Review Article

Anaesthesia for tracheal resection and anastomosis

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Abstract

Tracheal resection anastomosis is one of the most challenging surgeries. Notable advances in this field have made possible a variety of surgical, anesthetic, and airway management options. There are reports of newer approaches ranging from use of supraglottic airway devices, regional anesthesia, and extracorporeal support. Endotracheal intubation with cross-field ventilation and jet ventilation are the standard techniques for airway management followed. These call for multidisciplinary preoperative planning and close communication during surgery and recovery. This review highlights the anesthetic challenges faced during tracheal resection and anastomosis with specific considerations to preoperative workup, classification of tracheal stenosis, airway management, ventilation strategies, and extubation. The newer advances proposed have been reviewed.

Keywords: Cross-field ventilation, jet ventilation, tracheal resection anastomosis, tracheal stenosis

Introduction

A better understanding of pathology and improved management techniques has changed the management of tracheal stenosis. It has evolved from a conservative approach consisting of repeated dilatations and local and systemic steroids to more definitive surgical management. Anesthesiologists are involved for *diagnostic* (bronchoscopy), *palliative* (tracheal dilatation/stenting, endoscopic laser ablation), or *definitive surgical management*. These procedures are complex, carrying great risk (shared airway in altered airway anatomy and physiology). Thus, multidisciplinary management is mandatory.

Specialized centers performing tracheal resection and reconstruction (TRR) have reported >90% favorable outcomes with a low mortality rate of 1%–2%.[1] Wright *et al.* in 2004[2] analyzed 901 cases of TRR retrospectively and reported an 18.2% complication rate and identified key risk factors. There are few specialized centers where such procedures are performed regularly. This translates into a lack of randomized clinical trials comparing various anesthetic management strategies[3]; hence the experience and literature for these procedures are also limited.

The authors have conducted 70 plus cases with 4% complication and 1% mortality rate till the time of this publication. Therefore, the authors have attempted an overview of the classification of tracheal stenosis, various anesthetic management strategies available, decision making of airway control, and the newer techniques. This article deals primarily with anesthetic management of tracheal resection and anastomosis. Tracheal anatomy has been extensively covered in literature and is mainly relevant from a surgical point of view for dissection and mobilization of the trachea. Hence, it is not covered in this review.

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Etiology and Clinical Presentation

Adult tracheal stenosis results primarily from inflammatory lesions (postintubation, traumatic, and infectious) or tumors.[3,4] Although the incidence of postintubation stenosis has decreased following the introduction of high-volume, low-pressure tracheal tube cuffs, it is still the commonest cause (around 75%).[5] Over inflation of tracheal cuff, large size tracheal tube, tube movement in an intubated patient (bucking, ventilation, and traction of the circuit), prolonged intubation are the associated factors found to be associated with postintubation stenosis.[6] Steroid, diabetes, hypotension, and infection may be contributory.[6] Primary tracheal tumors are extremely rare. Squamous cell and adenoid cystic are the most common histologic types found with the former subtype having 5-year survival of 13%.[7] True incidence of secondary tracheal tumors is unknown but is more common than primary tracheal tumors. Secondary tracheal tumors are usually metastatic from thyroid, lung, esophagus, or breast.[8] Compressive lesions, i.e., goiter and vascular lesions, can also cause stenosis on rare occasions. Acquired lesions are due to traumatic airway injuries, inhalational, or surgical trauma.

Patients with tumors usually have an insidious onset of symptoms with a gradually progressive course. However, symptoms might appear abruptly as per the underlying pathology. Symptoms are nonspecific with cough, and dyspnea on exertion being the first to develop. Dyspnea on exertion is the most common presentation and correlates with 50% reduction in tracheal diameter, i.e., less than 8 mm. This can progress to dyspnea at rest, which correlates with 75% reduction in tracheal diameter, i.e., less than 5 mm.[9] Hoarseness of voice, dysphagia, and stridor might be present/develop and indicates recurrent laryngeal nerve involvement. Acute exacerbation might result from an upper respiratory infection. Inflammatory lesions have a preceding precipitating event/cause. Patients with prior history of intubation/tracheostomy can present after a variable interval and require a high degree of suspicion. Asthma and cardiac causes are the common differentials.

Congenital tracheal stenosis is rare with male preponderance (2:1). It comprises various tracheal abnormalities, tracheomalacia, and complete tracheal rings with funnel-shaped trachea being the most common.[9] Children with tracheal stenosis may have varying presentations including cyanosis, retractions, tachypnea, apnoea, flaring of nostrils, biphasic stridor, wheezing, recurrent upper respiratory symptoms, persistent laryngotracheobronchitis, and pneumonia. Attempts to swallow food may cause dysphagia with apnoea. Failure to thrive is almost universal.

Classification of stenosis

Several attempts to classify tracheal stenosis for description, treatment, and prognosis have been made but none has been found universally satisfactory. The Cotton *et al.*[10] self-modification of the original grading by Cotton *et al.*[11] is most commonly used. The anatomic location and percentage of obstruction were assessed endoscopically and graded I to IV. This classification is of limited value as a universal grading system yet successfully relates the severity of lesion to the prognosis of decannulation, to some extent. Grundfast *et al.*[12] in 1987 proposed a classification comprising of length, diameter, and consistency of the stenosis using radiography and bronchoscopy. Interinstitutional comparison of radiographic measurements and difficulties in estimating the length of stenosis in cases of severe stenosis limited its reproducibility. Myer *et al.*[13] in 1994 presented another classification of firm, mature stenosis into grades I to IV by comparison of endotracheal tube and patient's age. Freitage *et al.*[14] in 2007 classified central airway stenosis using bronchoscopy in a simple numerical score. Ghorbani *et al.*[15] in 2012 presented a scoring system helpful for decision making concerning therapeutic procedures. They evaluated and graded the diameter of the stricture (scores 1–4), type of stenosis (scores 1–4), and clinical symptoms (scores 1–4) into a scoring system where the patient graded from 2–12. The cutoff point for decision making is a score of 8.5 where those with a score of 8.5 or higher require surgical treatment.

Anesthesia Considerations

Patient management is dependent on the etiology and severity of the tracheal stenosis. The treatment aims at cure or at least palliation. Tracheal dilatation with or without stenting, irradiation, laser ablation, tracheostomy, or resection anastomosis surgery are the treatment options available. Moderate to severe obstruction warrants emergency tracheal dilatation (without or with stenting) or tracheostomy. Bronchoscopy in these patients is postponed and is typically a part of standard treatment.[16]

Patient selection

Optimal candidates for surgery are those with an operative glottis and resectable lesion. Prolonged positive pressure ventilation adversely affects the anastomosis, therefore conditions necessitating postoperative ventilation are considered contraindications, e.g. presence of severe pulmonary and neuromuscular dysfunction and ventilator dependence due to severe pulmonary failure. Increased risk of infection and anastomosis dehiscence secondary to poor wound healing make the following patients poor candidates for surgery: steroid-dependent, those with a history of neck and chest

radiation therapy, with invasive tumors, and microangiopathies due to diabetes mellitus.[9] Wright *et al*. found that steroid use was not associated with increased complication rates.[2] Currently, high dose corticosteroid therapy (>10 mg/d prednisone) is considered a contraindication and patients on steroids are weaned off for 2–4 weeks prior to surgery.[1] Risk factors associated with higher complication rates are redo surgery, longer resections >4 cm, age <17 years, diabetes, preoperative tracheostomy, and laryngotracheal resection.[2]

Preoperative evaluation

Preoperative evaluation of these patients is the same as for a patient for surgery under general anesthesia. This includes pertinent history, meticulous physical examination of the patient, and relevant laboratory investigations for corresponding ASA status. Pulmonary optimization (cessation of smoking, nebulization, and steam inhalation) preoperatively helps reduce morbidity. Patients with age more than 40 years and/or with marked cardiac risk factors should have a cardiology evaluation, and an echocardiography, stress echocardiography, or angiography if necessary. Any associated comorbidities are optimized.

The main focus is on ascertaining the location and extent of stenosis. The history and pattern of dyspnoea, especially dyspnoea at rest aid in determining the stenosis location and the diameter of the constriction. Functionally tracheal stenosis can be classified as *structural or fixed* (intraluminal or extraluminal) and *dynamic or functional*.[14] A fixed obstruction of the larynx and upper trachea is manifested by inspiratory symptoms, whereas lower airway pathology like dynamic collapse, tracheomalacia, and tumors is revealed by expiratory symptoms. Inspiration worsens extra thoracic while expiration worsens intrathoracic lesions. High-resolution computed tomography scan of the neck and thorax with a three-dimensional reconstruction [Figure 1], fiberoptic bronchoscopic examination, positron emission tomography scan, and pulmonary function test (PFT) are the modalities used to determine the exact location, severity, and extent of tracheal stenosis or tumor. PFTs and spirometry might not be consistent to quantify obstruction as flow volume loops are effort-dependent.[8] In our experience, the most important investigation is bronchoscopy, as it gives real-time desired information of the above-mentioned data. Tracheal stenosis is a progressive disease, therefore clinical condition may worsen between bronchoscopy and surgery. Besides, adequate time (i.e. 5–7 days) must be allowed between bronchoscopy and surgery for the tissue edema to settle.

Detailed airway and pulmonary system evaluation are of vital importance. The comprehensive examination must include tracheal palpation and range of neck mobility. The feasibility of bag and mask ventilation should be assessed and airway management strategies should be planned at this stage itself. The position that allows the patient to breathe most comfortably as well as the positions that worsen or relieve the symptoms should be noted. The patient should be counseled regarding avoidance of coughing in the postoperative period and the presence of guardian suture, which limits neck extension on waking up after surgery.

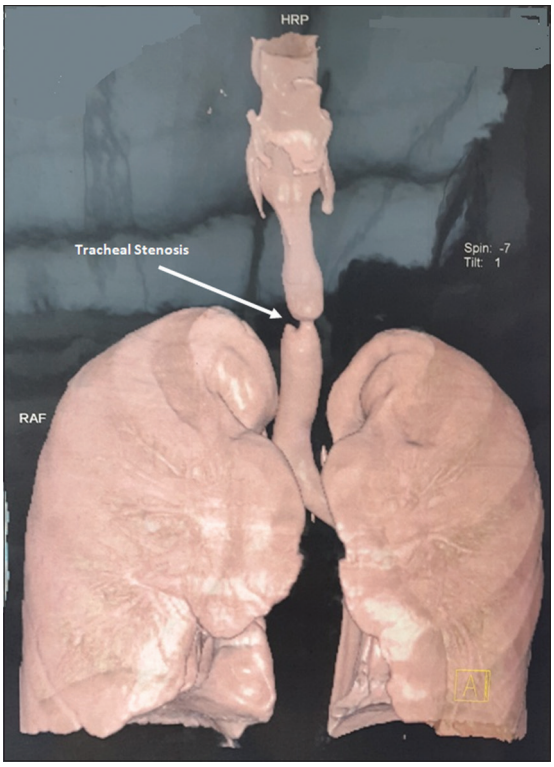

Figure 1: High resolution of CT of neck and thorax with three-dimensional reconstruction

Surgical considerations

The surgical approach depends upon the location of the stenotic segment and the extent of resection planned. From cadaveric studies, Grillo[17] concluded that 4.5 cm of the trachea (i.e., seven tracheal rings) can be excised and end-to-end anastomosis performed safely without jeopardizing blood supply or causing undue stress on the fresh anastomosis. More recently, it was documented that resection of lesions up to 6 cm can be performed safely in selected cases.[18] The blood supply of the tracheal is segmental with blood vessels entering the tracheal wall from the lateral aspect. Therefore, anteroposterior dissection avoids vascular compromise. Tracheal surgery has three self-explanatory phases—tracheal dissection, mobilization and tracheal resection-anastomosis (open airway) and closure.

The approach to *subglottic and upper tracheal lesions* is via a cervical/collar incision, with the patient in the supine

position and extended neck. It could be assisted with an upper sternotomy. The majority of subglottic stenosis (1–4 cm length) are amenable to segmental resection and primary anastomosis. The surgical treatment for malignant lesions involves radicle approach (laryngectomy). Stenosis proximate to glottis are managed with Montgomery T-tube as they risk vocal cord edema. Traction on anastomosis is minimized by neck flexion, maintained by a *Guardian* suture [Figure 2] bridging the skin over the chin and sternal region. *Mid tracheal* stenosis are operated via a cervico-mediastinal incision. The cervical incision helps approach proximal trachea and laryngeal drop is an additional option for mitigating stress on the anastomosis. The mediastinal incision involves a partial sternotomy as it allows access to the anterior carina and both tracheobronchial angles. *Carinal lesions* require a special mention as they require an individualized approach. Isolated carinal resections are approached via sternotomy. Carinal resection of up to 4 cm may be done without laryngeal release. Posterolateral thoracotomy or a clamshell incision is the best approach for carinal resections along with parenchymal resection.

Anesthesia Management

Preoperative preparation and monitoring

Special equipment regarding tracheal resection anastomosis surgery includes endotracheal tubes (ETT) of many sizes, in particular the smaller sizes (2.5 mm to 6.5 mm), flexomettalic ETT for cross-field ventilation, and flexible fiberoptic bronchoscope (FOB) (adult and pediatric). Even though blood loss is minimal, two wide bore (18 g) I.V. cannulas should be secured and extension tubing attached, as both arms are placed on either side of the patient and hidden by the surgical drapes. Preoperative dexamethasone is beneficial as it decreases airway edema due to ensuing tissue handling.[5] Standard ASA monitoring (ECG, SpO_2, NIBP, and $EtCO_2$) is sufficient for most cases. Certain situations, such as jet ventilation, the apnoeic interval to facilitate tracheal anastomosis, and monitoring hemodynamic alterations seen with retraction of the heart during hilar release, warrant the introduction of an intra-arterial catheter.[9] A central venous line is necessary only in patients with severe cardiomyopathy[9] and should be inserted via the femoral or subclavian veins to keep the neck free. An anesthesia depth monitor (BIS) is essential since intravenous anesthesia in toto or in part (as in open tracheal anastomosis) is an integral part of the anesthesia technique for this challenging surgical procedure.[5] Using neuromuscular monitoring (TOF) guarantees a motionless surgical field for precision suturing, and to ensure the complete reversal of any residual neuromuscular blockade at the end of the procedure.[9] Adequate organ perfusion can be monitored via urine output.

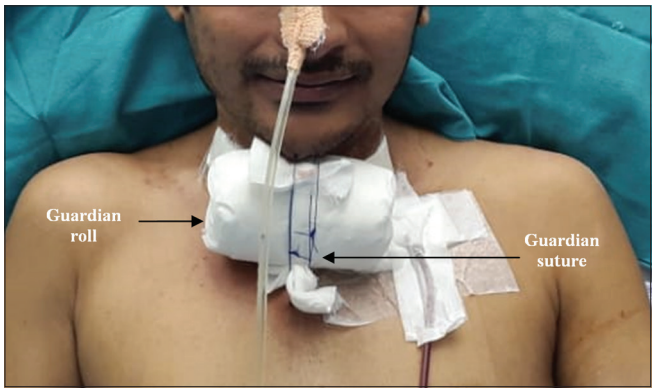

Figure 2: Guardian suture and Guardian roll

Induction and maintenance

The gold standard is to place the endotracheal tube distal to the stenotic segment to retain airway control. Recently, the use of supraglottic airway device (SADs) has been explored and found satisfactory, especially in severe subglottic stenosis.[19,20] They provide reliable ventilation with acceptable airway pressure (<25 mmHg), peripheral oxygen saturation (>95%), and end-tidal carbon dioxide level (<50 mmHg).[19] Use of SAD is especially indicated in anticipated difficult intubation, difficult transtenotic tube placement, and as a rescue device in case of failed intubation. SAD is also advantageous after completion of tracheal anastomosis and emergence as it mitigates the stress on anastomosis (avoiding bucking on the endotracheal tube) fiberoptic bronchoscopy (FOB). Assessment of anastomosis and vocal cord function by FOB through SAD is easily performed gastrointestinal (GI). Contraindications include active GI bleed, tracheal/laryngeal tumor, restricted mouth opening (<2 cm), diaphragmatic hernia, and pregnancy.

Induction is the most crucial part as it involves anesthetizing a compromised airway and has the potential for complete loss of airway. Safe surgical outcomes are possible only by advance planning by the anesthesiologist and surgeon for the induction and airway control, the latter being paramount for it is shared by both specialities. The strategies planned are based upon recent bronchoscopy findings. All the airway equipment that could be required is checked and kept ready. In our experience, the usual 3-min preoxygenation is not adequate for this compromised group of patients and a longer time period should be employed to build up oxygen reserves to give extended time for handling a difficult airway. The position for induction is the one that causes the least airway obstruction and in which the patient is most comfortable. The authors suggest the following approach based on tracheal diameter [Figure 3]:

a. *Tracheal diameter >8 mm but, symptomatic/ tracheostomised*: Following intravenous induction and

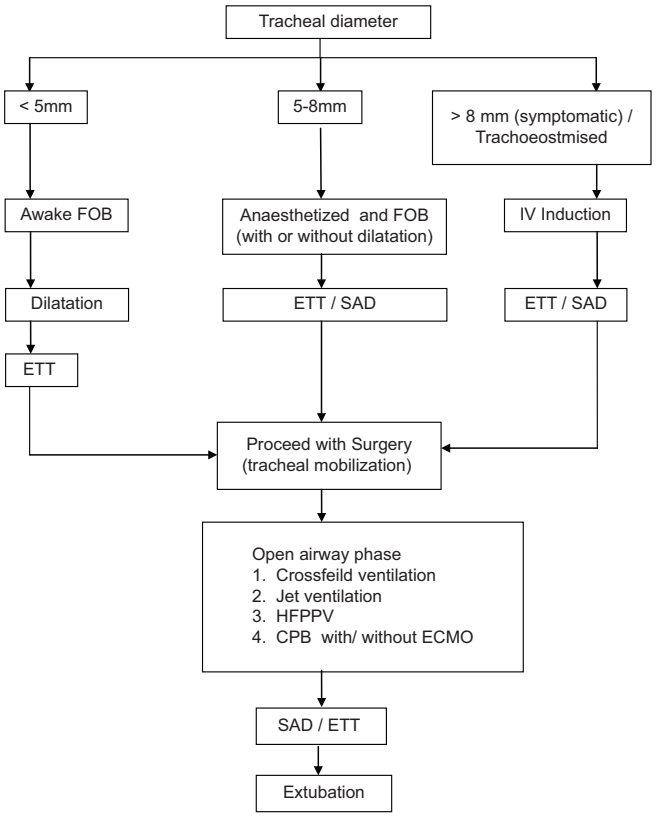

Figure 3: Flow diagram of airway control strategy

neuromuscular blockade, endotracheal intubation is done in the standard manner.[21] SAD can be a useful alternative for airway control.[22] Tracheostomized patients are induced with an intravenous agent, propofol being the first choice with or without ketamine, and ventilation is done through the tracheostomy tube, which is later replaced by a reinforced endotracheal tube.

b. Tracheal diameter 5–8 mm: Induction of anesthesia is inhalational with the gradual introduction of increasing concentrations of sevoflurane in oxygen. If necessary, a propofol infusion is added to increase the depth of anesthesia. Opioids (fentanyl) provide analgesia for noxious stimuli. Spontaneous breathing is maintained, although it may be assisted. Airway topicalization is an option, although fraught with the risk of stimulating cough. Patients may undergo bronchoscopy and tracheal dilatation just after induction. The airway can then be secured using an endotracheal tube or SAD.

c. *Tracheal diameter <5 mm*: Awake fiberoptic bronchoscopy is the best option to secure the compromised airway. This requires patient preparation with lignocaine nebulization and an intravenous antisialagogue. Spray as you go (SAYGO) with lignocaine helps perform the bronchoscopy with relative ease. Once the bronchoscope is past the stenotic segment, an appropriate size endotracheal tube is railroaded above the scope. After intubation, the muscle relaxant is given and positive pressure ventilation is started. Muscle relaxation is mandatory, otherwise airway instrumentation could lead to the development of negative pressure pulmonary edema.

After establishing airway control (ETT or SAD), anesthesia is maintained with an inhalational agent in oxygen. Preparation for ventilation during the "open airway phase" is done as the surgeons mobilize the trachea. Total intravenous anesthesia (TIVA) (i.e. propofol infusion) is the mainstay of anesthesia during the open airway phase, as it ensures consistent anesthesia delivery in altering airway conditions.[1] In our institution, ventilation during the "open airway" phase is controlled, however spontaneous ventilation/spontaneous assisted ventilation is also an option.[23,24] In nonintubated or intubated spontaneously breathing, patients' medications have to be titrated carefully to prevent movement on one hand and apnoea on the other. Supplementation with some form of regional or neuraxial anesthesia is important to prevent splinting of respiration, coughing, or movement.[1] Spontaneous ventilation can be considered with an experienced surgical team, low-risk patient with limited upper airway lesion, and those who can tolerate light sedation without movements. General anesthesia with controlled airway and ventilation is better suited with inexperienced surgical team with high-risk patients (ASA III/IV, BMI >25 kg/m^2, coagulopathy, poorly controlled obstructive airway disease, and cardiac patients with low ejection fraction). Dexmedetomidine infusion is a safe alternative during the open airway phase. Advantages of dexmedetomidine are analgesia, anxiolysis, and amnesia without significant respiratory depression.[25] Due to these desirable properties, dexmedetomidine is being explored as the sole agent for induction and smooth extubation.[26]

Ventilation strategies during "open airway"

The aim is to provide adequate and reliable ventilation without obstruction of surgical field, providing motionless patient and minimizing spurts of blood and secretions. Various options are available.

1. *Distal Tracheal Intubation with Cross-Field Ventilation*[27]: This is a conventional and safe approach. Perhaps that is why a bulk of cases in the literature have been conducted using this approach.[28] A sterile reinforced endotracheal tube is used to intubate the distal trachea before the surgeons attempt the tracheal resection. This is followed by cross-field ventilation [Figure 4], which is carried out by using a fresh sterile anesthetic circuit placed over the surgical drapes and connected to the anesthesia machine. Next, the oral endobronchial tube used during induction is withdrawn and replaced by a regular size endotracheal tube, which is placed proximal to the stenosis. The

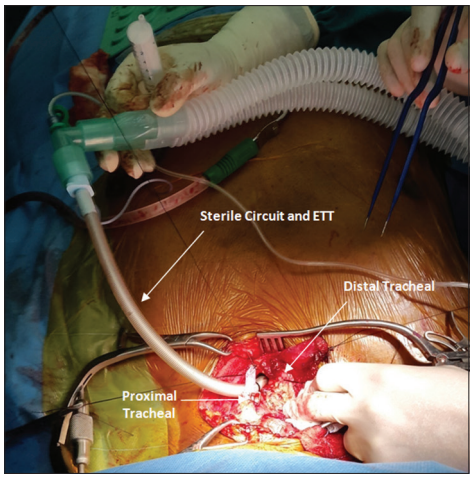

Figure 4: Cross field ventilation

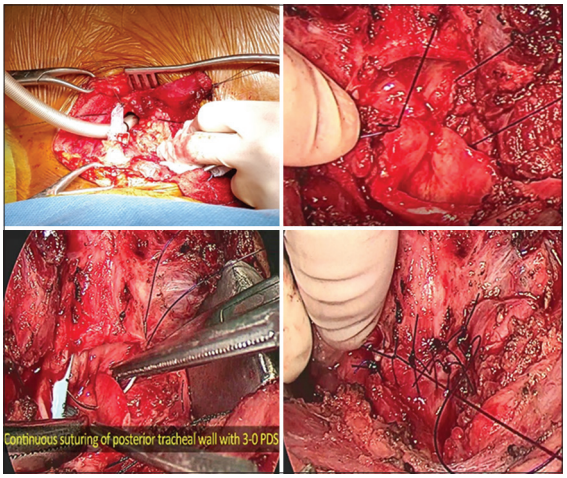

Figure 5: Ventilation-apnoea-ventilation technique

stenosed part of the trachea is resected and posterior anastomosis is done between the two incised ends of the trachea.[9] This is facilitated via apnoea-ventilation-apnoea technique [Figure 5]. After posterior anastomosis, the endotracheal tube kept proximal to the stenotic segment, is guided past the anastomotic site by the surgeon. The anterior anastomosis (anterior sutures) is carried out over the endotracheal tube. Geffin has described the variations of cross-field ventilation.[29] In patients with lower tracheal and carinal tumors, cross-field ventilation improvization is necessary. In these patients, the tube is placed in the left main bronchus to give access to the lower trachea and/or carina for resection by the surgeons. After resection, anastomosis of the right main bronchus to the margins of the resected trachea is performed. The next step involves repositioning the tube so that it allows ventilation of the right lung, whereas the left main bronchus is anastomozed to the anastomosis between the right main bronchus and the lower end of the trachea, creating a new carina. This is followed by tube withdrawal above the suture line and being kept at that level until extubation. Acceptable hypercapnia results from the use of the apnoea-ventilation-apnoea technique and is corrected after the anastomosis. Using propofol during the open airway, phase ensures an adequate anesthetic depth.

2. *Jet Ventilation*: Sanders was the first to introduce jet ventilation into clinical practice,[30] but it was only in the 1970s that this ventilatory mode was applied for the surgically challenging tracheal resection.[31,32] This mode of ventilation works by delivering inspiratory flows using intermittent jets of gas under pressure (15–20 psi) through a catheter with a narrow orifice, expiration is passive. In the case of lesions at the carina, separate catheters can be used for each main bronchus.[33] Low-frequency (10–20/min) or high-frequency (100–400/min) gas flow can be delivered via a pneumatic/electronically regulated interrupter. The efficacy of jet ventilation can be gauged by observing if the chest rises when low-frequency ventilation is used. Adjustable variables for high-frequency jet ventilation are the inspiratory time, the frequency, and the driving pressure. If the frequency of respiration is high, there is a hindrance to lung deflation and distension is the outcome, resulting in positive peripheral airway pressures with low peak and mean airway pressures.[34–37] The plus points of jet ventilation are that it is easy to use, provides a clear surgical field, and nonessentiality of any special equipment. Disadvantages of this mode of ventilation include contamination of distal trachea with blood and debris from surgical sites, auto-positive-end expiratory pressure (PEEP) generation, and inability to monitor EtCO2, inspired oxygen, and anaesthetic gas concentration. There is a possibility of tracheal laceration with pneumothorax from the tip of the ventilating catheter ("whip motion" trauma).
3. *High-Frequency Positive Pressure Ventilation*: This mode of ventilation uses a multiorifice insufflation placed at the lower end of the endotracheal tube catheter, which delivers a minimal tidal volume of 3–5 ml/kg. The low tidal volume provides a relatively still surgical field. The respiratory rate is increased to about 60 breaths/min to provide acceptable minute ventilation. Major advantages include the ability to provide time for complete tracheal anastomosis in one go and minimal chance of whip motion injury. Important disadvantages being the chances of barotrauma and the inability to monitor and quantify ventilation.
4. *Cardiopulmonary Bypass (CPB) and Extracorporeal Oxygenation:* CPB was used for carinal tumors as early as 1959,[38] but its use is situation-specific because of the need for systemic anticoagulation. Venovenous extracorporeal membrane oxygenation (VV-ECMO) and venoarterial

extracorporeal membrane oxygenation (VA-ECMO) are safer (activated clotting time goal 160–180 s) than CPB (activated clotting time goal > 400–450 s).[5] Specific indications for ECMO are: in small children undergoing tracheoplasty of long segments, and[39] in adults with malignant conditions that need combined cardiac and pulmonary procedure,[40] advanced tracheobronchial trauma,[41] and occlusive tracheal pathologies not negotiable by rigid bronchoscopy or tracheotomy.[42] Recent advancements in extracorporeal membrane oxygenation (ECMO), especially the ability to use ECMO with peripheral vascular cannulation instead of central vascular access,[43,44] has advanced its use in both pediatric and adult populations. Peripheral cannulation has reduced the need for anticoagulation. Therefore, complications consequent to anticoagulation have reduced significantly.

The authors would like to stress the fact that there is no airway management technique that is universally acceptable. All techniques have advantages and disadvantages along with the fact that each patient presents unique challenges concerning airway pathology and patient comorbidities. Thus, the anesthesia plan should be tailored to individual patients. Table 1 compares the various techniques.

Extubation and emergence

On completion of the tracheal anastomosis, an "anastomosis leak test" is carried out by subjecting the airway to 20–30 cm of positive airway pressure for about 10 s with the anastomozed trachea submerged in saline. Extubation after surgery is the norm unless there are compelling reasons to ventilate the patient. Extubation after surgery prevents the fresh tracheal anastomosis from the stress of positive pressure ventilation and possible trauma by endotracheal tube cuff. After completion of the surgery, bronchoscopy is

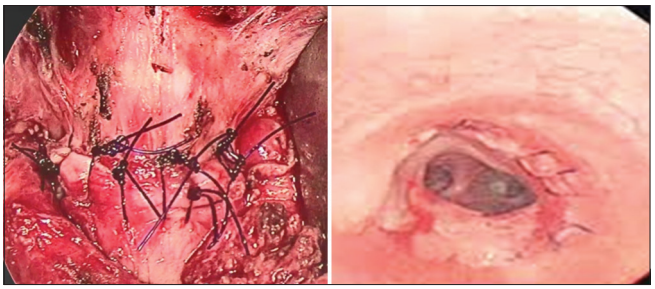

Figure 6: Tracheal anastamosis

Table 1: Comparison of different anesthetic techniques for tracheal surgery

Anesthesia/ AirwayTechnique	Patient characteristics	Advantages	Disadvantages
Conventional approach General anesthesia with endotracheal intubation and cross-field ventilation Mechanical ventilation	The default technique for most patients Patients with contraindication to regional anesthesia	Protects from aspiration Easy to suction fluid and blood from lower airway Secures airway and offers controlled oxygenation/ ventilation Easy to perform anastomotic leak test	Surgical exposure compromised by ETT Possible complications of intubation and mechanical ventilation (airway injury, disruption of friable tissue) Extubation might disrupt anastomosis Difficult to visualize vocal cord function
Spontaneous ventilation (Nonintubated) Mild to moderate sedation Regional, neuraxial, or local anesthesia Supraglottic airway device (SAD)	Ideally suited for Limited extent, benign disease Small incisions Experienced surgical team Patients who can tolerate up to 3h surgery Good cardiopulmonary function ASA class 1 or 2 BMI <25 kg/m^2 No local anesthetic allergy	Excellent surgical exposure Avoids complications of intubation(airway injury and disruption of friable tissue) Nonintubated trachea is more flexible- facilitates surgical re-approximation Decreased postoperative complications with residual opioids, anesthetics, and paralytics-early recovery Allows vocal cords function assessment	Ineffective ventilation can cause hypoxemia/hypercarbia Risk of aspiration Precise titration of anesthetics to prevent apnoea or coughing Inadequate pain control-patient movement/coughing Increased risk of regional block complications, block failure and local anesthetic toxicity Not possible in sicker patients and/or with extensive lesions
Jet ventilation (General anesthesia) High- or low-frequency jet Ventilation	Same as for patients with endotracheal intubation and with poor surgical visualization	Improved surgical visualization It is a rapid rescue technique Can augment other airway techniques	Difficulty monitoring ventilation Barotrauma Mucosal injury (whiplash injury)
Extracorporeal life support VV-ECMO, VA-ECMO, or CPB	Any anesthesia & any airway (including no airway) Cases with near-total obstruction Patients with extensive tumour infiltration Hemodynamically unstable patients	It is the ultimate rescue technique Provides best surgical exposure Provides reliable control of gas exchange Hemodynamic support	Needs to be prepared in advance Cannulation needs to be done before starting the case under LA Issues of coagulopathy Causes hemodilution Chances of vascular injury

performed for tracheobronchial toileting and a final visual check of fresh anastomosis [Figure 6]. Bucking and head extension at extubation should be strictly prevented. This is achieved by tapering off the muscle relaxant infusion, good analgesia, and propofol infusion. Normothermia prevents postoperative shivering that increases oxygen consumption and stresses respiration. Humidified gases are used to prevent drying of airway and postoperative airway irritation. After neuromuscular blockade has worn off, residual neuromuscular blockade is antagonized, and trachea is extubated after gentle suctioning. This protocol results in an awake patient with patent airway. Alternatively, the spontaneously breathing anaesthetized patient may be extubated and a SAD placed. SAD is removed as the patient regains consciousness.

It is imperative to counsel the patient, preoperatively, about the importance of avoidance of abrupt neck extension, the need of maintaining head in flexed position and presence of the guardian suture in the postoperative period. Reintubation, after extubation, can be difficult and disastrous because of the flexed position of neck, edematous, and blood-smeared operated airway. If required, reintubation should be performed with an FOB to avoid injury to the fresh anastomosis and possible dislodgement of stent.

Postoperative care

ICU care is warranted in the postoperative period to detect any complication of the anastomosed trachea. Periodic blood gas analysis along with clinical monitoring is needed for the first 24 h postoperatively. Patients are kept propped up at around 45° with head flexed with the help of guardian sutures. Effective pain management is essential to prevent agitated patients. Thoracotomies require patient-controlled epidural analgesia (PCEA) while cervical incisions and managed well with systemic analgesics. Multimodal analgesia helps prevent delirious patient and respiratory depression. Comprehensive ancillary care comprising of humidified oxygen supplementation, nebulization, physiotherapy, antitussive use, and gentle pulmonary toileting go a long way in good postoperative rehabilitation.

Complications

There are numerous potential complications of this complex surgical procedure. Common postoperative complications that can be avoided are the residual effect of drugs (analgesics, neuromuscular blockers) and atelectasis (due to secretions). The important surgical-related ones are dehiscence of anastomosis, recurrent laryngeal nerve dysfunction, hemorrhage, air leak, and tracheoesophageal fistula. Of note among the nonsurgical complications are respiratory failure, pneumonia, pulmonary embolism, deep vein thrombosis, myocardial infarction, and tetraplegia. Tetraplegia needs special mention as it is a dangerous preventable complication. Four cases of tetraplegia have been reported so far.[45] Hyperflexion of neck in the postoperative period is the most likely cause of compromised blood supply to the spinal cord. Three out of the four cases improved on reducing neck flexion. Propped up position of the patient might have led to relative hypotension, which could have been a contributory factor. *Guardian roll* use is recommended to prevent neurologic compromise secondary to the flexed neck.[45]

Regional Anesthesia

Literature describes four regional anesthesia techniques for conducting tracheal resection and anastomosis, which have been tried Since 2010.[46] However, these techniques need further evaluation before they can be adopted as the sole technique.

1. *Cervical epidural catheters*: An epidural catheter placed at C7/T1 level using local anaesthetic like 0.5% ropivacaine for tracheal resection anastomosis has been described.[47] Additionally, it may require local infiltration along surgical planes, airway topicalization with local anaesthetic, and systemic analgesics. Patients breathe spontaneously during the procedure along with oxygen supplementation. An incision on trachea may cause desaturation, which responds to oxygen insufflation in distal trachea through a sterile catheter. Patients without cardiac conditions and those who do not require sternotomy are best suited for a cervical epidural. Contraindications to neuraxial anesthesia need to be ruled out beforehand.
2. *Cervical plexus block*: Tracheal resection anastomosis has been reported in two patients under bilateral cervical plexus block aided by ultrasound visualization.[48,49] About 7 ml of 0.5% ropivacaine is injected on each side. Additional supplementation with intravenous analgesics and/or sedatives is required. However, of the two patients who received blocks for tracheal resection and anastomosis, one required laryngeal mask airway (LMA) insertion while the other was intubated.
3. *Local infiltration*: Tracheal resection and anastomosis can be done with stepwise local infiltration of local anaesthetic by the surgeons. Analgesia and sedation supplementation is necessary. Fentanyl and/or ketamine and midazolam are preferred agents. Literature has described a case of occluding subglottic hamartoma that was operated successfully, by stepwise local infiltration of local anesthetic.[50]
4. *Thoracic epidural*: An epidural catheter placed at T7/T8 level has been found to provide adequate operating conditions.[51] The patients need supplemental analgesia with intravenous opioids and/or intercostal nerve blocks, in addition to the epidural block. Patients are sedated and

the airway is secured by LMA insertion with intravenous propofol. Patient's spontaneous ventilation is maintained throughout the procedure and distal trachea needs oxygen insufflation as with cervical epidural.

Conclusion

Anesthesia for tracheal resection is among the most technically challenging task for the entire team. However, it remains the treatment of choice as it rectifies the pathology and has a high success rate and, thereby providing better quality of life. Improvements in diagnostic modalities, surgical techniques, and anesthesia management have contributed to the above. Newer anesthesia management approaches have emerged with respect to SADs, spontaneously breathing patients during the "open airway" phase, and nonintubated awake patients undergoing tracheal resection with regional anesthesia. These newer approaches offer potential advantages over the conventional approach. However, the lack of randomized clinical trials comparing newer techniques precludes conclusions about the applicability of these. There is insufficient data to determine appropriate patient selection, procedural specifics, and complications of these newer techniques. The authors, therefore, recommend tailoring the specific airway and anesthetic management strategy to individual patient airway pathology, patient comorbidities, and surgical preference. The need for multidisciplinary teamwork and close communication cannot be emphasized enough. We share our experiences for the benefit of all.

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Conflicts of interest

There are no conflicts of interest.

References

1. Smeltz AM, Bhatia M, Arora H, Long J, Kumar PA. Anesthesia for resection and reconstruction of the trachea and carina. J Cardiothorac Vasc Anesth 2020;34:1902-13.
2. Wright CD, Grillo HC, Wain JC, Wong DR, Donahue DM, *et al*. Anastomotic complications after tracheal resection: Prognostic factors and management. J Thorac Cardiovasc Surg 2004;128:731-9.
3. Grillo HC, Mathisen DJ. Diseases of trachea and bronchi. In: Paprella MM, Shumrick DA Gluckman JL, Meyerhoff WL, editors. Otolaryngology, Head and Neck. 3rd ed, vol. III. Philadelphia: WB Saunders Company; 1991. p. 2385-97.
4. Grillo HC. Benign and malignant diseases of the trachea, In: Shields TW, editor. General Thoracic Surgery. 3rd ed. Philadelphia: Lea and Febiger; 1989. p. 667-79.
5. Grillo HC, Donahue DM. Post intubation tracheal stenosis. Semin Thorac Cardiovasc Surg 1996;8:370-80.
6. Pinsonneault C, Fortier J, Donati F. Tracheal resection and reconstruction. Can J Anaesth 1999;46:439-55.
7. Napieralska A, Miszczyk L, Blamek S. Tracheal cancer-treatment results, prognostic factors and incidence of other neoplasms. Radiol Oncol 2016;50:409-17.
8. Mathisen DJ. Tracheal tumors. Chest Surg Clin N Am 1996;6:875-98.
9. Hobai IA, Chhangani SV, Alfille PH. Anesthesia for tracheal resection and reconstruction. Anesthsiol Clin 2012;30:709-30.
10. Cotton RT, Gray SD, Mller RP. Update of the cincinnati experience in pediatric laryngotracheal reconstruction. Laryngoscope 1989;99:1111-6.
11. Cotton RT. Pediatric laryngotracheal stenosis. J Pediatr Surg 1984;19:699-704.
12. Grundfast KM, Morris MS, Bernsley C. Subglottic stenosis: Retrospective analysis and proposal for standard reporting system. Ann Otol Rhino Laryngol 1987;96:101-5.
13. Myer CM 3rd, O'Connor DM, Cotton RT. Proposed grading system for subglottic stenosis based on endotracheal tube sizes. Ann Otol Rhinol Larygol 1994;103:319-23.
14. Freitag L, Ernst A, Unger M, Kovitz K, Marquette CH. A proposed classified system of central airway stenosis. Eur Respir J 2007;30:7-12.
15. Ghorbani A, Dezfouli AA, Shadmehr MB, Pejhan S, Saghebi SR, Ghare-Daghi AS, *et al*. A proposed grading system for post-intubation tracheal stenosis. Tanaffos 2012;11:10-4.
16. Shapshay SM, Valdez TA. Bronchoscopic management of benign stenosis. Chest Surg Clin N Am 2001;11:749-68.
17. Grillo HC. The development of Tracheal surgery: An historical review. Techniques of tracheal surgery. Ann Thorac Surg 2003;75:610-9.
18. Blasberg JD, Wright CD. Surgical considerationsin tracheal and carinal resection. Semin Cardiothorac Vasc Anesth 2012;16:190-5.
19. Schieren M, Egyed E, Hartmann B, Aleksanyan A, Stoelben E, Wappler F, *et al*. Airway management by laryngeal mask airways for cervical tracheal resction and reconstruction: A single center retrospective analysis. Anesth Analg 2018;126:1257-61.
20. Gadre VN, Ramteke DB, Yadav SR, Mundrawala EG. Anaesthesia for tracheal reconstruction- Neither a dilemma nor a catastrophe. Indian J Anaesth 2019;63:152-3.
21. Sandberg W. Anesthesia and airway management for tracheal resection and reconstruction. Int Anesthesiol Clin 2000;38:55-7.
22. Mentzelopoulos SD, Romana CN, Hatzimichalis AG, Tzoufi MJ, Karamichali EA. Anesthesia for tracheal resection: A new technique of airway management in a patient with severe stenosis of the midtrachea. Anesth Analg 1999;89:1156-60.
23. Sivakumar KR, Panneerselvam S, Uthaman D, Rudingwa P, Ravi R. Spontaneous ventilation as a key ventilation technique during open airway phase in tracheal resection and reconstruction: A case series. Indian J Anaesth 2019;63:1029-32.
24. Parikh DA, Jain RA, Lele SS, Bardoo RA. Anaesthetic management of tracheal restenosis in operated cases of tracheal resection and anastomosis: A retrospective review. Indian J Anaesth 2018;62:815-8.
25. Abdelmalak B, Makary L, Hoban J, Doyle DJ. Dexmedetomidine as sole sedative for awake intubation in management of critical

airway. J Clin Anesth 2007;19:370-9.
26. Hammer GB, Philip BM, Schroeder AR, Rosen FS, Koltai PJ. Prolonged infusion of dexmedetomidine for sedation following tracheal resection. Pediatr Anaesth 2005;15:616-20.
27. Ranganathan N, Arathi BHR, Ramamani PV, Gowda VB. Anaesthesia considerations for tracheal resection in oncological thyroid surgeries. Indian J Anaesth 2015;59:188-90.
28. Schieren M, Böhmer A, Dusse F, Koryllos A, Wappler F, Defosse J. New approaches to airway management in tracheal resections-a systematic review and meta-analysis. J Cardiothorac Vasc Anesth 2017;31:1351-8.
29. Geffin B, Grillo HC, Cooper JD, Pontoppidan H. Stenosis following tracheostomy for respiratory care. JAMA 1971;216:1984-8.
30. Sanders RD. Two ventilating attachments for bronchoscopes. Del Med J 1967;39:170-3.
31. Lee P, English ICW. Management of anesthesia during tracheal resection. Anesthesia 1974;29:305-10.
32. Ellis RH, Hinds CJ, Gadd LT. Management of anesthesia during tracheal resection. Anesthesia 1976;31:1076-9.
33. Clarkson WB, Davies JR. Anesthesia for carinal resection. Anesthesia 1978;33:815-7.
34. Howland WS, Carlon GC, Goldiner PL, Rooney SM, Concepcion I, Bains MS, *et al*. High frequency jet ventilation during thoracic surgical procedures. Anesthesiology 1987;67:1009-12.
35. Carlon GC, Kahn RC, Howland WS, Ray C Jr, Turnbull AD. Clinical experience with high frequency jet ventilation. Crit Care Med 1981;9:1-6.
36. Sjostrand U. High frequency positive-pressure ventilation: A review. Crit Care Med 1980;8:345-51.
37. Glenski JA, Crawford M, Rehder K. High-frequency, small volume ventilation during thoracic surgery. Anesthesiology 1980;59:577-80.
38. Louhimo I, Leijala M. Cardiopulmonary bypass in tracheal surgery in infants and small children. Prog Pediatr Surg 1987;21:58-63.
39. Benca JF, Hickey PR, Dornbusch JN, Koka BV, McGill TJ, Jonas R, *et al*. Ventilatory management assisted by cardiopulmonary bypass for distal tracheal reconstruction in a neonate. Anesthesiology 1988;68:270.
40. Ernst M, Koller M, Grobholtz R, Moosdorf R. Both atrial resection and superior vena cava replacement in sleeve pneumonectomy for advanced lung cancer. Eur J Cardiothorac Surg 1999;15:530.
41. Symbas PN, Justicz AG, Ricketts RR. Rupture of the airways from blunt trauma: Treatment of complex injuries. Ann Thorac Surg 1992;54:177-80.
42. Wilson RF, Stieger Z, Jacobs J, Sison OS, Holsey C. Temporary partial cardiopulmonary bypass during emergency operative management of near total tracheal occlusion. Anesthesiology 1984;61:103.
43. Hasegawa T, Oshima Y, Matsuihisa H, Okata Y, Yokoi A, Yokoyama S, *et al*. Clinical equivalency of cardiopulmonary bypass and extracorporeal membrane oxygenation support for pediatric tracheal reconstruction. Pediatr Surg Int 2016;32:1029-36.
44. Kim CW, Km DH, Son BS, Cho JS, Kim YD, I H, *et al*. The feasibility of extracorporeal membrane oxygenation in the variant airway problems. Ann Thorac Cardiovasc Surg 2015;21:517-22.
45. Kumar A, Marwaha A, Pappu A, Sharma S, Sood J. Regressive quadriparesis following tracheal resection anastomosis. J Clin Anesth 2018;44:42-3.
46. Macchiarini P, Rovira I, Ferrarello S. Awake upper airway surgery. Ann Thorac Surg 2010;89:387-90.
47. Vachhani ST, Tsai JY, Moon T: Tracheal resection with regional anesthesia. J Clin Anesth 2014;26:697-8.
48. Cho AR, Kim HK, Lee EA, Lee DH. Airway management in a patient with severe tracheal stenosis: Bilateral superficial cervical plexus block with dexmedetomidine sedation. J Anesth 2015;29:292-4.
49. Liu J, Li S, Shen J, Dong Q, Liang L, Pan H, *et al*. Non-intubated resection and reconstruction of trachea for the treatment of a mass in upper trachea. J Thorac Dis 2016;8:594-9.
50. Loizzi D, Sollitto F, De Palma A, Pagliarulo V, Di Giglio I, Loizzi M. Tracheal resection with patient under local anesthesia and conscious sedation. Ann Thorac Surg 2013;95:e63-5.
51. Li S, Liu J, He J, Dong Q, Liang L, Cui F, *et al*. Video-assisted transthoracic surgery resection of a tracheal mass and reconstruction of trachea under non-intubated anesthesia with spontaneous breathing. J Thorac Dis 2016;8:575-85.