complete tracheal rings and may involve significant lengths of the trachea. Not infrequently these lesions are associated with cardiovascular anomalies which also require repair, most often a pulmonary artery sling. Surgical reconstruction of long-segment tracheal stenoses has been described with a number of techniques including simple resection, incision and patching with pericardium, rib cartilage or tracheal autograft, and slide tracheoplasty all performed via median sternotomy [81, 82]. Slide tracheoplasty is performed by dividing the stenotic trachea at midpoint, incising the proximal and distal narrowed segments vertically on opposite anterior and posterior surfaces and sliding these together. The advantage of this approach is that only fully vascularized, cartilage-supported tissue is used which permits early extubation of many patients. There remains some debate among surgeons which procedure should be performed, whether CPB is always required when only airway reconstruction is performed and if cardiovascular repair is required if the procedures should be staged or performed as a single operation. These surgeries are performed in highly specialized centers, and early referral is recommended to avoid complications associated with lengthy preoperative periods of mechanical ventilation (see also Chap. 50).

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### Management of the Patient with a T-Tube

A T-tube may be placed for a finite period of time to allow an upper airway prone to malacia or scarring to heal and stabilize or in some cases becomes essentially permanent airway support. Patients with T-tubes may require airway examination, replacement, or adjustment of their T-tube or surgery unrelated to their airway. They present a significant challenge to the anesthesiologist. When a patient with a T-tube in situ required a general anesthetic, the risk of aspiration should be considered. If the procedure is elective, the upper airway can be controlled by a laryngeal mask airway either with spontaneous or controlled ventilation, in which the tracheostomy limb is capped. Alternately the use of a well-seated LMA which is then capped to block the escape from the proximal tracheal limb while ventilating the patient via the tracheostomy limb has been described [11]. Other methods of ventilation through the T-tube offer only partial airway protection from aspiration such as the placement of a Fogarty catheter through the tracheotomy limb into the proximal limb to block egress of gas into the upper airway, with simultaneous ventilation through the tracheotomy limb. Awake fiber-optic telescoping of a small endotracheal tube into the proximal tracheal limb of the T-tube has been



described, but aspiration around the T-tube is still possible. One report of airway management of a patient with a full stomach described awake fiber-optic placement of a 5mm microlaryngoscopy tube through both the proximal and distal limbs of the T-tube with the inflation of the cuff in the trachea [83]. Adult T-tube sizes vary from 8 to 16 mm external diameter. This approach may only be possible with the larger sizes. Finally, the T-tube can be removed, ideally with the help of the patient's surgeon, and replaced by a tracheotomy tube. If the tracheotomy is left for any length of time, the patient could suffer a recurrence of their airway compromise. They would require another general anesthetic for replacement of a T-tube.

## References

- Belsey R. Resection and reconstruction of the intrathoracic trachea. *Br J Surg.* 1950;38:200.
- Barclay RS, McSwan N, Welsh TH. Tracheal reconstruction without the use of grafts. *Thorax.* 1957;12:177.
- Grillo HC, Bendixen HH, Gephart T. Resection of the carina and lower trachea. *Ann Surg.* 1963;158:889.
- Geffin B, Bland J, Grillo HC. Anesthetic management of tracheal resection and reconstruction. *Anesth Analg.* 1969;48:884.
- Cooper JD, Grillo HC. The evolution of tracheal injury due to ventilator assistance through cuffed tubes: a pathological study. *Ann Surg.* 1969;169:334–48.
- Liu J, Zhang X, Gong W, et al. Correlations between controlled endotracheal tube cuff pressure and post procedural complications: a multicenter study. *Anesth Analg.* 2010;111:1133–7.
- Grillo HC, Mathisen DJ. Cervical exenteration. *Ann Thorac Surg.* 1990;49:401.
- Miura T, Grillo HC. The contribution of the inferior thyroid artery to the blood supply of the human trachea. *Surg Gynecol Obstet.* 1966;123:99–102.
- Minnich DJ, Mathisen DJ. Anatomy of the trachea, carina, and bronchi. *Thorac Surg Clin.* 2007;17:571–85.
- Pearson FG, Cooper JD, Nelems JM, et al. Primary tracheal anastomosis after resection of the cricoid cartilage with preservation of recurrent laryngeal nerves. *J Thorac Cardiovasc Surg.* 1975;70:806–16.
- Agrawal S, Payal YS, Sharma JP, et al. Montgomery T-tube: anesthetic management. *J Clin Anesth.* 2007;19:135–7.
- Merritt RE, Mathisen DJ. Tracheal resection. In: Patterson GA, Cooper JD, Deslauriers J, et al., editors. *Pearson's thoracic and esophageal surgery.* 3rd ed. Philadelphia: Churchill Livingstone; 2008. p. 377–82.
- Fabre D, Fadel E, Mussot S, et al. Autologous tracheal replacement for cancer. *Chin Clin Oncol.* 2015;4(4):46.
- Macchiarini P, Jungebluth P, Go T, et al. Clinical transplantation of a tissue-engineered airway. *Lancet.* 2008;372:2023–30.
- De Perrot M, Fadel E, Darteville P. Carinal resection. In: Patterson GA, Cooper JD, Deslauriers J, et al., editors. *Pearson's thoracic and esophageal surgery.* 3rd ed. Philadelphia: Churchill Livingstone; 2008. p. 383–92.
- Wright C, Grillo H, Wain JC, et al. Anastomotic complications after tracheal resection: prognostic factors and management. *J Thorac Cardiovasc Surg.* 2004;128:731–9.
- Young-Beyer P, Wilson RS. Anesthetic management for tracheal resection and reconstruction. *J Cardiothorac Anesth.* 1988;2:821–35.
- Pellegrino R, Viegi G, Brusasco V, et al. Interpretative strategies for lung function tests. *Eur Respir J.* 2005;26:948–68.
- Tomori Z, Widdicombe JG. Muscular, bronchomotor and cardiovascular reflexes elicited by mechanical stimulation of the respiratory tract. *J Physiol.* 1969;200:25.
- Hill AJ, Feneck RO, Underwood SM, et al. The haemodynamic effects of bronchoscopy, comparison of propofol and thiopentone with and without alfentanil pretreatment. *Anaesthesia.* 1991;46:266–70.
- De Perrot M, Fadel E, Mercier O, et al. Long term results after carinal resection for carcinoma. *J Thorac Cardiovasc Surg.* 2006;131:81–9.
- Licker M, Schweizer A, Nicolet G, et al. Anesthesia of a patient with an obstructing tracheal mass: a new way to manage the airway. *Acta Anaesthesiol Scand.* 1997;41:34.
- Pinsonneault C, Fortier J, Donati F. Tracheal resection and reconstruction. *Can J Anaesth.* 1999;46:439.
- Fischler M, Troche G, Guerin Y, et al. Evolution des techniques d'anesthésie pour resection-anastomose de trachée. *Ann Fr Anesth Reanim.* 1988;7:125–7.
- Conacher ID, Velasquez H, Morrice DJ. Endobronchial tubes – a case for re-evaluation. *Anaesthesia.* 2006;61:587.
- Hannallah MS. The optimal breathing tube for tracheal resection and reconstruction. *Anesthesiology.* 1995;83:419.
- Theman TE, Kerr JH, Nelems JM, et al. Carinal resection, a report of two cases and a description of the anesthetic technique. *J Thorac Cardiovasc Surg.* 1976;71:314.
- Sanders RD. Two ventilating attachments for bronchoscopes. *Del Med J.* 1967;39:170–3.
- Lee P, English ICW. Management of anesthesia during tracheal resection. *Anaesthesia.* 1974;29:305.
- Ellis RH, Hinds CJ, Gadd LT. Management of anaesthesia during tracheal resection. *Anaesthesia.* 1976;31:1076.
- McClish A, Deslauriers J, Beaulieu M, et al. High-flow catheter ventilation during major tracheobroncheal reconstruction. *J Thorac Cardiovasc Surg.* 1985;89:508.
- Baraka A. Oxygen-jet ventilation during tracheal reconstruction in patients with tracheal stenosis. *Anesth Analg.* 1977;56:429.
- Clarkson WB, Davies JR. Anaesthesia for carinal resection. *Anaesthesia.* 1978;33:815.
- Carlton GC, Kahn RC, Howland WS, et al. Clinical experience with high frequency ventilation. *Crit Care Med.* 1981;9:1.
- Howland WS, Carlton GC, Goldiner PL, et al. High-frequency jet ventilation during thoracic surgical procedures. *Anesthesiology.* 1987;67:1009.
- Sjostrand U. High-frequency positive-pressure ventilation: a review. *Crit Care Med.* 1980;8:345.
- Glenski JA, Crawford M, Rehder K. High-frequency, small volume ventilation during thoracic surgery. *Anesthesiology.* 1980;59:577.
- Carlton GC, Griffin J, Ray C Jr. High-frequency jet ventilation in experimental airway disruption. *Crit Care Med.* 1983;11:353–5.
- Beamer WC, Prough DS, Royster RL, et al. High-frequency jet ventilation produces auto-PEEP. *Crit Care Med.* 1984;12:734.
- Froese AS, Bryan AC. High frequency ventilation. *Am Rev Respir Dis.* 1987;135:1363.
- Adelsmayr E, Keller C, Erd G, et al. The laryngeal mask and high-frequency jet ventilation for resection of high tracheal stenosis. *Anesth Analg.* 1998;86:907.
- Watanabe Y, Murakami S, Iwa T, et al. The clinical value of high-frequency jet ventilation in major airway reconstructive surgery. *Scand J Thorac Cardiovasc Surg.* 1988;22:227.
- Magnusson L, Lang FJW, Monnier P, et al. Anaesthesia for tracheal resection: report of 17 cases. *Can J Anaesth.* 1997;44:1282.
- Perera ER, Vidic DM, Zivot J. Carinal resection with two high-frequency jet ventilation delivery systems. *Can J Anaesth.* 1993;40:59.

45. Galmén K, Harbut P, Freedman J, et al. The use of high-frequency ventilation during general anaesthesia: an update. *F1000Res*. 2017;6(F1000 Faculty Rev):756. <https://doi.org/10.12888/f1000research.10823.1>.
46. Eriksson I, Nilson LG, Nordstrom S. High-frequency positive-pressure ventilation during transthoracic resection of tracheal stenosis and during preoperative bronchoscopic examination. *Acta Anaesthesiol Scand*. 1975;19:113.
47. El-Baz N, Holinger L, El-Ganzouri A. High-frequency positive-pressure ventilation for tracheal reconstruction supported by tracheal T-tube. *Anesth Analg*. 1982;61:796.
48. El-Baz N, El-Ganzouri A, Gottschalk W, et al. One-lung high frequency positive pressure ventilation for sleeve pneumonectomy: an alternative technique. *Anesth Analg*. 1981;60:683.
49. El-Baz N, Jensik R, Penfield Faber L, et al. One-lung high-frequency ventilation for tracheoplasty and bronchoplasty: a new technique. *Ann Thorac Surg*. 1982;34:564.
50. Baraka A, Mansour R, Jaoude CA, et al. Entrainment of oxygen and halothane during jet ventilation in patients undergoing excision of tracheal and bronchial tumors. *Anesth Analg*. 1986;65:191.
51. Louhimo I, Leijala M. Cardiopulmonary bypass in tracheal surgery in infants and small children. *Prog Pediatr Surg*. 1987;21:58–63.
52. Benca JF, Hickey PR, Dornbusch JN, et al. Ventilatory management assisted by cardiopulmonary bypass for distal tracheal reconstruction in a neonate. *Anesthesiology*. 1988;68:270.
53. Ernst M, Koller M, Grobholtz R, et al. Both atrial resection and superior vena cava replacement in sleeve pneumonectomy for advanced lung cancer. *Eur J Cardiothorac Surg*. 1999;15:530.
54. Symbas PN, Justicz AG, Ricketts RR. Rupture of the airways from blunt trauma: treatment of complex injuries. *Ann Thorac Surg*. 1992;54:177–80.
55. Wilson RF, Steiger Z, Jacobs J, et al. Temporary partial cardiopulmonary bypass during emergency operative management of near total tracheal occlusion. *Anesthesiology*. 1984;61:103.
56. Hasegawa T, Oshima Y, Matsuihisa H, et al. Clinical equivalency of cardiopulmonary bypass and extracorporeal membrane oxygenation support for pediatric tracheal reconstruction. *Pediatr Surg Int*. 2016;32:1029–36.
57. Kim CW, Kim DH, Son BS, et al. The feasibility of extracorporeal membrane oxygenation in the variant airway problems. *Ann Thorac Cardiovasc Surg*. 2015;21:517–22.
58. Vyas AB, Lyons SM, Dundee JW. Continuous intravenous anaesthesia with Althesin for resection of tracheal stenosis. *Anaesthesia*. 1983;38:132.
59. Pittoni G, Davia G, Tottoletto F. Spontaneous ventilation and epidural anesthesia in a patient with a large tracheoesophageal fistula and esophageal cancer undergoing colonic interposition. *Anesthesiology*. 1993;79:855.
60. Macchiarini P, Rovira I, Ferrarello S. Awake upper airway surgery. *Ann Thorac Surg*. 2010;89:387–91.
61. Liu J, Li S, Shen J, et al. Non-intubated resection and reconstruction of the trachea for the treatment of a mass of the upper trachea. *J Thorac Dis*. 2016;8:594–9.
62. Li S, Liu J, He J, et al. Video-assisted transthoracic surgery resection of a tracheal mass and reconstruction of trachea under non-intubated anesthesia with spontaneous ventilation. *J Thorac Dis*. 2016;8:575–85.
63. Peng G, Cui F, Ang KL, et al. Non-intubated combined with video-assisted thoracoscopic in carinal reconstruction. *J Thorac Dis*. 2016;8:586–93.
64. Ratzenhofer-Komenda B, Offner A, Kaltenbock F, et al. Differential lung ventilation and emergency hyperbaric oxygenation for repair of a tracheal tear. *Can J Anaesth*. 2000;47:169.
65. Nouraei SAR, Giussani DA, Howard DJ, et al. Physiological comparison of spontaneous and positive-pressure ventilation in laryngotracheal stenosis. *Br J Anaesth*. 2008;101:419–23.
66. Abdelmalak B, Makary L, Hoban J, et al. Dexmedetomidine as sole sedative for awake intubation in management of the critical airway. *J Clin Anesth*. 2007;19:370–9.
67. Ramsay MAE, Saha D, Hebel RF. Tracheal resection in the morbidly obese patient: the role of dexmedetomidine. *J Clin Anesth*. 2006;18:252–4.
68. Hammer GB, Philip BM, Schroeder AR, et al. Prolonged infusion of dexmedetomidine for sedation following tracheal resection. *Paediatr Anaesth*. 2005;15:616–20.
69. Kailash F, DaSilva SL, Block FE. A novel approach to maintain positive pressure ventilation during difficult T-tube placement. *Can J Anaesth*. 2009;56:709–10.
70. Lane GA, Steude G, Pashley NRT. Anesthesia for a patient with a tracheal T-tube stent. *Anesth Analg*. 1981;60:218.
71. Baraka A, Muallem M, Noueihid R, et al. Oxygen jet ventilation of patients with tracheal T-tube. *Anesth Analg*. 1982;61:622.
72. Doyle DJ, O'Grady KF. Physics and the airway; essentials for the clinician. The difficult airway I. *Anesthesiol Clin North Am*. 1995;13:277.
73. Lang SA, Duncan PG, Shepard DAE, et al. Pulmonary oedema associated with airway obstruction. *Can J Anaesth*. 1990;37:201.
74. Koch SM, Abramson DC, Ford M, et al. Bronchoscopic findings in post-obstructive pulmonary oedema. *Can J Anaesth*. 1996;43:73.
75. Mussi A, Ambrogi MC, Menconi G, et al. Surgical approaches to membranous tracheal wall lacerations. *J Thorac Cardiovasc Surg*. 2000;120:115.
76. Devitt JH, Boulanger BR. Lower airway injuries and anaesthesia. *Can J Anaesth*. 1996;43:148–59.
77. Abernathy JH, Reeves ST. Airway catastrophes. *Curr Opin Anesthesiol*. 2010;23:41–6.
78. Johnson AP, Cavarocchi NC, Hirose H. Ventilator strategies for VV ECMO management with concomitant tracheal injury and H1N1 influenza. *Heart Lung Vessel*. 2015;7:74–80.
79. Salem MR, Wong AY, Lin YH, et al. Prevention of gastric distension during anesthesia for newborns with tracheoesophageal fistulas. *Anesthesiology*. 1973;38:82.
80. Au CL, White SA, Grant RP. A novel intubation technique for tracheoesophageal fistula in adults. *Can J Anaesth*. 1999;46:688.
81. Manning PB, Rutter MJ, Border WL. Slide tracheoplasty in infants and children: risk factors for prolonged postoperative ventilatory support. *Ann Thorac Surg*. 2008;85:1187–92.
82. Fanous N, Adil Husain S, Ruzmetov M, Rodefeld MD, Turrentine MW, Brown JW. Anterior pericardial tracheoplasty for long-segment tracheal stenosis. *J Thorac Cardiovasc Surg*. 2010;139:18–25.
83. Wouters KMA, Byreddy R, Gleeson M, et al. New approach to anesthetizing a patient at risk of pulmonary aspiration with a Montgomery T-tube in situ. *Br J Anaesth*. 2008;101:354–7.
84. Hantler C, Wildes TS, Andritsos M. Anesthesia for airway surgery. In: Patterson AG, editor. *Pearson's thoracic and esophageal surgery*. Philadelphia: Elsevier; 2008. p. 211–30.