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REVIEW ARTICLE

Mastering Anesthesia: Best Practices for Tracheal Resection Surgery Anesthesia for Tracheal Resection

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ABSTRACT

Tracheal resection is a technically challenging procedure due to altered airway anatomy and the requirement for shared airway management. Anesthetic planning involves comprehensive preoperative evaluation, including pulmonary function tests, flow–volume loops, CT scans, and bronchoscopy to define the site and degree of stenosis. Stenosis severity determines the induction and airway management method, ranging from inhalational induction with spontaneous ventilation to awake fiberoptic intubation. Total intravenous anesthesia (TIVA) is employed for maintenance due to its stability and versatility. Intraoperative ventilation modalities include cross-field ventilation, jet ventilation, high-flow nasal oxygenation, and, in some cases, ECMO. Each is selected based on the surgical stage and patient considerations. Operating room extubation is performed safely to protect the tracheal anastomosis, and postoperative care involves careful monitoring, airway protection, and pulmonary support. Overall, successful outcomes rely upon careful planning, multidisciplinary teamwork, and airway plans tailored to the individual patient, focused on both surgical and anesthetic requirements.

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

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Introduction

Tracheal stenosis is defined as a reduction in tracheal diameter, with an incidence ranging from 6% to 22%, mostly caused by prolonged mechanical ventilation (e.g., post-intubation or post-tracheostomy), followed by trauma, infections, and primary or secondary tumors. Other causes include congenital anomalies (tracheomalacia), chronic inflammation (sarcoidosis), collagen vascular diseases (Wegener's granulomatosis), and foreign body aspiration.[1–3] Key symptoms of inspiratory airway obstruction include coughing, expectoration, dyspnea, stridor, and episodic breathing difficulty, often exacerbated by physical activity.[4–6]

There are several approaches to resolving stenosis, such as local or systemic steroids, repeated tracheal dilation or stenting, and endoscopic laser ablation, though these are often only palliative.[7,8] The primary and definitive treatment is tracheal resection and anastomosis.[9] Because of altered airway anatomy, the surgeons' focus on the airway, and the inherent challenges of maintaining airway patency, ventilation, and optimal surgical conditions, these procedures present significant challenges for anesthesiologists. This review aims to outline the anesthetic management of tracheal resection surgery.

Preoperative Assessment

Patient Selection

Tracheal resection surgeries are primarily considered for patients with tracheal stenosis, tumors, or trauma-induced damage. Ideal candidates for the surgery are those with resectable lesions and a functional glottis—both key factors—minimal comorbidities, and good pulmonary function. Conversely, prolonged positive pressure ventilation can adversely affect anastomotic healing. For this reason, patients with severe pulmonary failure, neuromuscular dysfunction, or ventilator dependence are exclusion criteria.[8]

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In conclusion, patients with severe obstructive or restrictive lung disease, high-risk cardiovascular conditions, extensive tumor invasion, or those unable to tolerate single-lung ventilation or extracorporeal support should be excluded from consideration for tracheal resection.

Risk Factors for Complications

- Reoperation is a clear risk factor since previous tracheal resection leads to greater anastomotic tension in future procedures.
- Diabetes significantly increases the risk of anastomotic complications, with an odds ratio of 3, likely due to impaired microcirculation and delayed wound healing.
- Resections longer than 4 cm have a dramatic rise in failure, with laryngotracheal resections being the most challenging.
- Tracheostomy dependence before the surgery is an independent risk factor.
- High-dose corticosteroid therapy (>10 mg/d Prednisone)
- Pediatric patients (<17 years).[10]

Examination and Functional Assessment

The main purpose of evaluation is to determine whether the tracheal lesion will cause airway obstruction during anesthesia induction or during subsequent surgical manipulation and/or resection.

Patients should be evaluated using a routine approach, including a thorough medical history—specifically onset, progression, and baseline respiratory status—and a comprehensive physical examination; stridor, voice changes, and signs of airway compromise must be assessed. However, special attention should be given to a detailed assessment of the airway and pulmonary system.[11]

To prepare for a potential difficult intubation, an upper airway examination, Mallampati scoring, and other relevant assessments should be performed carefully.

The degree of airflow obstruction can be assessed by asking the patient to take a deep inspiration and then exhale forcefully—this is known as the "birthday candle test." The strength of the expiratory airflow provides an indication of obstruction severity.[12]

Additionally, observing the patient's respiratory patterns in different positions, the positions they adopt to optimise tracheal patency, and their respiratory function in the supine position can provide valuable clinical insights, as this simulates conditions in the operating room. Ideally, the induction position should match the patient's preferred posture.[8,13]

Pulmonary function tests (PFTs) provide objective data on airway obstruction. Arterial blood gas analysis, together with lung function tests such as flow–volume curves and carbon monoxide diffusion capacity, offers essential data for accurately assessing respiratory function. Specifically, flow–volume loop analysis helps determine the type of obstruction. If stenosis occurs in the extrathoracic trachea, symptoms are predominantly inspiratory, whereas stenosis in the intrathoracic trachea primarily causes expiratory symptoms.[2,14]

Computed tomography (CT) is the primary imaging modality for evaluating tracheal pathology and planning surgical resection, whereas routine chest radiographs are typically not diagnostic. If vascular or soft-tissue invasion is suspected, magnetic resonance imaging (MRI) should be considered.[15,16]

Direct visualisation via flexible bronchoscopy is crucial for both diagnosis and intra-operative planning. This approach allows assessment of key characteristics, including the type of pathology (e.g., fibrous, tracheomalacia), its location (distance from the vocal cords), consistency (soft or rigid), and the residual lumen of the affected airway segment.[17]

Anesthetic Management

The induction and maintenance of anesthesia for tracheal resection surgery require meticulous planning, individualized airway management strategies, and close collaboration between the anesthesiologist and surgeon.

In preoperative preparation, the primary focus is airway management. All necessary devices, including endotracheal tubes and laryngeal mask airways (LMAs) of various sizes, tube changers, essential interconnections for cross-field ventilation, and a bronchoscope, must be checked and readily available.

In addition to standard ASA-recommended monitoring, continuous blood pressure monitoring via arterial catheterization, train-of-four (ToF) monitoring for neuromuscular blockade assessment, and anesthesia depth monitoring are recommended.[18,19]

Standard preoxygenation with 3 minutes of mask ventilation is most of the time not sufficient for patients with compromised airways. Extended preoxygenation is recommended. The peri-induction period should be conducted with the patient positioned in the most comfortable posture previously identified during the preoperative assessment.[20]

Induction and Maintenance of Anesthesia

Intravenous induction with commonly used agents, such as propofol and fentanyl, can be performed in combination with a short-acting and reversible muscle relaxant like rocuronium.

Table 1. Suggested airway management strategies for each phases

Dissection	Resection	Closure
• Spontaneous ventilation (native airway or LMAs) • LMA • Suprastenotic or transstenotic intubation • Tracheostomy • ECMO (VV or VA)	• Spontaneous ventilation (native airway or LMAs) • Transtracheal intubation or jet ventilation • Cross-field intubation or jet ventilation • Intermittant apnea • Apneic oxygenation • ECMO (VV or VA)	• Spontaneous ventilation (native airway or LMAs) • LMA • Repositioned tracheal tube • Tracheostomy

LMAs: Laryngeal mask airways; ECMO: Extracorporeal membrane oxygenation; VV: Veno-venous; VA: Veno-arterial.

For patients with moderate stenosis (tracheal diameter of 5–8 mm), induction with an inhalational anesthetic while maintaining spontaneous breathing is preferred. Sevoflurane is the best option for this approach.

In cases of severe stenosis, where the tracheal diameter is less than 5 mm, awake fiberoptic intubation (AFI) is the preferred method for securing the airway while minimizing the risk of total airway collapse.[8]

During the induction phase, precautions must be taken for the possibility of airway collapse or a "can't intubate, can't ventilate" scenario. The availability of a rigid bronchoscope, trans-tracheal jet ventilation (TTJV), and an emergency tracheostomy setup is mandatory. Although the use of cricothyroid puncture is limited, it should still be considered as a last-resort option. Extracorporeal membrane oxygenation (ECMO) should be considered for high-risk cases.[21–23]

Total intravenous anesthesia (TIVA) is the preferred method for maintaining anesthesia. Propofol combined with remifentanil infusions is favored for achieving a stable depth of anesthesia. While volatile anesthetics can be used, potential airway management changes during the intraoperative period make it more challenging to maintain consistent anesthesia levels. Dexmedetomidine is a valuable alternative, offering sedative and analgesic properties while primarily preserving airway patency during both induction and maintenance.[11,18]

Airway Management, Ventilation, and Oxygenation

Tracheal resection surgery consists of three phases: dissection, resection, and closure. Each phase presents unique challenges based on lesion location, surgical approach, and patient-specific factors; therefore, one approach alone is not sufficient. Instead, several methods should be mixed and matched to achieve the best outcome.[24]

The gold standard approach consists of orotracheal intubation followed by cross-field ventilation with a sterile endotracheal tube placed into the distal airway during the open tracheal phase.[25] However, as mentioned before, different approaches may be required (Table 1).

Endotracheal tube: A single-lumen reinforced endotracheal tube is the best option. Due to the risk of obstructing the surgical field, double-lumen tubes are not recommended. If single-lung ventilation is required (e.g., in carinal resection), long single-lumen tubes or endobronchial blockers are preferred. In addition to preventing aspiration, endotracheal tubes allow for positive pressure ventilation and oxygen delivery. However, during the dissection phase, placing an appropriate tube proximal to the subglottic tracheal stenosis may be challenging or even impossible. Alternatively, trans-stenotic tube placement can be considered, but it carries a risk of airway trauma and bleeding.[25]

Cross-field ventilation is a technique in which a sterile endotracheal tube is placed directly into the distal trachea or main bronchus by the surgeon after the trachea has been incised. It serves as a reliable and versatile rescue technique when other methods, such as jet ventilation or spontaneous breathing, fail during the resection phase. This approach offers several advantages, including a clear surgical field, direct ventilation to the lungs during the open tracheal phase, and flexibility for adjustments. However, it also has disadvantages, such as the risk of accidental extubation, contamination due to frequent manipulation, potential anastomotic damage during the closure phase, and limited ventilation control caused by reduced tidal volumes compared to conventional ventilation[13,25,26] (Fig. 1).

Laryngeal mask airways (LMAs): LMAs can facilitate a smooth emergence from anesthesia and spontaneous ventilation during the closure phase compared to tracheal intubation.[27] However, the general limitations and contraindications of LMA use—such as restricted mouth opening, morbid obesity, and conditions associated with an increased risk of aspiration (e.g., severe gastroesophageal reflux, diaphragmatic hernia, bowel obstruction)—also apply to tracheal surgery. LMA use should be avoided in patients with a residual tracheostomy, tracheal or laryngeal tumors, or active airway bleeding.[28]

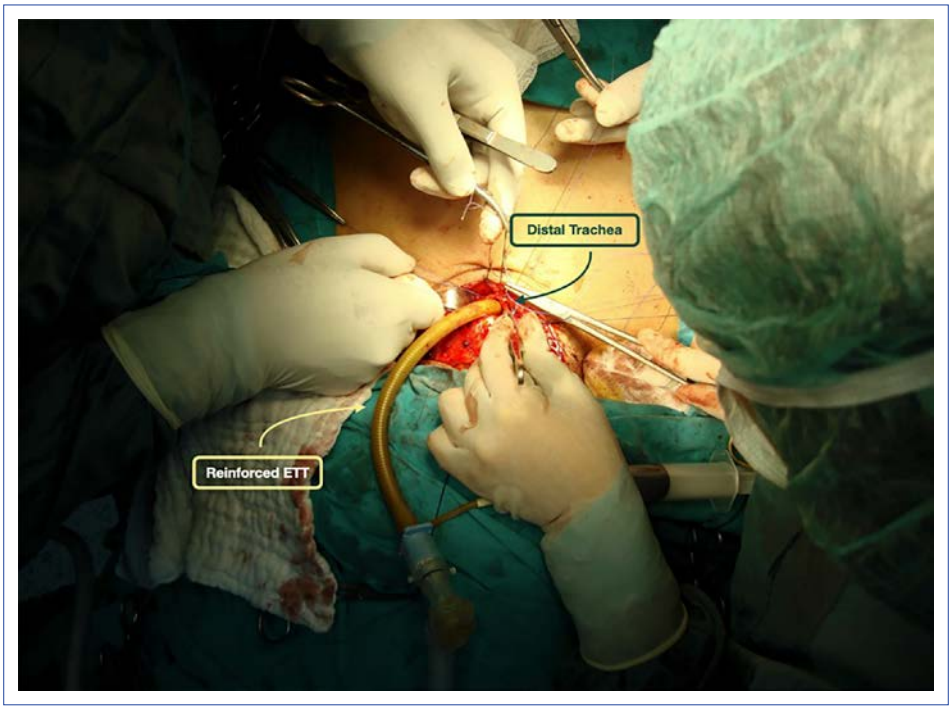

Figure 1. Crossfield ventilation.

In cases of severe airway stenosis, an awake LMA can be placed under topical oropharyngeal anesthesia, providing a secure airway while allowing for ventilatory support and precise oxygen titration, making it a preferred option for reconstructive airway procedures performed under sedation with preserved spontaneous ventilation. However, during the dissection phase, surgical manipulation may make LMA use less ideal for patients with tracheomalacia.[28,29]

Spontaneous ventilation: It has been explored as an alternative to conventional intubation-based techniques and can be maintained with adequate anesthesia using a combination of TIVA and regional anesthesia, such as thoracic epidural blocks.

Spontaneous ventilation minimizes the need for airway manipulation, ensuring an unobstructed surgical field and lowering the risk of airway collapse during surgery. However, it requires comprehensive interdisciplinary training and expertise to address anesthetic and surgical challenges, and patients with severe airway compromise or high-risk lesions may require more controlled ventilation strategies.[8,11,29]

High-Flow Nasal Oxygenation (HFNO) has been used, particularly in combination with spontaneous ventilation techniques, as part of a non-intubated patient approach. It provides titratable oxygen delivery and a high level of patient comfort. With adequate airway patency, high-flow nasal cannula therapy has been shown to maintain effective oxygenation during airway surgery, even in cases of prolonged apnea exceeding 15 minutes. Compared to low-flow techniques, it offers better gas exchange while avoiding the risks associated with jet ventilation, such as barotrauma and volutrauma. Despite these advantages, HFNO does not prevent CO_2 accumulation, potentially leading to respiratory acidosis if apnea persists.[18,30]

Jet ventilation: Jet ventilation is a good option for oxygenation during both the resection and reconstruction phases. Specifically, in the reconstruction phase, small-bore jet catheters can be placed into the distal trachea or mainstem bronchus via an existing airway device (tracheal tube or LMA) or across the surgical field. These tubes interfere less with surgical access compared to transtracheal or cross-field intubation. If there is no impairment in diffusion capacity, oxygenation is usually adequate.

Jet catheters can't secure the airway from aspiration; for that reason, effective bleeding management and airway suctioning are key components of this technique. In addition, it can cause auto-PEEP and limits the ability to monitor $ETCO_2$, inspired oxygen, and anesthetic gas concentrations.[8,13,20]

Apneic oxygenation: This type of oxygenation is effective for short periods and can facilitate tubeless anesthesia for TRR by delivering high-flow oxygen across the open trachea under apneic conditions.[30] However, like all ventilation techniques that involve apnea, it does not prevent CO_2 build-up.

ECMO: There are two main approaches to ECMO use in tracheal resection. The first is as a bridge to airway control, ensuring adequate gas exchange in patients at

risk for a difficult airway until airway control is achieved via endotracheal or cross-field intubation. The second approach involves using ECMO for the entire surgical procedure.[21]

Veno-venous ECMO can provide adequate gas exchange without any interference from airway devices in the surgical field and eliminates the risk of intraoperative airway fire. Veno-arterial ECMO provides hemodynamic support in addition to adequate gas exchange.[13] In cases of severe airway obstruction, anticipated difficulties with other airway management techniques, or significantly impaired pulmonary or cardiac function, 'awake' ECMO cannulation under local anesthesia may be considered for selected high-risk patients.

Given the risks of vascular injuries, coagulopathy, systemic inflammatory response, and neurological damage, the primary use of ECMO in tracheal and carinal resections is generally reserved for complex and extensive reconstructions involving the distal trachea or carina.

Extubation and Postoperative Care

The primary objective is to ensure a safe extubation in the operating room, as prolonged intubation may compromise the integrity of the anastomotic line.[31] Several strategies are recommended to achieve this. First, upon completion of reconstruction, bronchoscopy should be performed for airway clearance and anastomosis inspection, followed by an anastomosis leak test using 20–30 cm H_2O positive airway pressure while immersing the anastomosed trachea in saline.[29,32] Secondly, to prevent neck extension and straining during extubation, muscle relaxants should be gradually tapered, adequate analgesia ensured, and, if necessary, a propofol infusion considered.[29] Finally, when extubation is performed, the patient's head should be elevated at a 45° angle with guardian sutures in place to minimize neck hyperextension and reduce tension on the anastomosis.[8,12]

Postoperative intensive care unit monitoring is required to detect complications such as respiratory failure, anastomotic breakdown, and airway edema. Regular blood gas analysis combined with clinical monitoring is essential during the first 24 hours postoperatively. Multimodal analgesia should be applied to help prevent delirium and respiratory depression. Pulmonary care with humidified oxygen, chest physiotherapy, and nebulization helps prevent atelectasis and infections.[8]

If reintubation is required, it should be performed using a flexible bronchoscope (FOB) to prevent injury to the fresh anastomosis.[12] Preoperatively, patients should be informed about the importance of avoiding abrupt neck extension, maintaining head flexion, and the presence of guardian sutures in the postoperative period.[15]

For subsequent operations, avoiding intubation is recommended whenever possible. However, if intubation is necessary for the surgery, an FOB should be used to ensure accurate tube placement and assess the distal airway. Due to the shortened trachea, the risk of endobronchial intubation is increased, and confirming tube position may be challenging as anatomical landmarks, such as the carina, may become less distinct. Additionally, there is a risk of stenosis at the anastomosis site. To prevent tissue damage and further narrowing, the endotracheal cuff should not be positioned over the anastomotic region.

Conclusion

Successful tracheal resection requires strong teamwork with the surgical team, ensuring seamless collaboration throughout the procedure. Proper patient selection and a tailored, patient-specific approach are crucial for optimizing outcomes. A well-structured plan, including primary and backup strategies, should be in place to handle potential challenges. Detailed preparation of necessary equipment is essential for smooth intraoperative management. Ultimately, the safest method should be chosen based on the team's expertise and confidence in execution, prioritizing patient safety and surgical success.

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