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Treatment of Tracheobronchial Injuries
A Contemporary Review

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Tracheobronchial injury is a rare but a potentially high-impact event with significant morbidity and mortality. Common etiologies include blunt or penetrating trauma and iatrogenic injury that might occur during surgery, endotracheal intubation, or bronchoscopy. Early recognition of clinical signs and symptoms can help risk-stratify patients and guide management. In recent years, there has been a paradigm shift in the management of tracheal injury towards minimally invasive modalities, such as endobronchial stent placement. Although there are still some definitive indications for surgery, selected patients who meet traditional surgical criteria as well as those patients who were deemed to be poor surgical candidates can now be managed successfully using minimally invasive techniques. This paradigm shift from surgical to nonsurgical management is promising and should be considered prior to making final management decisions.

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Tracheobronchial injury is a potentially life-threatening clinical scenario. Blunt or penetrating trauma and iatrogenic injury are the most common causes of tracheobronchial injuries[1] (Table 1). Penetrating airway injury can occur from sharp objects, such as knives and ice picks, or from gunshot wounds.[2-5] Iatrogenic airway injury can occur during surgery, endotracheal (ET) intubations, or bronchoscopy.[6-10]

The incidence of airway injury is likely to be underestimated as these injuries are often underrecognized and underreported. The incidence of airway injury is estimated to be 0.005% for all ET intubations.[1] This incidence increases in patients intubated with a double-lumen tube and has been reported to be between 0.05% and 0.19%.[6,11,12] During percutaneous dilatational tracheostomy (PDT) tracheobronchial injury occurs in approximately 1% of cases in the form of posterior tracheal wall perforation.[13] Other causes of tracheobronchial injury include intrathoracic, esophageal, and head and neck surgical interventions including mediastinoscopy.[14-16] Tracheo-esophageal fistula as an intermediate or late complication of open surgical tracheostomy may occur due to incidental intraprocedural damage to the posterior tracheal wall.[17] For esophageal surgeries requiring combined intrathoracic and intraabdominal approaches airway injury

ABBREVIATIONS: ET = endotracheal; PDT = percutaneous dilatational tracheostomy; SEMS = self-expanding metallic stent

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TABLE 1] Etiology of Tracheobronchial Injury

Iatrogenic	Traumatic
1. Endotracheal intubation	1. Penetrating injuries
2. Rigid bronchoscopy	2. Blunt force trauma
3. Tracheobronchial stent removal	
4. Balloon bronchoplasty	
5. EBUS-TBNA, EUS-TBNA	
6. Surgical procedures: • Thoracic • Head and neck • Thyroid	
7. Tracheostomy: Open, PDT	

EBUS = endobronchial ultrasound; EUS = esophageal ultrasound; PDT = percutaneous dilatational tracheostomy; TBNA = transbronchial needle aspiration.

TABLE 2] Risk Factors for Tracheobronchial Injury

1. Mechanical
   - Procedural
     - Inexperience
     - Multiple attempts at intubation
   - Instrumentation
     - Use of a stylet during intubation
     - Incorrect endotracheal tube size
     - Double-lumen tube
     - Poor postintubation treatment
     - High balloon diameter during bronchoplasty
2. Anatomic
   - Congenital tracheal diverticulum
   - Tracheal bronchus
   - Tracheal distortion: Airway or mediastinal neoplasms
   - Age > 65 y
   - Female sex
   - Tracheal inflammation
   - Use of inhaled corticosteroids
   - Mounier-Kuhn syndrome

occurs in approximately 1% to 1.8% of cases.[18] Tracheal necrosis could also occur due to excessive use of cautery on or around the trachea during thyroidectomy. Tracheobronchial injury may occur during rigid bronchoscopy, but the incidence is unknown.[19] Airway injury related to endobronchial and esophageal ultrasound-guided transbronchial needle aspiration is extremely rare.[20-22] Tracheobronchial mucosal laceration during balloon dilation for benign strictures may occur in almost one-half of cases, yet rarely extends transmurally.[23] Self-expandable metal stent placement and removal can be complicated by airway laceration, bleeding, stent migration, and stent fracture among others.[24-26]

Here we describe risk factors, clinical manifestations, and the present-day treatment of tracheobronchial injuries. We also aim to highlight the advance treatment of poor surgical candidates with tracheobronchial injuries.

Risk Factors

Risk factors for tracheobronchial injury can be categorized as mechanical and anatomic (Table 2).[1-7,11,12,27-31] Of these, the most important modifiable risk factors are procedural or instrumentation related. These risk factors can be addressed by appropriate education about airway treatment. In a systematic review involving 182 patients, Miñambres et al[1] found that being female, older than 65 years of age, and emergency intubations were the most important nonmodifiable risk factors.[1,31]

Anatomic risk factors include congenital abnormalities (eg, congenital tracheal diverticula, Mounier-Kuhn syndrome, tracheal distortion by mediastinal or endobronchial masses) and may or may not be known prior to endobronchial procedures. Prior radiographic and bronchoscopic imaging data if available should be reviewed and may alert the proceduralist to preexisting anatomic variations. Other factors that might weaken the membranous portion of the trachea include chronic inhaled corticosteroids, advanced age, and inflammation due to tracheobronchitis and should be considered while planning any tracheobronchial procedures.

Manifestations of Tracheobronchial Injury

Clinical presentation of iatrogenic or traumatic tracheobronchial injuries can be nonspecific irrespective of the etiology. Typical findings in the setting of tracheobronchial injury can be subcutaneous emphysema, pneumomediastinum, and pneumothorax.[7,32,33] Acute respiratory failure can also occur, but the diagnosis could be difficult in patients with preexisting respiratory failure. On occasion, hemoptysis,[34] pneumoperitoneum (if the air dissects the fascial layers into the abdomen)[35] or pneumopericardium, angina, and shock have been reported.[1] Chronologically, tracheobronchial injury may produce symptoms immediately or in a delayed fashion following extubation or manipulation of the ET tube. Delayed presentation may occur in intubated patients if the ET tube cuff overlies the tracheal tear and prevents air from leaking into the mediastinum.[36] One should

consider tracheobronchial injury in the differential diagnosis of a patient who develops acute respiratory distress immediately following extubation.

Diagnosis of Tracheobronchial Injury

A high degree of clinical suspicion, CT imaging, and bronchoscopy, in that order, can help diagnose tracheal injury. Radiographic imaging may reveal pneumomediastinum, subcutaneous emphysema, pneumothorax, or the tracheal tear itself[37,38] (Fig 1). Bronchoscopy remains the "gold standard" for the diagnosis of tracheal injury. Bronchoscopy not only helps in identifying the exact location and size of the injury but may also help in treatment of the injury.[39,40] In endotracheally intubated patients the ET cuff may cover the injured portion of the trachea and hinder assessment of the extent of tracheal injury. For this reason such patients usually receive diagnoses of tracheal injury only after extubation. In cases with a high suspicion of tracheal injury, the cuff may be deflated during bronchoscopic evaluation and manipulated to visualize the tracheal injury and to assess its extent and severity. In the event of a complete laceration of the tracheal wall, it is important to assess for concomitant esophageal injury. This may require upper gastroenterologic endoscopy and/or CT chest imaging with oral contrast to identify esophageal leak and pneumomediastinum.[41] Acute mediastinitis can be diagnosed on chest CT imaging with signs such as increased attenuation of the mediastinal fat pad and mediastinal fluid collection.[42]

Location and Types of Tracheobronchial Injury

The anterior trachea, including the cartilage, or the ligamentous portions between the tracheal rings, are most commonly injured during penetrating trauma.[37] Most traumatic tracheobronchial injuries take place within 2.5 cm of the carina, and mainstem bronchial injuries comprise more than 85% of these injuries.[43] The most frequent cause of penetrating tracheobronchial injuries is gunshot wounds. These injuries could occur in any region of the respiratory tract.[44] Patients with gunshot wounds to the lower one-third of the trachea usually suffer from fatal injuries to the heart or great vessels and die before reaching trauma centers.[45] ET intubation-related iatrogenic injury tends to be a longitudinal tear involving the membranous portion of both the cervical and intrathoracic segments of the trachea.[37] On the other hand, injury due to ET tube cuff overinflation occurs predominantly in the proximal trachea.[6,11]

In a prospective study involving adult patients with postintubation tracheobronchial laceration, Cardillo et al[46] proposed a morphologic classification (Table 3, Figs 2 and 3). The purpose of this classification based on the depth of tracheal wall injury was to help standardize its treatment.

Treatment of Tracheobronchial Injury

Treatment of tracheobronchial injury in most instances needs to be individualized, based on the patient's comorbidities, clinical presentation, and anatomy of the

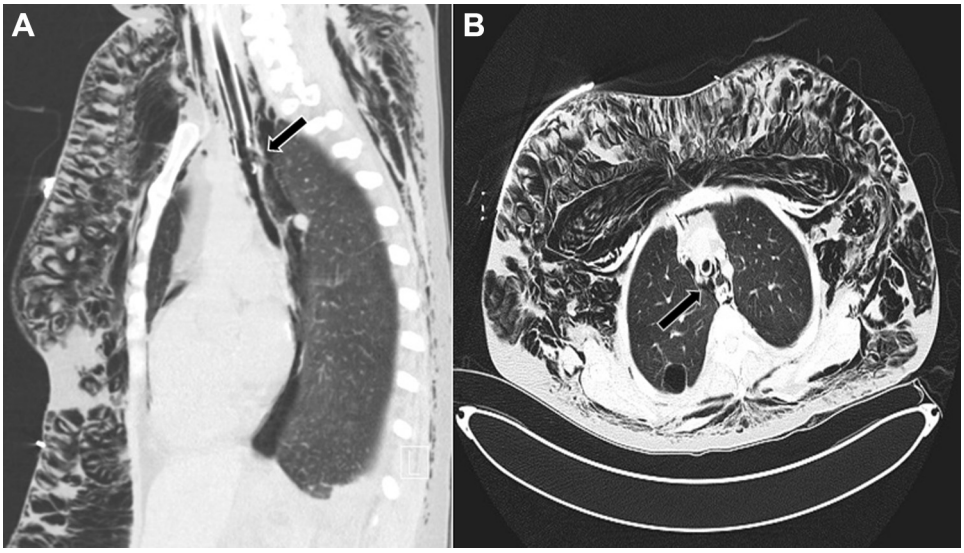

Figure 1 – *A and B, Example of endotracheal intubation-related airway injury with full-thickness posterior membranous tear (arrow) complicated by pneumomediastinum on a sagittal reformatted CT image (A), andsubcutaneous emphysema on an axial CT image (B).*

TABLE 3] Tracheal Wall Injury: Morphologic Classification

Level I
Mucosal or submucosal injury without mediastinal emphysema and esophageal injury
Level II
Lesion extending to the muscular wall with subcutaneous or mediastinal emphysema without esophageal injury or mediastinitis
Level IIIA
Complete laceration with esophageal or mediastinal soft-tissue herniation without esophageal injury or mediastinitis
Level IIIB
Any laceration with esophageal injury or mediastinitis

Modified with permission from Cardillo et al.[46]

tracheobronchial injury. For superficial tracheobronchial injuries (level I) conservative treatment with follow-up bronchoscopy is preferred.[7] In tracheobronchial injuries involving the mucosal layer with subcutaneous or mediastinal emphysema (level II injuries), patients are usually treated on a case-by-case basis. The role of prophylactic antibiotics remains unclear because of the lack of evidence. In this regard, most studies have not distinguished level II from level III injuries. Treatment has been described on the basis of clinical presentation and extent of tracheobronchial injury rather than the depth of the injury.[1,11,25,26,35,36,39-41]

Patients with tracheobronchial injuries with either mediastinal, soft tissue, or esophageal involvement (level III injuries) require multidisciplinary evaluation to determine which patients need emergency vs modern minimally invasive approaches such as airway stent deployment.[24,47,48] The best outcome can be achieved with a multidisciplinary approach inclusive of critical care, surgery, and interventional pulmonary teams.

Patients with acute respiratory failure, or acute decompensation after extubation, may require reintubation under bronchoscopic guidance to place the cuff of the endotracheal tube beyond the site of the injury. Bronchoscopy is essential to prevent the formation of a false track or worsening the extent the tracheal tear.[49] If a patient fails mechanical ventilatory support because of the underlying injury, advanced life support with extracorporeal membrane oxygenation may be required as a bridge to recovery[50] and/or definitive surgical intervention[51-54] (Fig 4).

Surgical Treatment

There are no specific guidelines regarding the surgical treatment of tracheobronchial injury. Traditionally, most experts have agreed that patients with tracheal tears longer than 4 cm in length and those who deteriorate clinically should be treated surgically (Table 4).[33,39,55,56] In a retrospective study of tracheobronchial injuries, 39 of 50 patients had iatrogenic injury; of these 30 patients were treated by open surgical repair while the rest were treated conservatively. The authors concluded that surgery should be the primary mode of treatment for postiatrogenic airway injury, and only in a selected minority should conservative therapy be used.[57] In a retrospective case series involving 11 patients with

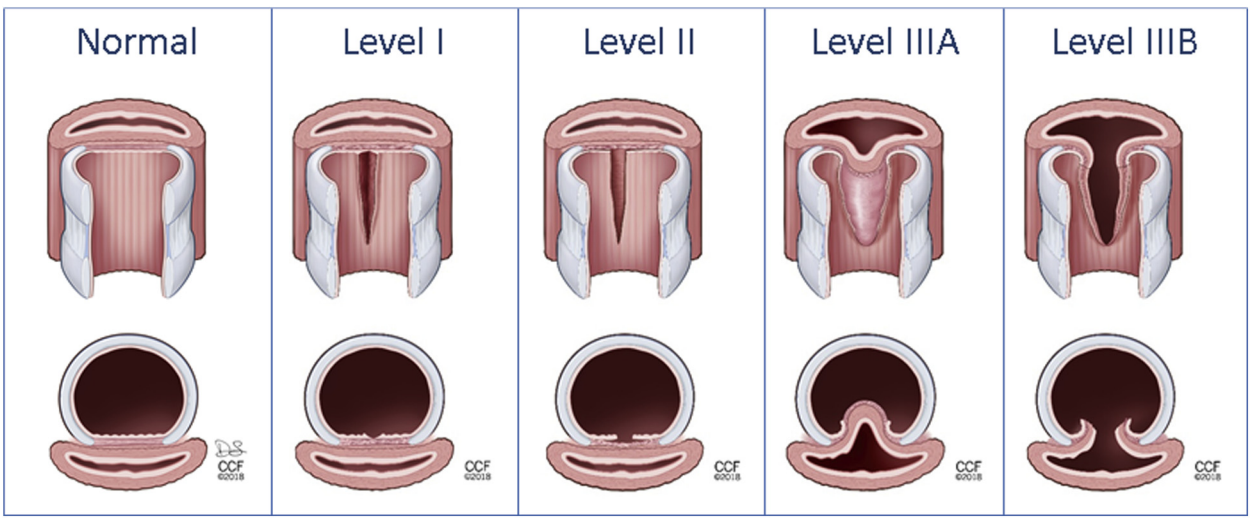

Figure 2 – *Morphologic classification of tracheal injury as reported in Table 3. (Images designed by illustrator David Schumick. Image created at the Cleveland Clinic, Cleveland, OH.)*

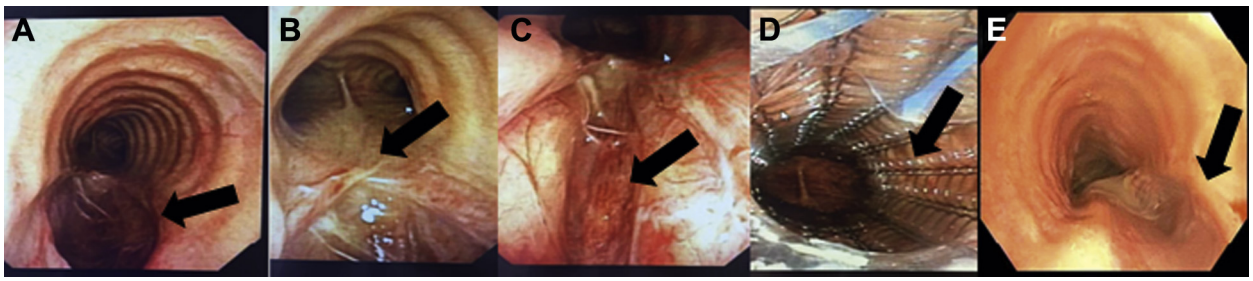

Figure 3 – *Example of level IIIA injury in a case of iatrogenic tracheal injury with full-thickness longitudinal tear in the trachea of the membranous portion (A, arrow) extending to just above the carina (B, arrow); mediastinal soft-tissue structures can be visualized (C, arrow) and treated with self-expanding metallic tracheal stent placement (D, arrow) with complete healing (E, arrow) after removal of the stent.*

iatrogenic tracheobronchial injury nine underwent primary surgical repair. There was no difference in mortality or morbidity between surgical vs conservative treatment.[58]

In patients who have worsening subcutaneous emphysema, pneumomediastinum, pneumothorax, development of persistent air leak, and/or failure of lung reexpansion despite chest tube placement, emergency surgical treatment is required. Other indications for emergency surgical treatment include esophageal wall prolapse into the tracheal lumen, and/or ineffective mechanical ventilation in the setting of tracheobronchial injury distal to the placement of the ET tube. We could apply the classification developed by Cardillo et al[46] for tracheobronchial injury due to ET intubations to other forms of iatrogenic injury. Based on this classification surgical treatment is indicated for level IIIA and IIIB injuries.

When a tracheal tear is detected intraoperatively during cardiothoracic surgery, it is best to treat it surgically.[1,11,50] The surgical approach depends on a variety of factors including location of the tracheal injury, whether it is in the proximal one-third to two-thirds vs distal one-third of the trachea extending to the main bronchus; and the presence or absence of

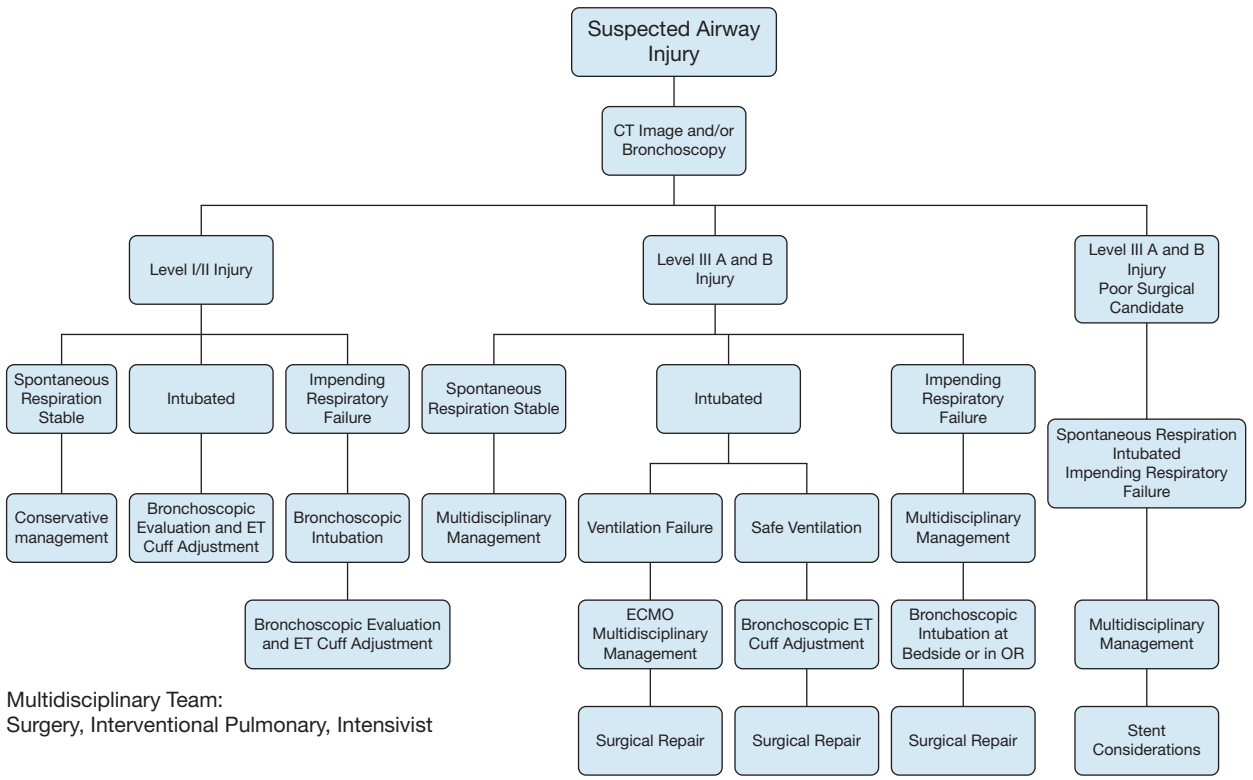

Figure 4 – *Algorithmic approach for contemporary treatment of tracheobronchial injuries. ECMO = extracorporeal membrane oxygenation; OR = operating room.*

TABLE 4] Indications for Conservative and Surgical Treatment of Tracheobronchial Injury

Conservative
• Spontaneously breathing patients
• Minimal mechanical ventilation
• No evidence of esophageal or mediastinal compromise
Surgical indications after failure of conservative treatment
• Worsening subcutaneous emphysema
• Progressive pneumomediastinum
• Pneumothorax with persistent air leak
• Pneumothorax with failure of lung reexpansion despite chest tube placement
Emergency surgical indications
• Esophageal wall prolapses into the tracheobronchial lumen
• Failure to ventilate
• Intraoperative diagnosis of tracheobronchial injury[a]

[a]Not an emergency but should be repaired intraoperatively.

concomitant vascular injury or injury to adjacent organs. For each surgical approach it is important to gain excellent exposure to examine the surrounding vessels for injury.

Surgical approaches range from a right thoracotomy as a more traditional approach, a transcervical approach first described by Angelillo-Mackinlay[59] in 1995, and a more recent combined transcervical-transtracheal approach that includes a tracheal T-shaped incision.[60] If tracheal injury involves the proximal one-third to two-thirds then the tear can be repaired via cervicotomy. A low cervical collar incision is made that provides excellent exposure to examine vascular or esophageal injuries.[61] This approach is preferred because of its efficacy and minimal invasiveness.[32,62]

If the middle one-third of the trachea is injured, then the manubrium may need to be split, using a T incision, to examine any concomitant vascular injury. This can be used instead of a median sternotomy. Injuries of the left mainstem bronchus are most easily approached through a left thoracotomy. Tracheobronchial injury in the lower one-third of the trachea extending to the carina, main bronchus, or just a few centimeters beyond the carina will need a right thoracotomy with or without a cervicotomy. The extensive thoracosternotomy or bilateral thoracosternotomy or "clamshell" incision described in penetrating trauma tracheobronchial injury is usually not needed for iatrogenic injuries.

In a case series of 11 patients, Mussi et al[62] described successful surgical repair in nine patients. They used a modification of the transcervical approach first described by Angelillo-Mackinlay. In the original transcervical repair, Angelillo-Mackinlay[59] described a cervical mediastinoscopy-like approach by making a vertical incision in the anterior wall of the trachea.

Nonsurgical Treatment

Patients with airway injuries (levels I and II) and who are clinically stable, that is, breathing spontaneously, or those who require minimal ventilator support and have tracheal tears less than or equal to 2 cm, should be considered for nonsurgical treatment (Table 4).[1,11,32,41,63] Other suggested criteria for conservative treatment include the following: absence of esophageal injury, minimal mediastinal air, and nonprogressive pneumomediastinum or subcutaneous emphysema.[41] Previously it was unclear whether patients with tracheal tears between 2 and 4 cm should be treated surgically or conservatively. This can be better determined now and based on the anatomy, clinical status, comorbidities, and on-site expertise.

Clinical parameters that should be assessed periodically in this population include stability of subcutaneous emphysema and stable respiratory status (eg, continued spontaneous ventilation or mechanical ventilation without difficulties). For patients receiving mechanical ventilation, one must ensure that the ET tube cuff is positioned distal to the site of injury with bronchoscopic guidance. In cases of tracheal tear extending to the carina, single lung ventilation can be attempted with selective intubation of left or right mainstem bronchus. Ventilator management should include minimizing airway pressures and positive end-expiratory pressure.[39] Eroglu et al[64] described a case of endoscopic primary repair of severe injury to the posterior tracheal wall through a preexisting tracheal stoma under direct visualization through a fiberoptic telescope. If there is concomitant esophageal injury, oral intake and placement of nasogastric/orogastric feeding tubes should be avoided to allow healing and to prevent aspiration of food particles. These patients will require temporary percutaneous gastrostomy tube placement for nutrition. Also, broad-spectrum prophylactic antibiotics should be instituted for at least 1 week or longer.[27,41,57,63]

Treatment of Poor Surgical Candidates

Patients who are deemed to be at high surgical risk due to comorbidities or the severity of the underlying disease can now be treated by minimally invasive techniques. Temporary placement of a covered self-expanding metallic stent (SEMS) could offer some advantages under these circumstances (Fig 3). First, the stent will

mechanically obstruct the tracheal defect. Second, there may be an exuberant inflammatory response with granulation tissue formation that could potentially augment closure of the tracheal defect. A SEMS can also hold more complex shapes down the length of the trachea or bronchi. Such contouring is difficult to achieve with silicone stents (Fig 3). The principle behind this approach is similar to that used in the treatment of tracheobronchial dehiscence following lung transplantation. Tracheal stent placement can be used successfully even in cases that would have been historically treated via a surgical approach.[47,48,65,66] After 4 to 6 weeks of adequate healing these stents can be removed.[24,67-71] The complications associated with long-term stent placement for tracheal injury repair are similar to those for other indications. These include, but are not limited to, infection, stent migration, metal fatigue, granulation tissue formation leading to tracheal stenosis, and mucus plugging.[67,72-75] Hence, these stents should be removed as soon as healing of the tear is noted. Rarely, replacement of a fresh stent may be required because of overwhelming granulation tissue formation compromising the stent's patency and safe removal. In poor surgical candidates, benefits of minimally invasive interventional techniques appear to far outweigh the risk of complications. There have been reports of successful placement of multiple SEMSs or silicone Y-stents in patients with injury that extends beyond the trachea.[47] In cases where a tracheostomy is part of the injury it may be difficult or impossible to place a stent since it may lead to closure of the tracheal stoma.

We prefer a SEMS when possible given several theoretical advantages as highlighted above, which should be balanced by potential risks of injury on removal. A covered stent is typically preferred and will be required if there is a persistent air leak or worsening subcutaneous emphysema. We recommend that these patients be evaluated at high-volume centers on a case-by-case basis for appropriate patient and procedure selection.

Prevention of Tracheobronchial Injury

Injury to the tracheobronchial tree may not be preventable in the setting of blunt or penetrating trauma. However, in cases of iatrogenic injury, prevention is the key. Appropriate training for practitioners who perform endotracheal intubation can help prevent multiple failed attempts. It is well known that the difficulty of intubation increases with each unsuccessful attempt and predicts failure on subsequent attempts.[76] Appropriate training and education of support staff, including respiratory therapists and nurses, regarding preparation of the ET tube; stylet positioning; and proper maintenance of the ET tube, including deflation of the cuff prior to tube repositioning or manipulation, are mandatory. The stylet should never extend beyond the tip of the ET tube during intubation to prevent trauma to the upper airways as well as the posterior tracheal wall. Appropriate use of muscle relaxants and sedation prior to the intubation should facilitate the procedure and prevent any injury.

Surgical procedure-specific training, risk factor assessment for airway injury, and preoperative planning on how to deal with any inadvertent airway injury should be developed by the surgical and anesthesia teams. In patients undergoing esophagectomy for cancer, preoperative bronchoscopy should be performed to look for evidence of tracheal invasion by the tumor for surgical planning.[18] Judicious use of cautery to prevent injury in and around the trachea in head and neck surgeries may help prevent tracheal necrosis.

The American College of Chest Physicians, American Thoracic Society, and European Respiratory Society have made recommendations for appropriate training in performing bronchoscopy. These recommendations include the type of training and minimum number of procedures required to gain and maintain competency in performing bronchoscopy. Adherence to such recommendations could help in preventing tracheobronchial injuries.[77] Tracheobronchial injury during placement and removal of SEMSs can be prevented by careful radiographic and/or bronchoscopic assessment of the tracheobronchial anatomy.[24-26] Prior to performing balloon bronchoplasty for airway stenosis, practitioners must review radiographic images to carefully determine the length of stenosis, select appropriate candidates and preplan the procedure to minimize complications.[78]

In cases of PDT appropriate patient selection is a key. A bedside checklist similar to an operating room check should be used for patients undergoing bronchoscopy-guided PDT to help reduce complications.[79] Bronchoscopic guidance can help prevent airway injury by facilitating correct median puncture of the trachea and appropriate withdrawal of the endotracheal tube.[80] Iatrogenic tracheobronchial injury is preventable, and the incidence can be reduced by appropriate procedure-specific training and patient selection.

Prognosis

The prognosis for the patient with tracheobronchial injury depends on various factors related to the underlying clinical status of the patient, the extent of tracheobronchial injury, and the type of repair. Miñambres et al[1] indicated that although tracheobronchial injury is more common among females, males tend to have a higher risk of mortality. In their study, the overall mortality was 22% (n = 40/182), but this was felt to be due to the underlying cause for respiratory failure rather than being directly related to the tracheobronchial injury.[1] Superimposed mediastinitis increases mortality.[1] For patients with a delayed diagnosis of tracheobronchial injury and undergoing surgical repair, mortality rises twofold. This mortality can be as high as 70% in critically ill patients, especially when surgical repair is needed.[39,81]

Patients may need long-term follow-up for complications due to the initial injury and therapeutic interventions such as dilatation of post-tracheal injury stenosis. Therefore, these patients should be monitored closely until resolution of the symptoms and complete healing of the injury is confirmed. It is also associated with a significant increase in health care costs accrued both during the index admission and during subsequent hospitalizations required to treat the injury.[82]

Conclusion

Tracheobronchial injury may not be as rare as previously reported. It occurs infrequently but remains a high-impact event with significant morbidity and mortality. Injuries that were historically treated by surgical repair can now be successfully treated via careful multidisciplinary patient selection for interventional pulmonology techniques at centers of excellence. This is a promising treatment strategy and should be considered prior to surgical treatment; especially in patients who do not meet absolute indications for surgery or who are high-risk surgical candidates.

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