Traumatic injuries to the trachea and bronchi: a narrative review

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Objective: In this narrative review, we aim to provide a definition of traumatic tracheo-bronchial injuries as well as an approach to their diagnosis and management, including operative and non-operative strategies.

Background: Traumatic tracheo-bronchial injuries are relatively uncommon, but are associated with a high mortality, both at the scene and among patients who survive to hospital. Management often requires an emergency airway, usually intubation over a flexible bronchoscope, followed by definitive repair.

Methods: The published literature on the diagnosis and management of traumatic airway injuries was searched through PubMed. Additional references were identified from the bibliography of relevant publications identified. The evidence was then summarized in a narrative fashion, incorporating the authors' knowledge, experience, and perspective on the topic.

Conclusions: Definitive diagnosis of traumatic tracheo-bronchial injuries usually involves direct visualization through liberal use of bronchoscopy in addition to cross-sectional imaging to evaluate for associated injuries, notably to the great vessels and esophagus. Important considerations for management include concerns for airway obstruction, uncontrolled air leak, and mediastinitis. Early repair of injuries recognized acutely is favored in attempts to prevent the development of airway stenosis. Key operative principles include exposure, conservative debridement to preserve length when possible, creation of a tension-free anastomosis, preservation of the blood supply, and creation of a tracheostomy, particularly in polytrauma patients. An interposition muscle flap is also required, specifically in the setting of combined esophageal and airway injuries. Patients with penetrating injuries tend to have more favorable outcomes, possibly on account of fewer concomitant injuries. Selective non-operative management is also an option in the subset of patients with iatrogenic injuries to the posterior membranous wall of the trachea, and includes broad-spectrum antibiotics and surveillance bronchoscopy.

Keywords: Trachea; bronchus; trauma; blunt; penetrating

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Introduction

Traumatic tracheobronchial injuries (TBIs) present diagnostic and therapeutic dilemmas that require rapid management in order to prevent significant morbidity and mortality. Although not straightforward, the presence of these injuries can be identified by practitioners having a high index of suspicion and by evaluation of appropriate radiographic studies and clinical adjuncts. Management should be expeditious, with vigilance to measure success of intervention. We present a narrative review of the topic for better understanding of this complex injury pattern. We present the following article in accordance with the Narrative Review reporting checklist (available at https://med.amegroups.com/article/view/10.21037/med-21-21/rc).

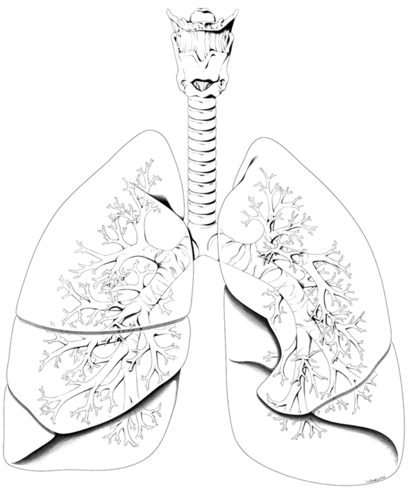

Figure 1 Schematic representation of the tracheobronchial tree.

Definition

Anatomically, TBIs encompass the larynx, trachea, primary carina, and mainstem bronchi to where they bifurcate into lobar or secondary bronchi (*Figure 1*). They can further be divided into upper and lower airway, with the larynx and cervical trachea constituting the former and the thoracic trachea and mainstem bronchi the latter (1-4). The intra-thoracic tracheobronchial tree is typically protected from injury by rigid surrounding structures, including the sternum, rib cage, and thoracic spine, and its intrinsic elasticity also provides an additional level of protection from injury. Nevertheless, both penetrating trauma and significant blunt forces can lead to disruption of these structures with potentially fatal clinical consequences.

Incidence and importance

Traumatic TBIs are relatively uncommon, with a incidence of 2% to 3% among patients with cervical or thoracic trauma, including patients who die at the scene, and an incidence of 0.5% to 0.9% among all patients evaluated in the trauma bay (4,5). Eighty percent of patients with blunt TBIs die at the scene, with a, at best, 9% overall mortality among all those who survive to hospital, although mortality rates between 20% and 40% are more commonly quoted (2,6). In a recent 40-year retrospective review of traumatic airway injuries managed at a level 1 urban trauma center in Canada, Madani *et al.* identified hemodynamic instability, Glasgow Coma Scale (GCS) less than 8 on arrival, and the presence of any head trauma as predictors of in-hospital mortality (7). The need for an emergency airway on arrival was also found to independently predict higher risk of fatal outcome (1,2). Cricoid and thyroid fractures were found to be associated with vocal cord injury during follow-up (7).

Another important category of traumatic TBIs includes those incurred during procedures, such as endotracheal intubation and balloon inflation, tracheostomy creation with inadvertent injury to the posterior membranous trachea, as well as during surgery, specifically during esophageal surgery (8-11). The incidence of these iatrogenic injuries ranges from 0.005% for routine single-lumen endotracheal intubation to 0.05% for double-lumen intubation to 0.2% for tracheostomy creation, and to as high at 1% during emergency airway procedures (11-13). Lastly, the tracheobronchial tree can also be injured by other mechanisms, including inhalation and caustic injuries (4). The remainder of this review will not specifically address inhalational and/or chemical TBIs and will focus on injuries found within the thoracic cavity.

Mechanism of injury

TBIs can result from either penetrating or blunt trauma, as well as from iatrogenic etiologies. Injuries caused by either mechanism can broadly be divided into cervical (larynx, vocal cords, and cervical trachea) and thoracic injuries (thoracic trachea, carina, and mainstem bronchi), with cervical injuries representing between 75% and 84% of all TBIs in one series (7,14).

Penetrating injuries are more common than blunt ones, with relative incidences of 4.5 and 0.5% to 2% of all penetrating and blunt trauma respectively (1). Due to the relatively exposed location of the upper airway in the neck, penetrating cervical injuries lead to a TBI more frequently (3% to 6%) than do penetrating thoracic injuries (1% to 2%) (4). Penetrating cervical TBIs also come to clinical attention more frequently than their intra-thoracic counterparts, and this is true of both gunshot (GSW) and stab wounds (4). One possible explanation for this observation is the fact that transthoracic GSWs tend to cause more immediate fatalities than do stab wounds due to associated great vessel or cardiac trauma (15). Moreover, stab wounds are less commonly of sufficient depth to reach the intra-thoracic tracheobronchial tree, such that airway injuries from stab wounds are more often encountered in a cervical location. In general, stab wounds cause either puncture-type injuries or linear lacerations, in contrast with GSWs, which can result in significantly greater tissue loss (4,14).

Blunt TBIs are less common, with a reported incidence between 0.5% and 2%. Although some reports have found a predominance of cervical airway injuries with blunt trauma (1), others have found blunt airway injuries to more commonly occur at the level of the intra-thoracic tracheobronchial tree, and more specifically at the level of the carina and mainstem bronchi within 2.5 cm of the carina in 62% to 75% of these cases (4,6,14,16-18). Injuries can include transverse (in 75% of cases) or longitudinal (18%) tears, which can be partial or complete, as well as complex combined injuries including both cartilage fractures and dislocations and airway avulsion and tears (10,14).

Blunt intra-thoracic TBIs can occur after either a high-energy impact or a direct impact of lesser energy. Three principal mechanisms have been identified that can disrupt the intra-thoracic tracheobronchial tree. First, high-velocity antero-posterior crush injuries to the chest wall can cause abrupt displacement of intra-thoracic contents and result in TBI from the lateral traction exerted by the mobile lungs on the relatively immobile tracheobronchial tree. Additionally, injuries that crush the intra-thoracic airway between the sternum and vertebral column can cause an abrupt increase in airway pressure which, combined with a closed glottis, can lead to airway rupture. This rupture usually occurs at membrano-cartilaginous junctions or between cartilaginous tracheal rings. Finally, deceleration injuries occur from shear stress at tethered points along tubes. The cricoid and carina represent such points along the tracheobronchial tree and, as such, are particularly vulnerable to this type of injury (4,14,16). As mentioned earlier, an injury at the tracheal bifurcation is often accompanied by disruption of a mainstem bronchus and, due to its anatomy, the right mainstem bronchus appears to be most at risk (6,16,19).

Similarly, blunt injuries of the cervical trachea are usually the result of combined deceleration and neck hyperextension followed by a blunt anterior compressive force, with either one of these mechanisms in isolation also sufficient to cause significant tracheal injury. The thyroid and cricoid cartilages are most prone to fractures, with lacerations occurring at the level of the cervical trachea itself, usually below the fourth tracheal ring, at the junction of membranous and cartilaginous elements (18). Examples of such injuries include high-riding seatbelt injuries, high-speed motor vehicle crashes (MVCs) followed by impact with the dashboard, steering wheel, or front seat, high-speed snowmobile encounters with clotheslines, weightlifting accidents, and hockey puck blows to the neck (4).

Patients with blunt TBIs typically have higher Injury Severity Score (ISS) on presentation and worse outcomes, including higher mortality, likely on account of the significant force required to disrupt the intra-thoracic tracheobronchial tree and associated injuries resulting from this high energy transfer (1). Between 40% and 100% of patients have associated orthopedic injuries, with pulmonary contusions, intra-abdominal or pelvic injuries, and facial fractures present in half of these patients as well (4,6,17). Conversely, penetrating airway injuries are typically seen in conjunction with esophageal and vascular injuries in 25% to 59% of cases in a cervical location and in 50% to 80% of cases in an intra-thoracic location (4,6,7,10,17). Regardless of mechanism, lower traumatic airway injuries usually portend a poorer prognosis than upper airway injuries, which likely reflects a combination of timely recognition and easier accessibility of both the upper airway and extra-thoracic vascular and digestive structures, as well as severity of injuries associated with lower TBIs (1).

As previously mentioned, iatrogenic tracheal injuries usually result either from endotracheal intubation or inadvertent overinflation of the endotracheal tube balloon (10). The former usually presents as a longitudinal tear of the membranous trachea, both in its cervical and thoracic location, whereas the latter generally affects the proximal trachea primarily (11). Iatrogenic trauma can also occur at the time of tracheostomy creation, whether this is done in an open fashion or percutaneously, with laceration of the posterior membranous trachea (10). Other instances when TBIs can occur include procedures such as rigid bronchoscopy, removal of endobronchial stents, and dilatation of bronchial strictures (11). Finally, TBI can also occur at the time of esophageal surgery, due to proximity of the airway and esophagus. Risk factors that have been identified for this type of injury include older age, presence of a proximal tumor, presence of squamous cell carcinoma, and neoadjuvant chemoradiation (8). The management of iatrogenic TBIs follows the same principles outlined below with the exception that it typically requires either operative or interventional techniques with stent placement (11,20-22). Iatrogenic injuries are often preventable, and appropriate training as well as meticulous technique are paramount to avoid the sequelae of the injury itself and of the ensuing intervention (23).

Clinical presentation

Clinical presentation can range from subtle signs and

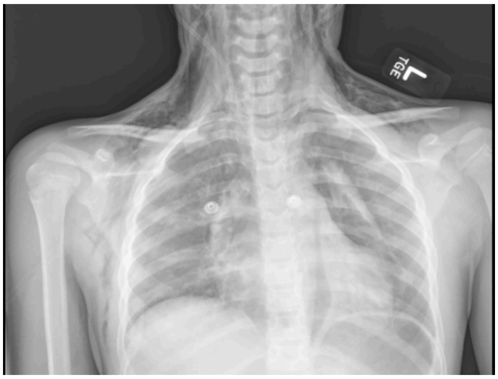

Figure 2 Extensive subcutaneous emphysema and pneumomediastinum, suggestive of an airway injury.

symptoms to life-threatening airway obstruction or tension pneumothorax. Injuries are also generally more apparent after a penetrating mechanism, thus requiring a high level of clinical suspicion for detection in the context of blunt trauma.

Signs and symptoms that should be identified during the primary survey vary in reported frequency in the literature. However, they classically include stridor, air moving through the wound (in up to 60% of patients), subcutaneous emphysema, and hemoptysis (hard signs) as well as voice changes, dysphonia or aphonia, cough, and hoarseness, which is present in up to 85% of patients with cervical tracheal trauma and can indicate either direct laryngeal trauma, vocal cord trauma, or recurrent laryngeal nerve involvement (soft signs) (4,10,24). An interesting variant of subcutaneous emphysema is mediastinal emphysema, which can theoretically be identified by auscultating for Hamman's sign (defined as a mediastinal crunching sound synchronous with the patient's heartbeat) and can also lead to vocal changes in the non-intubated patient (24). In the setting of penetrating injury, the presence of hard signs typically prompts operative exploration, whereas the presence of soft signs allows for additional diagnostic testing. With blunt injury, additional diagnostic testing is indicated the vast majority of the time. Importantly, between 25% and a third of cervical airway injuries are asymptomatic upon initial evaluation and can become more apparent over the next 24 to 48 hours, which is in contrast to thoracic airway injuries, which more significantly affect lung mechanics and result in more obvious difficulty with oxygenation and ventilation (7,10).

The chest X-ray (CXR) is usually inherent to the evaluation of the patient in the trauma bay and can provide additional information. A pneumothorax can be identified in up to 70% of cases and, together with subcutaneous emphysema (present in 35% to 85% of cases), is highly suspicious for blunt tracheobronchial disruption (4). For penetrating injuries, bubbling through the wound that ceases after endotracheal intubation is also very suggestive of significant proximal TBI, and care must be taken to avoid inflating the endotracheal tube cuff exactly at the site of injury (4,24). Interestingly, both a pneumothorax that persists and one that does not resolve despite adequate tube thoracostomy drainage can be indicative of a TBI, with mediastinal soft tissue buttressing the injury and potentially leading to a ball-valve effect in the latter case (6). Moreover, a patient who experiences worsening hypoxia with the chest tube to suction rather than to water seal should also be suspected of having a major TBI (4).

Definitive diagnosis requires a combination of clinical suspicion about the presence and likely location of the injury and imaging modalities to confirm the clinical impression and define the injury.

Imaging modalities

Signs and symptoms of TBI or high clinical suspicion based on the mechanism and pattern of injuries should prompt further diagnostic work-up. CXR and computed tomography (CT) of the neck and chest are useful modalities in this setting, but the gold standard for diagnosis of traumatic TBIs remains fiberoptic bronchoscopy with direct visualization of the airway and injury.

CXR

CXR is abnormal in 80% to 90% of patients with TBI (17,24) and can readily identify the presence of pneumothorax (in 70% of cases), pneumomediastinum (in 60% of cases), and subcutaneous emphysema (*Figure 2*), all highly suggestive of an intra-thoracic airway injury (4,10,14). The "fallen lung sign of Kumpe" is another characteristic finding, wherein a pneumothorax is associated with a lung that is collapsed in a dependent position, away from rather than toward the hilum as well as towards the diaphragm and posteriorly (24). This sign raises concern for a complete mainstem bronchus transection, as does the "absent hilum sign (4,6,18,19)". Importantly, when there is near-complete airway transection but the adventitia remains intact, the typical radiographic findings indicative of an air leak may not be clearly apparent, and a high level of suspicion along with direct visualization of the airway remain paramount to making the diagnosis (18). Extra-thoracic cervical

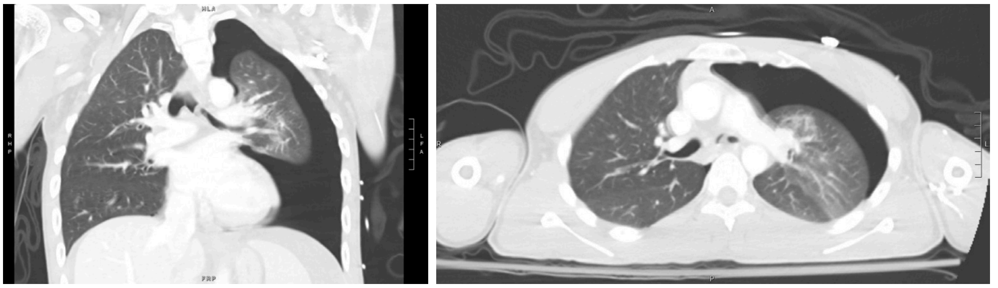

Figure 3 (CY7810 CT CAP from 10/10/2020). Curvilinear endoluminal filling defect within left mainstem bronchus with associated bronchial wall step-off, concerning for left mainstem bronchial injury. Moderate to large left-sided pneumothorax. CT, computed tomography; CAP, chest, abdomen and pelvis.

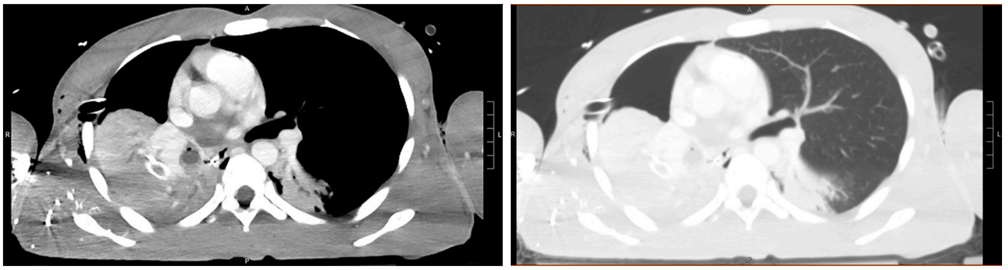

Figure 4 (D2816898 CT CAP from 07/05/2020). Large right pneumothorax with complete collapse of the right lung and rightward shift of the mediastinum. Fluid within the right mainstem bronchus and distal airways is suggestive of hemorrhage. A locule of air adjacent to the right mainstem bronchus raises the possibility of bronchial injury. CT, computed tomography; CAP, chest, abdomen and pelvis.

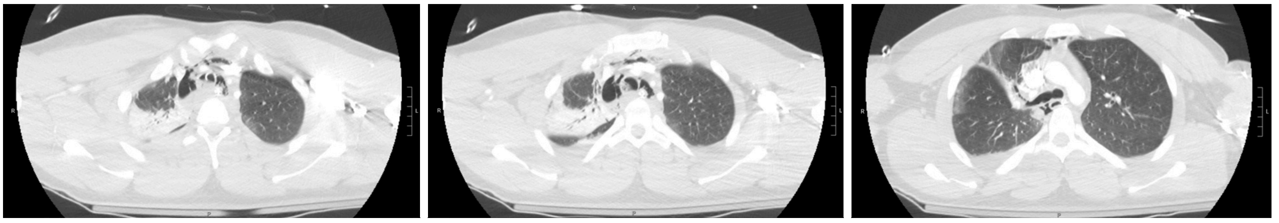

Figure 5 (CC8805 CT CAP from 02/03/2020). Gas seen around the trachea and right mainstem bronchus, suggestive of a tracheal injury. Extensive pneumomediastinum extending into the superior neck. CT, computed tomography; CAP, chest, abdomen and pelvis.

airway injuries may also not demonstrate such marked pneumomediastinum or pneumothorax, but CXR or cervical spine X-ray may reveal deep cervical emphysema (4,14). Occasionally, one might also be able to actually appreciate disruption of the normal anatomic air column, which can also point towards the presence of a TBI (4).

CT

In patients who are stable and with a secure airway, CT of the neck and chest with iv contrast can be helpful, perhaps even more so for laryngeal trauma than for thoracic TBI (24). CT can delineate the airway injury itself and identify associated neck and truncal injuries, as well as establish the trajectory of the missile in the setting of penetrating trauma. Associated injuries include but are not limited to sternal fractures, mediastinal hematomas and pneumomediastinum, vascular injuries, and pneumopericardium, and may require separate surgical management (4,6,10,18). CT findings suggestive of TBI include bronchial step-offs (*Figure 3*), fluid within the bronchial tree and locules of air outside the airway (*Figures 4,5*), and pneumomediastinum, pneumopericardium, and/or pneumothorax (*Figure 6*). More

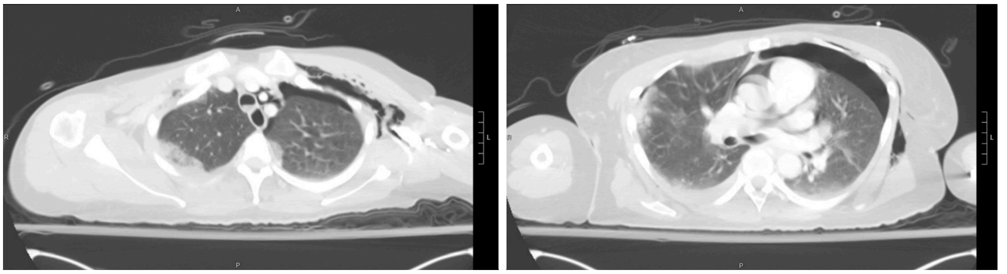

Figure 6 (M96857 CT CAP from 12/26/2019). Extensive subcutaneous emphysema within the neck and anterior chest wall, moderate left pneumothorax, pneumomediastinum, and pneumopericardium. Air-fluid level within the trachea. Respiratory motion artifact limits evaluation of the trachea and esophagus. Esophagogram and bronchoscopy recommended. CT, computed tomography; CAP, chest, abdomen and pelvis.

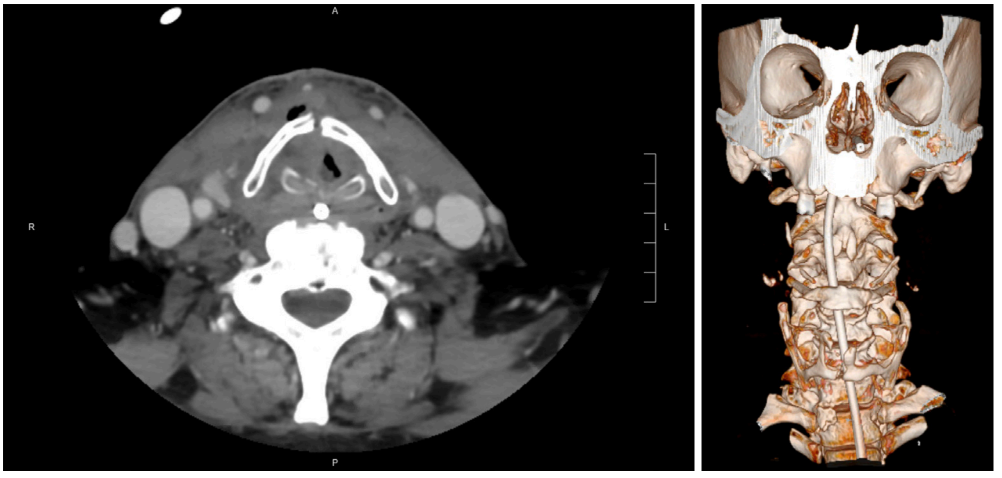

Figure 7 (D2900552 CT neck soft tissue from 1/11/2021). Displaced fracture of the thyroid cartilage and cricoid, with associated air within the soft tissues. This patient also had numerous other comminuted and displaced fractures of the trachea, including displaced fractures of the hyoid bone and arytenoid cartilage. The tracheal rings were not discretely visualized, and the airway appeared effaced. Pneumomediastinum was also noted. CT, computed tomography.

proximal injuries of the trachea itself can be identified as direct fractures of the thyroid cartilage or cricoid (*Figure 7*) and discontinuity of both the anterior cartilaginous and/or posterior membranous trachea (*Figure 8*). Other CT findings suggestive of a TBI include abnormal elevation of the hyoid bone, superior to its expected anatomical position at C3 (which occurs only with complete or near-complete tracheal transection), an overinflated endotracheal tube cuff (28 mm rather than the upper limit of normal 25 mm in men and 21 mm in women) sitting outside the normal outline of the trachea, as well as air within the wall of the trachea or mainstem bronchi (18,19,24). Care must be taken to recognize the possible presence of the so-called Macklin effect (*Figure 9*), when alveolar rupture leads to atelectasis and air tracking along the bronchi and into the mediastinum, indicative of a much more distal injury than the trachea or mainstem bronchi. Bronchoscopy is useful in making a definitive diagnosis in these instances and remains the gold standard for all TBI, and especially for more distal airway injuries that may be less well defined on CT (4,6). Despite a CT that may be negative for TBI, bronchoscopy generally remains indicated to definitively rule-out these injuries (4). Over time, technology has evolved such that multi-detector CT (MDCT) is standard of care today. Compared to single-detector CT, it provides better quality images, may pin-point location of injury, and is faster, both in data acquisition and reconstruction, making it possible to rapidly and accurately "pan scan" hemodynamically normal trauma patients (18,24).

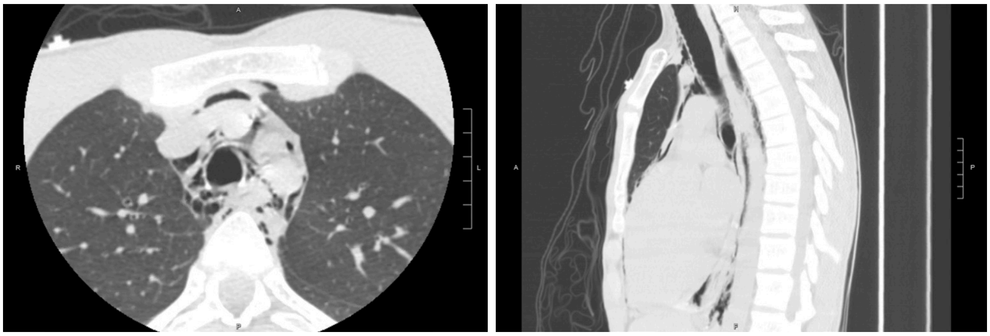

Figure 8 (X54999 CT airway protocol 02/15/2017). There is apparent discontinuity of both the anterior cartilaginous and posterior membranous trachea at the level of the arch vessels with associated extensive mediastinal emphysema. Direct visualization of the airway is recommended to exclude injury. CT, computed tomography.

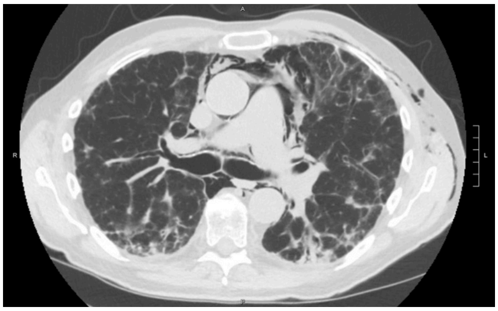

Figure 9 (KS4308 CT chest 01/18/2021). New pneumomediastinum tracking up into the neck and along left lateral chest wall. Findings likely represent ruptured alveoli with subsequent Macklin effect. CT, computed tomography.

In the context of very proximal (laryngotracheal) trauma, the combination of CT and flexible fiberoptic laryngoscopy is recommended, once again emphasizing the importance of direct visualization of the airway in addition to cross-sectional imaging (2).

Bronchoscopy

Concern for existing or impending airway compromise, from edema or from the injury itself, often makes securing the airway of utmost importance early in the evaluation of patients with suspected TBI (10). This can generally be accomplished in the standard fashion, using direct or video laryngoscopy to visualize the larynx and vocal cords. So-called blind intubations are not acceptable given the potential to further disrupt the airway and cause complete obstruction (2). In a review of all patients presenting to a level 1 urban trauma center with traumatic airway injuries over a 16-year period, Kummer *et al.* found that establishing a definitive airway required either placing an endotracheal tube through the wound, obtaining a surgical airway (cricothyroidotomy), or performing an awake intubation in 30% of their patients (1). Awake endotracheal or nasotracheal intubation over a flexible fiberoptic bronchoscope is often the preferred procedure in these cases, allowing not only successful airway management but also direct visualization of the injury and delineation of its extent (6,7,14). Awake intubations over a flexible bronchoscope have several advantages. They typically do not require extension of the head and neck, thus preventing further disruption of the injured airway and also protecting the cervical spine, which is not infrequently injured in patients with cervical airway trauma. They can also be performed without sedation or paralysis, which is particularly useful in the patient at imminent risk of losing their airway (4,14).

Beyond its role during awake intubations, the flexible bronchoscope can also be used for mainstem intubations or to guide placement of bronchial blockers as needed to protect distal tracheal injuries or injuries at the level of the carina or mainstem bronchus (6,7,14). In the patient who is already intubated, it may be necessary to withdraw the endotracheal tube to allow adequate visualization of a more proximal injury (4,25,26). This remains somewhat controversial and should only be performed in a controlled setting such as the operating room, over a fiberoptic bronchoscope to maintain access, by physicians experienced in advanced airway techniques. Its excellent optics despite its small diameter and flexibility also make it the most appropriate tool to evaluate the distal segmental and subsegmental airways. This being said, it may not always be possible to fully delineate the site and extent of injury, with blood and debris and the inability to visualize the airway beyond the injury then serving as clues to a significant TBI (14,24). Minor trauma may also be missed on bronchoscopy, which nevertheless remains the gold standard in the setting of suspected TBI. Bronchoscopy can be performed by an experienced Anesthesiologist, Thoracic Surgeon, or Trauma Surgeon, taking great care not to further disrupt the injured airway. Whether in the context of obtaining an urgent or emergent airway, or more electively to evaluate the tracheobronchial tree along its length, flexible bronchoscopy remains instrumental in the evaluation of patients with suspected TBI and is highly accurate, sensitive, and specific (7,27).

CT bronchography

A newer modality that deserves mention is CT bronchography, also known as virtual bronchography (VB). In essence, this is a three-dimensional reconstruction of the tracheobronchial tree from CT-generated images. Adequate reconstructions require breath-holding and are susceptible to motion artifact as well as being operator-dependent. Thus far, VB has primarily been studied in non-traumatic tracheobronchial pathology, where it was found to have pooled sensitivity of 84% and specificity of 75%. As such, VB may be most valuable when CT is obtained to evaluate for other injuries and there is high suspicion for TBI (4,24,28).

Additional diagnostic studies

Finally, due to the high proportion of patients with associated esophageal injuries, particularly in the setting of penetrating trauma, contrast esophagography and/or esophagogastroduodenoscopy (EGD) should generally be performed as well (4). In isolation, either of these modalities can have up to 20% false negative rate. Combined however, the sensitivity for detecting clinically significant esophageal injuries is nearly 100%.

Indications for intervention

Management of TBIs ranges from surgical to endoscopic to conservative.

Securing the airway while minimizing risk to worsen injury is paramount and remains the highest initial priority, with the decision to intervene depending on the patient's clinical status, the presence or absence of absolute indications, and the extent of tissue loss, devitalization, and edema. Absolute indications include the presence of a massive hemothorax or air leak that does not resolve with tube thoracostomy, as well as involvement of greater than a third of the airway circumference or the presence of a defect greater than two centimeters (7,16,24). Given the infrequent occurrence of TBIs and the multidisciplinary approach to diagnosis and management as well as the potential morbidity and mortality associated with missed injuries and complications from repair, these are best managed in high-volume centers.

Non-operative management

Non-operative management may be considered for TBI for injuries that are less than 4cm in length, involve less than one-third of the circumference of the trachea, have wound edges that are well opposed and do not present devitalized tissue (23). It is imperative to ensure that this management is considered only when the patient is hemodynamically stable, without signs of sepsis and without an associated esophageal, arterial, or other concomitant neck injury requiring repair. Elective intubation is not a requirement in stable tracheobronchial injury. When necessary, intubation should be performed with great care in order to minimize risk of expanding a partial disruption or completing the injury to a complete transection. A non-operative approach can be used in patients on mechanical ventilation provided they meet appropriate criteria as described above and no evidence of difficulty with mechanical ventilation, development of subcutaneous or mediastinal emphysema (23-27). The conservative approach comprises humidified air, voice rest, neck flexion, antibiotics, proton pump inhibitors, and repeat interval bronchoscopy. Patients can be discharged upon evidence of healing during interval bronchoscopy and followed up on an outpatient basis at 2 weeks interval for another confirmatory bronchoscopy (23,24,27). Lower tracheal injuries with pleural communication need the placement of thoracostomy tube to alleviate pneumothorax.

Tracheal stenting can be instituted at centers of expertise, when primary repair needs to be delayed owing to the extent of concomitant injuries, lack of local expertise and resources requiring patient transfer among others (28). A covered expandable metallic stent can be inserted into the airway and an endotracheal tube (or if appropriate a tracheostomy tube) can be positioned to lie within the stent using a fiber-optic bronchoscope. The fiber-optic bronchoscope is passed through the endotracheal tube or the tracheostomy tube and is then inserted into the stent allowing for the definitive airway to be placed with confidence into the center of

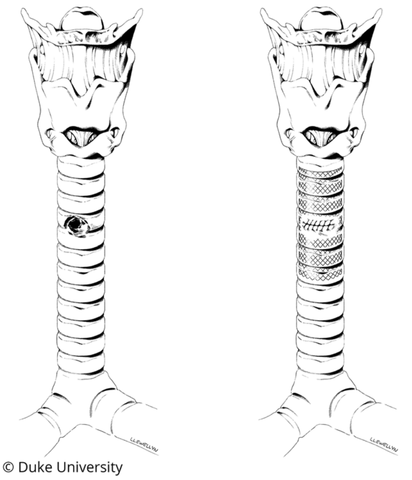

Figure 10 Schematic representation of endotracheal/endobronchial stent.

the stent under direct visualization. Bronchial toilet is essential and antibiotic therapy is prescribed to provide prophylaxis against, or to treat inter-current, infection. The recommendations vary based on the type of stent used; varying in material and type, including silicone, tungsten to being covered, un-covered or hybrid. Laryngeal stent is another useful adjunct during supra-hyoid release and reconstruction of the proximal trachea with or without larynx. Despite their increased use, stents are mostly used for temporizing injuries until definitive surgical management is possible (28-30) (*Figure 10*).

Operative considerations

For unstable patients and those that do not meet the criteria for non-operative management, an operative approach needs to be taken. The operative technique primarily depends on the location, severity and grade of injury, associated injuries and patient's hemodynamic status. Initially, a wide prep of the patient should be undertaken: covering the patient's neck and extending inferiorly to the entire thoraco-abdominal region. In patients with blunt injury whose respiratory status is not emergently compromised careful endobronchial intubation to the healthy bronchus using a single lumen or double lumen endotracheal tube should be undertaken, taking care to not disrupt a partial injury into a complete one and attempting to place the tip of the endotracheal tube distal to the injury. This should preferably be done in the operating room with instruments for emergent tracheostomy and thoracotomy on stand-by, should the intubation become unsuccessful or worsen the patient's condition. In that scenario, we recommend emergent cricothyroidotomy, or tracheostomy if a laryngeal injury exists, through a generous incision. We strongly recommend against debridement or attempts at converting the injury to tracheostomy before a stable airway can be established. Only after a secure airway has been established, and under controlled conditions, should debridement occur and conversion to an elective tracheostomy be undertaken, as necessary. Furthermore, primary repair of the injury and tracheostomy creation at a near proximal location so that the tube tip is located distal to injury is recommended.

The operative incision will depend on the level of injury. In adults approximately 50% of the proximal tracheal length cephalad can be accessed through cervical incision. The incision is usually made about 2 cm above the suprasternal notch in a transverse fashion and deeper layers are dissected to expose the trachea, upon visualization of the trachea, an assessment of the degree of injury and adequacy of exposure is determined, if the injury extends caudad, a median sternotomy, or right thoracotomy, might be required. Once optimal exposure is obtained, debridement of injured tissue is judiciously performed before repair. For lacerations with viable tissue, simple interrupted absorbable monofilament sutures should be placed with knot on the external surface of the trachea should be done when the anterior cartilaginous portions are involved. However, when the posterior membranous surface of the trachea is injured, this can be repaired with either interrupted or running absorbable suture.

For large injuries or injuries with devitalized tissue requiring extensive debridement, resection and reconstruction is the procedure of choice. While some experts advocate that up to half the length of trachea can be safely resected and reconstructed, this might not be true of all patients as anatomy can vary based of their overall body habitus (31-34). Resecting greater than 5 cm of trachea for immediate reconstruction may require specialized techniques in order to allow for re-approximation with minimal tension. Maneuvers such as suprahyoid release and mobilization of the right hilum, together with division of the pericardium around the right hilum, may achieve up to an additional 2.5 cm of mobilization of the proximal and distal ends of the trachea (31,35-37).

Careful examination to rule out concomitant injuries, especially that of the esophagus or adjacent arterial structures is critical with injuries involving lateral and

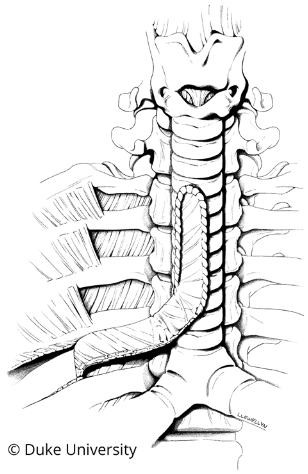

Figure 11 Schematic representation of surgical repair of tracheal injury with interposed intercostal muscle flap.

posterior membranous trachea. If there is esophageal injury, we recommend primary repair when feasible with placement of an interposition muscular buttress; using strap muscles in the neck or intercostal muscle in the chest. Primary repair of esophagus requires identification of the extent of mucosal injury by longitudinal esophageal myotomy. After identification and debridement, primary repair is accomplished over a 40- or 46-F Maloney bougie, the mucosal tear is repaired with interrupted 4-0 absorbable suture, and the muscularis is reapproximated with a running or interrupted 3-0 suture followed by buttress. The cavity is then irrigated and drain placed. There is no need for drain placement in isolated tracheal injuries to the neck. Post-operative neck flexion can prevent undue tension of the repair/reconstruction and aid in healing.

For injuries occurring in the distal trachea up to about 2 cm from the carina depending upon patient habitus, a median sternotomy is recommended. Injuries involving the carina, proximal left main bronchus and right main bronchus are best exposed through a right postero-lateral thoracotomy performed in either the right 4^{th} or 5^{th} intercostal space with patient in a semi-recumbent position. Intercostal muscle flap should be harvested prior to placement of the rib retractors in order to allow for the ease of continuity of procedure. Similar principles are applied for repair of the carina or bronchus with debridement, assessment, direct repair or resection and reconstruction with intercostal muscle flap to buttress (*Figure 11*). Papaverine could be used to enhance the blood flow of the flap by up to 60% in some cases if required, however, its routine use is not recommended. Careful exam of distal injuries should be performed to rule out, as well as prevent, broncho-pleural fistulas which might result in morbidity requiring repeated operative intervention. Extensive injuries involving the distal bronchi may require lobectomy instead of reconstructive attempts. Injuries beyond the proximal left primary bronchus will require left postero-lateral thoracotomy for adequate exposure and repair.

Upon completion of repair, placement the endotracheal/endobronchial tube distal to the injury will avoid direct positive pressure ventilation on the repair during immediate perioperative period facilitating healing. Other options include dual lung ventilation and extracorporeal life support during the immediate postoperative period (38). Chest tubes and mediastinal tube will be placed based on the operative incision and location.

Despite appropriate imaging at presentation, smaller TBIs can be missed initially, particularly in the context of more apparently life-threatening injuries, such as vascular or neurosurgical injuries. Unexplained persistent pneumothorax, pneumomediastinum, subcutaneous emphysema, or difficulty with ventilation or oxygenation should prompt further work-up, with bronchoscopy as the preferred diagnostic modality (6). In the first month after trauma, missed injuries of the trachea or bronchi lead to formation of granulation tissue and possibly strictures. When stenosis occurs at the level of the trachea, this may manifest as stridor and dyspnea, whereas bronchial stenosis can present with wheezing and post-obstructive pneumonia. CXR, CT, and bronchoscopy then become useful modalities to make the diagnosis (4). In order to minimize these morbidities, rapidly identifying and thoughtfully treating these injuries remains an issue of extreme importance. As injuries to the trachea and bronchi are relatively rare, and can be difficult to identify, high degrees of suspicion and constant vigilance are necessary to effectively treat this malady.

Conclusions

In this narrative review, we defined the entity of traumatic injury to the trachea and bronchi and highlighted its importance despite its relatively low incidence. Mechanisms of injury, including penetrating, blunt, and iatrogenic, were presented. The clinical presentation, including but not limited to voice changes, subcutaneous emphysema, and stridor was also introduced and evidence-based recommendations for appropriate imaging modalities were made. Most patients will get a CXR in the trauma bay, however direct visualization of the injury with a bronchoscope as well as cross-sectional imaging (CT) to identify associated injuries remain a necessity in the approach to the patient with suspected TBI. Management can occasionally be conservative, but is generally either operative or interventional. Operative repair follows the of key principles of thoughtful choice of incision and exposure, conservative debridement to healthy mucosa, creation of a tension-free anastomosis, preservation of the blood supply, interposition of healthy tissue in the face of combined injuries, and creation of a tracheostomy. Penetrating injuries and those recognized and repaired promptly have more favorable outcomes, underscoring the importance of a streamlined approach and management in a center with experience in such complex injuries.

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