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Breathing Through a Straw: Considerations for Tracheal Stenosis Surgery

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Abstract Tracheal stenosis can be a grave threat to patients' lives. Absent invasive, and temporary, devices available only in intensive care units, the trachea is the only conduit for oxygen entering the body. Repairing tracheal stenosis requires advanced planning by both surgical and anesthesiology teams to ensure safety throughout the procedure. This paper aims to discuss key management highlights of tracheal stenosis from the preoperative stages through completion of surgery.

Keywords Tracheal stenosis · Cross-field ventilation · Extrathoracic tracheal lesion · Jet ventilation · Chin stitch · Airway surgery

Introduction

Surgery directly involving the airway requires a delicate balance between the surgeon, anesthesiologist, and often the intensivist as well. Tracheal surgery is a particularly complex procedure, as it presents challenges at different stages of care, from establishing an airway past the stenotic region, sharing an airway during surgery, to extubation and postoperative care. The surgeon must be immediately available during induction in case the need arises for airway access bypassing the stenotic area or if the patient cannot be successfully intubated or ventilated. These patients, in addition, often require multiple anesthetics, from airway dilatations, to preoperative fiberoptic assessment, and postoperative healing surveillance. This paper aims to review several techniques used for surgeries in patients with tracheal stenosis.

The Evolution of Tracheal Stenosis

Tracheal stenosis is primarily associated with a history of endotracheal intubation, but has several distinct etiologies [1, 2••] including tumor growth and inflammatory autoimmune diseases. The causes of tracheal stenosis can be broadly classified into congenital, idiopathic, and acquired. Acquired tracheal stenosis is, far and away, the most represented category in adults, and is usually the result of tracheal trauma of some variety, with the majority of cases resulting from endotracheal intubation [3] with associated factors including length of intubation, endotracheal cuff pressure, movement of the endotracheal cuff, hypotension, infection, and other comorbid conditions [4]. The symptoms may not be immediately apparent and can even take several weeks, or even months to years following the injury to evolve. Tracheal stenosis develops somewhat slowly as the lumen narrows due to scar formation following an episode of mucosal ischemia in predisposed individuals. Most adults do not become significantly symptomatic until the tracheal lumen is reduced to less than 5 mm [5]. Patients who present with stridor or

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unexplained dyspnea after intubation should have tracheal stenosis investigated as a possible cause for their symptoms. As little as 15 min of cuff over-inflation can lead to mucosal ischemia [6].

When significantly symptomatic, tracheal stenosis patients use accessory muscles of respiration for both inspiration and expiration and must breath slowly because peak flow rates are so limited. They can be stridorous, and even dyspneic, sometimes while still at rest. If spirometry is obtained, flow-volume loops will display flattening of both inspiratory and expiratory curves [5]. Of course, many patients may present for surgery without exhibiting all of the above symptoms. For instance, they may come to surgery for serial tracheal dilations guided by subjective changes in symptomatology.

Anatomy

By definition, stenotic lesions in the trachea must occur proximal to the carina and distal to the cricoid cartilage [7]. The blood supply to the trachea is from branches of the inferior thyroid artery proximally, and more distally from branches of bronchial and intercostal arteries [8]. These blood supplies approach the trachea laterally and there is no independent anterior or posterior blood supply, it comes only from end arteries supplying each ring segment off of the lateral supplies [9••]. Blood supply can be interrupted by surgical dissection, thus circumferential dissection must be avoided [5]. Finally, both the right and left recurrent laryngeal nerves run posteriolaterally to the trachea in the groove between it and the esophagus [7] and are also at risk during surgical dissection.

Evaluation and Workup

A patient with stridor at rest, especially if intubated for any length of time in the reasonably recent past, should be evaluated for tracheal stenosis. Exertional dyspnea is also a red flag, even in the absence of stridor [5]. Tracheal stenosis should be expected in patients with asthma diagnosed as adults that is medically refractory to treatment. These patients are often treated with beta agonists and inhaled steroids prior to being correctly diagnosed.

Once tracheal stenosis is suspected, there are a variety of modalities that can give more data and ultimately lead to diagnosis. Spirometry will show a decrease in peak expiratory flow rates, and flattened inspiratory and expiratory curves [5]. Spirometry findings are, however, only one view into the pathology and the findings are shared with any other entity that compresses the trachea, including extra-tracheal masses. PFTs are, however, quite useful as an initial step in a patient that may need thoracic surgery for pulmonary indications [10]. In addition, though more subtle, spirometry can be useful to diagnose post-stenosis airway pathology, such as underlying bronchial airway reactivity, which can be helpful in managing the patient during and after surgery [11].

Old radiographic methods such as filtered linear radiographs and tomograms are not widely available despite some surgeons who are keen on them [12]. They have been replaced with more modern studies such as the helical CT scan with 3D reconstruction. Radiographic studies are useful, but are not considered stand-alone studies in preparation for surgery [13]. Flexible bronchoscopy is the diagnostic modality of choice, particularly for post-intubation tracheal stenosis [13]. Flexible bronchoscopy and spiral CT scan both have a prominent role in preoperative preparations. MRI, fluoroscopy, and other techniques target specific disease entities [14]. Rigid bronchoscopy can be used to dilate critically small airways, providing temporary relief of symptoms.

Tracheal stenosis is more common in the extrathoracic trachea. Radiographic studies can localize the lesion well, and bronchoscopy can evaluate dynamic issues during the respiratory cycle. Severity of stenosis is a combined measure that incorporates degree of tracheal narrowing, as well as functional limitations from history and physical exam.

Surgical Interventions

Surgical interventions for tracheal stenosis range from dilation to segmental resection and end-to-end anastomosis. Depending on the location of the stenotic region, the operation may be done by otolaryngologists or, more commonly, by thoracic surgeons.

Dilations, particularly for stenosis immediately below the glottis, are often performed by ENT surgeons. These surgeries involve a combination of dissection, laser ablations, and balloon dilations [15]. Stents are also often placed, generally removable [15]. If the stenosis is sufficiently complex, recurrent, or otherwise not amenable to the above interventions, resection is the definitive therapy. For some patients with lesions below the cricoid cartilage but above the intrathoracic trachea, resection can be the first-line therapy [16].

When a tracheal stenosis must be removed surgically, the resection most commonly consists of removing the stenotic portion of the extrathoracic trachea circumferentially and pulling the intrathoracic trachea up for a primary anastomosis. Ventilation during these surgeries can be complex and the technique will vary based on surgical approach. Below, we will discuss airway management during these different procedures.

Anesthetic Considerations

Preop

Preoperatively, patients need to be assessed for severity of symptoms. Of particular importance is knowing the location of the tracheal stenosis and its minimum diameter, since, whenever possible, it is desirable to intubate the patient past the stenotic segment of trachea. A detailed history and physical exam plus a review of the patient's imaging will answer most questions. Additional questions that can only be known with any certainty on the day of surgery include whether the patient can lie flat, how well they can handle secretions, presence of stridor at rest, or other indicators that the patient will be difficult to manage if supine or unconscious without a secure airway. Stridor at rest, or worse yet, cyanosis to any degree, are harbingers of immanent airway loss [5] and indicate an extreme severity of disease.

Anatomical factors likely to complicate airway management, such as an anterior airway, large tongue, or a history of a known difficult intubation, are no less likely in patients with tracheal stenosis; this can make the anesthetic plan even more complex by potentially eliminating some approaches to intubation such as direct laryngoscopy. This will be discussed more below.

Whether or how much preoperative anxiolysis to give pharmacologically can be a difficult choice. Sedating medications should be held until the patient is in the operating room, and instead the patient should be made comfortable with verbal and mindfulness techniques. Non-pharmacologic anxiolysis, such as cognitive behavioral techniques, remains significantly understudied in adults [17]. Although outside mainstream anesthetic practice, acupressure and acupuncture may transiently reduce preoperative anxiety [18]. Even with specific data lacking, it is commonly observed that calm interactions with patients, particularly using active listening, can provide some level of comfort or at least distraction.

In addition to the preoperative evaluation of the patient's status, a thorough preoperative discussion with the surgery team is also critical. Tracheal stenosis surgeries require the surgeons and anesthesiologists to have a comprehensive joint plan for the sequence of airway management techniques that will be used [5] and, more importantly, to have established good rapport to facilitate easy communication. Tracheal stenosis surgery can be a challenging environment because the patient has an intermittently unsecured airway for a lengthy period of the case; cohesive team communication is essential.

Preoperative preparation for the case should include multiple airway adjuncts, video laryngoscopes, fiberoptic bronchoscopes, endotracheal tubes of multiple sizes, likely as small as 4.0 mm, depending on the size of the stenotic lesion. Arterial lines are routinely placed for monitoring and serial blood gas analysis. Good intravenous access is also critical as both arms are typically tucked for these procedures.

Induction

The approach to induction will be largely guided by the results of the preoperative imaging, history, and physical exam done immediately prior to the procedure. If the patient cannot lie flat, it may be necessary to consider induction with the patient sitting to some degree. Thorough denitrogenation is especially critical in these patients as the airway may take longer to establish. The induction agent is usually propofol, unless patient comorbidities indicate otherwise. Alternately, an inhalational induction using sevoflurane can be considered. Judicious use of short acting opioid such as fentanyl is generally added in small doses. The goal is to have the patient breathing spontaneously for the initial part of the surgery.

Airway Access

Airway access and adequate ventilation are the anesthesiologist's primary concerns at several points during cases involving tracheal surgery. At our institution, we routinely place a laryngeal mask airway (LMA) after induction to facilitate flexible bronchoscopy, which always precedes the surgical repair and has two important goals: sizing the airway at the stenotic area and identifying the exact tracheal location of the lesion. Ventilating through the LMA also assures the anesthesiology team that manual mask ventilation will likely be possible, thus providing useful information for airway management. At this point, we usually paralyze the patient, or increase the depth of anesthetic, then using a video laryngoscope and an appropriately sized endotracheal tube intubate the patient by placing the tip of the ET tube past the stenotic lesion. Often the position of the ET tube, its relation to the stenotic area, carina, and vocal cords is confirmed using fiberoptic bronchoscopy. In terms of ET size selection, it is approximated to the lesion size, but we always try to upsize it to have a larger internal diameter for easier ventilation and to facilitate extubation. Most adult fiberoptic bronchoscopes cannot fit through and ETT less than size 7.0, therefore a pediatric size fiberoptic bronchoscope should be available. If, after induction or after LMA placement, ventilation is not possible or substantially inadequate, the surgeon has to be ready to proceed with a rigid instead of a flexible bronchoscopy.

Maintenance

As a significant portion of the surgery will be done with an open airway, our preference is to provide a steady depth of anesthesia and avoid recall using a total intravenous anesthetic with propofol or dexmedetomidine with remifentanyl. Although volatile agents could be used for portions of these procedures, a complete intravenous approach is generally preferred for simplicity and to avoid operating room contamination [19, 20•]. Remifentanyl is often chosen because of its short duration, ability to suppress the respiratory drive, and blunt responses to tracheobronchial stimulation, but simple intravenous fentanyl could certainly be substituted. We generally keep the patient paralyzed until the anastomotic sutures are secured, since spontaneous breathing can cause the distal section of the trachea to move. However, deep paralysis is often not needed to accomplish this if a remifentanyl infusion is used. It is generally not necessary to give long-acting narcotics, such as hydromorphone, as the postoperative course is generally not very painful. We use fentanyl as the only intermittently dosed opioid to good effect.

Blood loss is not a major factor during tracheal resection, thus an arterial line is generally not placed unless indicated for another reason. Some advocate the use of an arterial line for post-surgical gas-exchange surveillance. In addition, if the surgery is expected to be a sleeve resection involving the carina and the patient will be in the ICU for their postoperative care, the surgeon may request one to be placed for postoperative care. Two peripheral IVs are usually placed—one for the intravenous anesthesia and the other for IV pushes. The arms are tucked for the procedure, so access is limited for placing additional IVs once the surgery has begun.

Cross-Field Ventilation

Cross-field ventilation is a technique wherein a separate, sterilized circuit is placed on the surgical field and the connections to the inspiratory and expiratory limbs of the ventilator are handed to the anesthesiologists for connection to the ventilator. The cross-field circuit should include a sterile gas sampling line so that end-tidal carbon dioxide and oxygen can be measured while it is in use. Once the trachea has been entered surgically, the anesthesiologist replaces the circuit connectors to the initial endotracheal tube placed at the beginning of the case with the cross-field circuit connectors. The surgeon then cannulates the trachea with a fresh, sterile endotracheal tube attached to the cross-field circuit, which is then used to ventilate the patient. We use an armored ET tube for the cross-field circuit because the soft tip is less traumatic to the distal airway and it is less likely to injure the carina. The oral endotracheal tube can then be retracted to facilitate surgical exposure; if possible, it is left distal to the vocal cords. A suture or rubber string can be placed through the Murphy eye of the oral endotracheal tube to help avoid inadvertent extubation.

The cross-field endotracheal tube will be intermittently removed by the surgeon for exposure while the anastomosis sutures are being placed. This will require apneic periods for the patient, which is the preferred method. Although jet ventilation could also be used, it is very rare to do so. During apnea, oxygen saturation is monitored closely and communication between the surgical and anesthesiology teams ensures that ventilation can be resumed in a timely manner, generally when saturations dip below 90 %. Intermittent apnea will be tolerated differently from patient to patient varying with the patient's functional residual capacity (FRC), diffusion capacity, and oxygen consumption, among other factors [19]. In patients who have short apneic periods before desaturation, such as the obese with their significantly reduced FRC, the time can sometimes be lengthened by passive insufflation of oxygen through the oral ET tube from above the surgical site [21]. Because electrocautery is generally not used during cross-field ventilation, FiO_2 of 1.0 can be used during ventilation periods by the anesthesiologist.

As the anastomosis is completed, the original oral ET tube is advanced past the anastomosis site and secured. Its placement is confirmed visually by the surgeon prior to placing the last tracheal sutures, making sure that the ET cuff is distal to the anastomosis. The original circuit is then re-attached to the anesthesia ventilator for the remainder of the case. Cross-field ventilation has been successfully utilized for decades for the anesthetic management of lesions requiring tracheal surgery [22].

Jet Ventilation

The use of jet ventilation is largely reserved for surgeries correcting sub-glottic stenosis. The surgeon will have a metal catheter attached to the rigid bronchoscope used for surgical field exposure to which the anesthesiologist can attach a jet ventilation set-up. Jet ventilation uses bursts of high-pressure oxygen delivered at or just distal to the glottis to refresh the gasses in the lung. Jet ventilation would perhaps better be called "jet oxygenation" as it does keep oxygen available in the large conducting airways for diffusion into alveoli, but it does not ventilate with any great efficiency. Patients being jet ventilated must be able to withstand permissive hypercapnia. Comorbid conditions in which hypercapnia must be avoided, such as pulmonary hypertension, may render this technique too risky for consideration.

Jet ventilation is not generally used for lengthy surgeries but is more commonly encountered for quick cases such as

dilations. Jet ventilation can be high frequency or low frequency. Low-frequency jet ventilation setups can often be put together with just a few pieces of equipment and can be manually operated. High-frequency jet ventilation requires a dedicated device, but can operate around 150 cycles per minute as compared to the 20–30 cycles per minute of a low-frequency technique [23]. Newer techniques such as superimposed high-frequency jet ventilation promise to decrease some of the drawbacks of jet ventilation such as hypercapnia by offering better gas exchange [24]. The more distal the delivery device is in the airway, the greater the risk of barotrauma. Desaturations are usually from inadequate gas exchange, but the risk of pneumothorax should be considered if it is refractory to mask ventilation. The insufflation pressure can be increased, inspiration time can be increased, or the FiO_2 of the gas used for insufflation can be increased [25].

Extubation

Stress on the new suture lines must be minimized, as must any possibility of endotracheal cuff pressure over the anastomosis. Appropriate nausea and vomiting prophylaxis is critical as retching can put undue strain on the suture line. Coughing must also be avoided for the same reasons. If non-depolarizing neuromuscular blockade was used, complete reversal is absolutely necessary to ensure smooth transitioning to spontaneous ventilation and subsequent successful extubation.

The ETT, having been placed beyond the suture line as described above, is safe, but the cuff must be completely deflated so as not to disrupt the anastomotic sutures. The goal is always to extubate following tracheal surgery as both positive pressure ventilation and the presence of an ETT are disadvantageous for anastomotic healing. Lidocaine can be given intravenously 2–3 min before the removal of the ETT to blunt coughing reflexes [26, 27]. A low dose continuous dexmedetomidine infusion can ensure that the patient remains calm during emergence; low dose remifentanyl infusion can also be used. The ETT cuff should be let down and a positive leak test noted immediately prior to extubation. At the end of the surgery, a chin stitch is placed by the surgeon in order to keep the neck flexed. Preoperative patient education about expectations upon emergence is critical [19]. Patients must be informed not only about neck positioning, but that they can have subjective sensations of inadequate breathing even in the presence of reassuring objective data including good oxygenation. Usually, 6 days after surgery, the patient is taken back to the OR for a fiberoptic inspection of the healing process, if it is adequate the chin stitch is removed at this point.

Post-anesthesia Care

A calm and relaxed patient is the most important factor in a successful post-surgical recovery. Educating the patient on what to expect after surgery is critical. The subjective experience of breathing will likely be different, and they may need to be coached through feelings of dyspnea, which may remain in the postoperative phase of recovery due to airway edema. Should bronchospasm occur, direct acting bronchodilators should be given via nebulizer. Racemic epinephrine should also be considered early, especially for postoperative stridor. If the need for re-intubation is imminent, the surgeon should be present and the intubation should be carried out fiberoptically with the ETT cuff beyond the suture line.

Conclusion

Tracheal stenosis surgery is a complex procedure demanding impeccable preparation and excellent, constant communication between the surgeon, anesthesiologist, and operating room staff. Executing the perfect plan for airway control throughout the entire encounter is the key to success. The above review highlights the methods and techniques often used for these patients from evaluation and preparation through execution of the surgery and eventual recovery in the PACU or ICU. If difficulties are anticipated and communication is clear between all those involved, these cases are a rewarding challenge.

Compliance with Ethics Guidelines

Conflict of Interest Nathaniel J. Brown and Ferenc Puskas declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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