Tracheobronchial Injuries

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Objectives: At the completion of this module fellows will be able to

1. **Explain the initial management of a patient with a tracheobronchial injury**
2. **Describe the diagnostic approach for tracheobronchial injuries**
3. **Discuss the surgical exposure and technique for repair of tracheobronchial injuries**

Introduction:

- Tracheobronchial injuries are uncommon but potentially lethal.
- Tracheobronchial injuries may result from:
  - blunt or penetrating trauma.
  - iatrogenic trauma following endotracheal intubation or tracheostomy.
- Most patients with tracheobronchial injuries will die before reaching the hospital due to airway obstruction or associated injuries.
- Traumatic tracheobronchial injuries are frequently associated with significant tissue disruption or associated injuries, mandating surgical intervention and repair.
- Iatrogenic tracheobronchial injuries less frequently involve the esophagus or significant tissue disruption; in appropriate, defined settings they may be managed with nonoperative treatment.
- Due to variation in mechanism of injury and management, traumatic and iatrogenic injuries will be discussed separately.

TRAUMATIC TRACHEOBRONCHIAL INJURIES

Background:

- Blunt trauma tracheobronchial injuries most commonly occur in the distal thoracic trachea or mainstem bronchi, with roughly ¾ of injuries occurring within 2.5 cm of the carina. Blunt thoracic tracheal injuries (usually after a motor vehicle crash) may occur by one of three mechanisms:
  - A sudden increase in the airway pressure when the glottis is closed leads to tracheal perforation or rupture of the main bronchi.
  - Extensive anteroposterior chest compression forces the lungs apart laterally, causing distention and rupture of central airway structures near the carina.
  - Rapid deceleration with shearing force applied to the fixed portions of the trachea at the junctions to the cricoid or the carina causes rupture of the mobile portions of the trachea.
- Blunt injuries may also occur in the neck from a direct blow to the cervical trachea.
- The unprotected cervical trachea is most commonly injured portion of the trachea following penetrating trauma.
  - Penetrating neck injuries have a 3-6% incidence of cervical tracheal injuries
  - <1% of penetrating chest injuries have a thoracic tracheobronchial injury

- Associated injuries are the rule with tracheobronchial injuries. After penetrating trauma, there should be a high index of suspicion for associated major vascular injury as well as esophageal injury.

Initial Management:

Cervical tracheal injury

- Maintaining and/or establishing a secure airway is the first priority for any patient with a suspected cervical tracheal injury. Any patient with a compromised airway should have a definitive airway placed in the emergency department.
- A patient with a cervical tracheal injury by definition has a difficult airway and appropriate steps should be taken to gather all necessary equipment and expert personnel prior to intubation.
- Although rapid sequence intubation is the method of choice for securing a definitive airway, several factors should be considered:
  - A partial airway obstruction may be transformed into a complete airway obstruction with an uncontrolled airway intervention.
  - The endotracheal tube may pass through the tracheal wound leading to a false passage and loss of airway. Fiberoptic intubation may avoid this complication.
  - If there is an open wound and obvious tracheal injury on physical exam, an endotracheal tube may be placed directly into the trachea through the anterior neck wound.
  - Once intubated, the endotracheal tube should be advanced and the balloon inflated past the point of injury.
  - A surgical airway may be required and necessary equipment should be readily available.
- Patients with hard signs of aerodigestive injury to the neck (air escaping from a wound) should be taken directly to the operating room for exploration. Otherwise patients may follow the diagnostic approach described below.

Thoracic tracheobronchial injury

- Maintaining and/or establishing a secure airway is the first priority for any patient with a suspected tracheobronchial injury. However, endotracheal intubation and positive pressure ventilation may exacerbate a thoracic tracheobronchial injury.
- Most patients with a thoracic tracheobronchial injury will present with a right sided or bilateral pneumothorax. A pneumothorax should be treated with a tube thoracostomy, however several additional factors should be considered:
  - After tube thoracostomy placement a large air leak is common.
  - Tube thoracostomy placement may not completely resolve a pneumothorax.

Diagnostic Approach

Cervical tracheal injury

- Cervical tracheal injuries are easier to diagnose due to the superficial location of the trachea in the anterior neck.
- Clinical signs associated with a cervical tracheal injury include:

  - air escaping from a neck wound (typically after penetrating trauma)
  - hemoptysis
  - stridor
  - bruising or swelling of the neck
  - subcutaneous emphysema
  - dysphagia
  - dyspnea, tachypnea, or respiratory distress
- A chest radiograph (CXR) is the initial diagnostic test of choice and may display subcutaneous emphysema (Figure 1), pneumothorax, or pneumomediastinum.
- A computed tomographic (CT) scan of the neck will show the same findings as a CXR but may also reveal paratracheal air and deep cervical emphysema.
- Bronchoscopy is the diagnostic test of choice for cervical tracheal injuries:
  - If the patient has not been endotracheally intubated and is cooperative, an awake bronchoscopy with sedation and topical anesthetic may be considered, but is not mandatory.
  - If the patient has been endotracheally intubated, then under bronchoscopic guidance the endotracheal tube will need to be carefully withdrawn enough to visualize the injury.
- Some cervical tracheal injuries are discovered at the time of neck exploration when patients present with hard signs of aerodigestive injury (air escaping from a wound) or hard signs of vascular injury and are taken directly to the operating room from the emergency department.

Thoracic tracheobronchial injury

- Thoracic tracheobronchial injuries may be more difficult to diagnose due to the relatively protected position of the trachea within the mediastinum.
- Clinical findings associated with tracheobronchial injury include:
  - hemoptysis
  - stridor
  - subcutaneous emphysema (often very significant)
  - persistent lung atelectasis or pneumothorax, despite adequate drainage
  - dyspnea, tachypnea, or respiratory distress
- A CXR is the initial diagnostic test of choice and may display subcutaneous emphysema, pneumothorax, or pneumomediastinum.
- If a tube thoracostomy has been placed for treatment of pneumothorax, a thoracic tracheobronchial may manifest a large, persistent air leak or by persistence of a pneumothorax despite adequate chest tube placement.
- A CT scan of the chest (Figure 2) will show same findings as a CXR but may also reveal paratracheal air, persistent pneumothorax after chest tube placement, deep thoracic emphysema, or a specific site of airway disruption.
- Bronchoscopy is the diagnostic test of choice for thoracic tracheobronchial injuries.

Operative Management:

Cervical tracheal injury

- If an endotracheal tube was placed through the wound in the emergency department, an oral endotracheal tube should be placed to allow visualization and direct repair of the tracheal injury.
- Following placement of a secured airway the next immediate priority in the management of cervical tracheal injuries is to address any associated major vascular injury in the neck. Once the vascular injury has been repaired the tracheal injury may be addressed.
- Cervical tracheal injuries are best approached through a low collar incision. If a unilateral or bilateral incision anterior to the sternocleidomastoid was used to treat a vascular injury, this may be extended to a collar incision to assist in visualization of the trachea.
- The trachea can be mobilized along several tracheal rings to assist with visualization and repair of injury, taking care not to injure the esophagus or recurrent laryngeal nerves.
- If needed, a vertical incision from the collar incision down to the sternal notch and an upper sternal split may be added to assist with visualization.
- The tracheal injury should be repaired with a single-layer of interrupted, absorbable suture, preferably with the knots on the outside of the trachea.
- If the injury is destructive, a tracheal resection with mobilization and primary anastomosis may be required.
- If the patient has an anterior tracheal wound the posterior trachea should be explored (either through the anterior wound or directly by rotating the trachea) to rule out a second tracheal injury.
- Patients with a tracheal injury should also have their esophagus explored to rule out concomitant injury. (Figure 3)
    - Upper endoscopy may aid in the identification of an esophageal injury.
    - If there is an associated esophageal injury, a flap of strap muscle or sternocleidomastoid should be rotated and interposed between the tracheal and esophageal repairs to limit subsequent tracheoesophageal fistula formation.
- A tracheostomy is not required for simple tracheal repairs but may be necessary for more complex or destructive injuries.
- A loose stay suture from the chin to the chest, maintaining the neck of the patient in a flexed position can decrease tension in those repairs requiring more than 3 tracheal rings resected, assuming the cervical spine is not injured.

Thoracic tracheobronchial injury

- The majority of thoracic tracheobronchial injuries can be managed through a right posterolateral thoracotomy. This approach will allow access to the distal trachea, carina, right bronchus, and proximal left bronchus. The azygous vein may need to be mobilized or divided to allow adequate visualization.
- A distal left mainstem bronchial injury should be approached via a left posterolateral thoracotomy.
- A proximal thoracic tracheal injury may be approached through a sternotomy down to the level of the aortic arch. The innominate vein may need to be mobilized to allow adequate visualization.
- A double lumen tube is not required and may exacerbate and enlarge the tracheal injury.

- The endotracheal tube should be advanced beyond the injury, or may be mainstemmed into either bronchus to provide single lung ventilation, in order to allow adequate visualization for exposure and repair.
- The tracheal injury should be repaired with interrupted, absorbable suture, preferably with the knots on the outside of the trachea.
- If the injury is destructive, a tracheal or bronchial resection with mobilization and primary anastomosis may be required.
- Bronchial injuries associated with severely distorted lung parenchyma may be managed with an anatomic lung resection, buttressing the bronchial stump with vascularized tissue if feasible.
- If the patient has an anterior tracheal wound the posterior trachea should be explored to rule out a through-and-through injury
- The esophagus should be explored to rule out concomitant injury. Identified esophageal injuries should be managed as previously described for cervical tracheal injuries.

Postoperative Care and Outcomes:

- If the patient's physiology allows, they should be extubated at the end of surgery to remove positive pressure transmission onto the repair.
- If ongoing endotracheal intubation and mechanical ventilation is required then ideally the endotracheal tube balloon should reside distal to the injury
- Mortality after tracheobronchial repair is 6-18% and is usually due to associated injuries.
- Anastomotic dehiscence occurs in 5-6% of patients after tracheobronchial reconstruction.

IATROGENIC TRACHEOBRONCHIAL INJURIES

Background:

- Iatrogenic tracheobronchial injury is a rare direct complication of endotracheal intubation, percutaneous dilatational tracheostomy, and rigid bronchoscopy.
- Nearly 100% of iatrogenic injuries involve tracheal membrane lacerations (TML).
- Iatrogenic TMLs may be associated with an injury to the esophagus, significant mediastinal emphysema, pneumothorax, and subcutaneous emphysema.
- Partial and less severe injuries may be treated with nonoperative management, injuries with significant risk of mediastinitis, air leaks, and esophageal injuries require operative repair.

Diagnostic Approach:

- The presence of subcutaneous or mediastinal emphysema or pneumothorax following endotracheal intubation or percutaneous dilatational tracheostomy should raise the suspicion for a potential tracheobronchial injury.
- Plain radiographic and CT examination of the chest may reveal mediastinal and subcutaneous emphysema, pneumothorax, and enlarged tracheal diameter around the cuff of the endotracheal tube.
- Bronchoscopic evaluation of the trachea and bronchi is the diagnostic test of choice, with simultaneous suction to clear the bronchial system of blood and secretions.

- The endotracheal tube must be adequately withdrawn during bronchoscopy to view the trachea completely.
- Assessment of depth of the injury (i.e. if through the membranous portion of the trachea) and location along the trachea are important for decisions regarding management strategies.

Management of Iatrogenic TMLs:

Nonoperative management

- Some iatrogenic TMLs may be managed nonoperatively.
- Partial thickness and less severe injuries may be treated with nonoperative management
- Injuries with significant risk of mediastinitis, air leaks, and esophageal injuries require operative repair.
- Criteria for nonoperative treatment include:
  - stable vital signs
  - if intubated, no difficulty ventilating the patient
  - if extubated, no respiratory distress
  - absence of esophageal injuries (by bronchoscopy and esophagoscopy or esophagram)
  - minimal mediastinal fluid surrounding the injury
  - nonprogressive mediastinal and/or subcutaneous emphysema demonstrated by serial radiographs or CT scans
  - no signs of sepsis
  - no gaping of the wound during spontaneous breathing
  - no major communication with the mediastinal space demonstrated on bronchoscopy or CT imaging
  - injury less than 2 cm in length by endoscopy
- For nonoperative management, the cuff of an endotracheal tube or tracheostomy tube should be distal to the injury

Operative repair

- Appropriately selected patients may undergo direct endoluminal repair of the TML
- Open repair principles are the same as of traumatic injuries
- Surgical approach depends on the location of the injury – transcervical versus a right posterolateral thoracotomy
- Repair should be made with absorbable suture, either running or interrupted
- If not involving esophagus or no mediastinitis, coverage with flap not needed

Pearls from the Experts: Drs. Thomas Scalea, Riyad Karmy-Jones, and Bill Long

- Localizing tracheal injuries is extremely important to select the correct incision. The operating surgeon should perform bronchoscopy. The area of injury should be localized relative to the carina and the thoracic outlet.
- Injuries at or just below the thoracic outlet can be dealt with via a collar incision. The anterior trachea can be mobilized using a dissection similar to that used for a mediastinoscopy. It is possible to mobilize 2 to 3 tracheal rings in to the operative field using a tracheal hook obviating the need for thoracotomy.
- Pure posterior tracheal injuries can often be treated non-operatively. If treated surgically, the anterior trachea can be opened at the appropriate site. Intraoperative bronchoscopy

can be extremely helpful to localize the exact level. This can be identified by seeing the light from the end of the scope through the trachea, with the OR lights turned off. The anterior trachea should be widely opened transversely. The posterior trachea can be repaired via the anterior tracheotomy and the anterior trachea then closed.

- Tracheal repairs are best done using interrupted absorbable suture. We incorporate two tracheal rings into the repair, passing the suture above the superior and under the inferior ring. The sutures should all be placed prior to tying. They should be tied down snugly but not too tight.
- Depending on the location, large or complex tracheal injuries often must be repaired around the endotracheal tube. This requires great cooperation with the anesthesiologist. Often, the endotracheal tube must be withdrawn to a level above the injury. The surgeon can then place one or two sutures, and the endotracheal tube can then be threaded distally for a period of time to allow for oxygenation and ventilation. The process is repeated until the repair is completed. Care must be taken not to injure the endotracheal tube balloon during the repair.
- Bronchoscopy should be performed after the repair in the OR. This assures the repair is acceptable and that there are no additional injuries.
- Emergency airway control can always be obtained via the open trachea in the operative field. An extra endotracheal tube or tracheostomy tube should be placed on the field in case emergency airway control is required.
- Tracheostomy should be avoided if it all possible in patients with tracheal injuries. Performing a tracheostomy risks developing tracheal stenosis in the area of the tracheostomy and the tracheal injury. Instead, early extubation, at the time of the initial operation if possible is best.
- Complex tracheal reconstruction should be avoided at the time of initial operation. Patients are often not in physiologic shape for complex reconstruction at the time of injury. Even if not perfect, tracheal repair can almost always be accomplished. Consultation can be obtained and tracheal reconstruction should then be performed at a later date.
- Pulmonary contusions often occur in concert with tracheal injuries. These often require high pressure ventilatory strategies. While double lumen tubes can worsen the tracheal injury, it can be difficult to repair the injured trachea with the lungs hyperinflated. In a few cases in patients with severe respiratory failure, we have placed the patient on ECMO to facilitate optimal exposure for the tracheal repair.
- With the exception of distal left main bronchial injuries, which are approached through the left, the preferred approach is a right posterolateral thoracotomy. The landmark is the azygous vein, which should be doubly ligated and divided. This opens the mediastinal space, the mediastinal pleura is incised and exposure improved by tacking the mediastinal pleura. Placing an NG tube will also facilitate dissection by identifying the esophagus.

<u>Diagnosis:</u>

- If the patient had a penetrating neck injury with air bubbling out and this stops once the patient is intubated, they have an airway injury
- One cause of persistent or residual pneumothorax and atelectasis without air leak is tracheobronchial rupture; early bronchoscopy should be considered. Differential includes

chest tube or pigtail misplacement, plugging, parenchymal consolidation, air plugging, and fractured rib sticking into lung.

Initial and Subsequent Airway Management:

- Single lumen endotracheal tube is the quickest; it can be advanced through the cervical tracheal injury or into left mainstem for isolation (double lumen tubes make exposure and repair more difficult, more plugging, and can enlarge the tracheal or bronchial injury. A bronchial blocker placed during rigid or flexible bronchoscopy can be less traumatic.
- Rigid bronchoscopy can be used to explore and secure an airway but is uncommon as it requires the patient to have a lesion that is not immediately life threating and yet have failed more standard interventions.
- With open cervical wounds if trachea not evident, reach down with finger and feel the rings, grab edge of tracheal wound with Kelly clamp, pull up the edge to open tracheal wound further, then intubate with ETT small enough to enter tracheal without ripping tracheal further.
- For massive air leak with severe hypoxia (rare injury), you may have to do right thoracotomy and intubate a distal trachea or main stem bronchus, again with a long small ETT. Consider jet ventilation via this route. Other oscillatory strategies (e.g. VDR without peep) may be tried. Also, consider a portable ECMO, if the equipment and perfusionist are immediately available.
- In the neck, in particular, be prepared to perform above procedures in the field, with low pressure ventilation.
- Jet ventilation can also be used for complex carinal injuries; place a catheter in each airway.

Exposure:

- For cervical injuries, exposure depends on suspicion of vascular injury. If bilateral/through and through, the surgeon can use a collar approach; if neck injury is clearly vascular (hematoma) start with low or proximal common carotid control and work cephalad; may have to do bilateral sternocleidomastoid approach and join with a transverse incision.
- Older patients, particularly female, can have a high riding innominate or carotid artery on the right. Palpate for this so there is no inadvertent injury.
- Morbidly obese patients with penetrating neck injuries and massive subcutaneous emphysema, pose additional challenges with airway control. Macroglossia in such patients is not uncommon; failure to intubate with the glide scope, may force the surgeon to insert a pediatric bronchoscope through a 6 or 7 French ETT through a nares partially anesthetized with lidocaine jelly, to get the ETT pass the vocal cords.
- Emergency Tracheostomy on patients with large jowls poses additional challenges. A u shaped cervical collar incision extending to the suprasternal notch, and down to the deep fascia, allows the surgeon to pull the fatty skin cephalad, exposing the deep fascia, making the anatomy easier to do an emergency tracheotomy. A wire wound ETT, 8 F is preferred, if immediately available. Once airway is secured, and the patient is stable, a defatting tracheostomy can be carried out, with a vertical slit caudad for drainage in the flap. The wire wound ETT can be sutured to the skin above the tracheotomy and to the anterior chest wall skin for stability.

- If a penetrating injury to cervical trachea, and worried about esophageal injury, may have to divide the trachea to look behind it at the esophagus (usually GSW when it is pretty clear the esophagus has been injured).
- Most thoracic tracheal injuries are approached by a right postero-lateral 4th intercostal space thoracotomy.
- Landmarks are the azygous on the right (divide and you will right on distal mainstem) and under surface of arch on the left (much deeper, harder to see).
- If doing a thoracotomy for intrathoracic injury with airleak, do not use electrocautery on opening the pleural cavity as the anesthesiologist administers 100% oxygen to avoid the risk for fire.
- The distal trachea, right main stem bronchus and first rings or two of the left mainstem bronchus are best approached via right thoracotomy.
- If there are associated great vessel injuries, you can approach the tracheal carina via median sternotomy or clamshell incision followed by a vertical pericardiotomy as high as the aortic arch, then marsupialize the pericardium to keep it open; move the superior vena cava to the patient's right, snip the fibrous tissue joining the ascending aorta and main pulmonary artery and with finger dissection separate the two vessels and then pass a Sims clamp around the ascending aorta, than pass an umbilical tape around the ascending aorta, and pull the ascending aorta to the patient's left; the right main pulmonary artery lies behind the ascending aorta and superior vena cava. here; mobilize the right main pulmonary artery and pull it or retract it caudad; that exposes the tracheal carina and right main stem bronchus.

<u>Repair:</u>

- Most tracheal or bronchial repairs need only simple sutures of 4-0 Tevdek, Vicryl, PDS, or Prolene.
- In the chest, most distal tracheal tears involve the membrane pulling away from the cartilage; horizontal mattress sutures used to re approximate the membrane usually suffice.
- For more complex injuries requiring debridement and reconstruction, we prefer to sew the membrane with continuous sutures, the cartilage with interrupted simple or figure of eight, intussuscepting the inferior cartilage ring into the superior cartilage ring.
- Our bias is to use PDS, but vicryl or prolene are equally acceptable.
- In the neck, if one must divide the trachea, place two heavy nylon retraction sutures in the distal trachea to hold it so it does not disappear into the mediastinum.
- In the chest, complex membranous tears with missing or morselized tissue can be repaired using bovine pericardial patch, acell or similar material or intercostal muscle flap.
- Fibrin glue is a useful adjunct.
- In the neck, if there are any associated vascular or esophageal injuries, buttress the repair with a muscle flap. The sternocleidomastoid is an excellent option.
- In the thorax, a pleural or pericardial flap can be used; pericardial fat pad can be mobilized to pad between the distal right main stem bronchus and pulmonary artery; an intercostal flap can be used, but should never used as a wrap around a bronchial

repair, as the muscle has a tendency to calcify over time, thus creating a rigid stricture and constriction.

- When repairing a combined esophageal and cervical tracheal injury, after repairing the esophagus, lay sternocleidomastoid muscle over the repair site THEN repair the back wall of the trachea.
- Usually, in trauma, relaxing incisions are not needed. When mobilizing the cervical trachea limit the dissection laterally to only the area needed to see and repair. If tension is felt to be a problem, then first perform an anterior release. This is a fancy phrase for running one's fingers anterior to the trachea as far down as possible, just as when does a medistianoscopy. The second maneuver is to suture the chin to the chest wall and maintain for 5-7 days to prevent the patient from extending his or her neck and pulling apart the repaired trachea. Finally, place two heavy nylons laterally one or two rings above and below the reconstruction as buttress sutures.
- In general, tracheostomy is best avoided, and early extubation performed. If there are troublesome secretions, a "micro" or "mini" trach can be placed.
- In the thorax the first release maneuver is to divide the inferior pulmonary ligament. The second release maneuver is to make a "U" incision based on the pulmonary veins (The base "u" is the diaphragmatic side) to relax the venous attachments.
- Primary airway injuries of the upper lobe bronchus can be repaired with simple sutures; more complex upper lobe bronchial injuries take time, and consideration should include an upper lobectomy.
- Devastating injuries at the right upper lobe origin can be managed as with sleeve lobectomy.
- It is rare that pneumonectomy is need purely for complex airway injury. If pneumonectomy is done, try and leave the bronchial stump no more than 2 rings long, to prevent bronchial break down. Also on the right, covering it with pleura helps.
- If pneumonectomy is done for massive hilar vascular injury, a TA-90 stapler can be used. We prefer blue load but green is ok (typically when doing the bronchus separate from the vessels green load is used to reduce ischemic insult). However, when doing a mass hilar stapling it is vital that you a) close the stapler to show that you have vascular control b) fire the stapler c) remove the stapler d) then cut out the lung. If the surgeon closes the staple BUT DOES NOT FIRE IT and then "amputates" the lung the vessels will slip out because the cartilage will prevent complete closure in some cases. We recommend if you can reinforce the bronchial stump as described above OR delay 1-2 days to come back, wash out and then reinforcing the stump.
- Pneumonectomy in an emergency associated with major blood loss in the chest and elsewhere with massive transfusion causes intense pulmonary artery hypertension, right ventricular dilation and right heart failure. Pulmonary vasodilators and inotropes are helpful. Anesthesiologists must be judicious with IV fluid replacement to avoid causing pulmonary edema. ECMO may be the last resort to unload the right heart, and give it a chance to recover with time.
- For any intrathoracic repair, do a bronchoscopy at the end of the case to assess narrowing and secretions.

- In the vast majority of cases cardiopulmonary bypass, V-A ECMO or V-V ECMO is not required. However, in unstable patients, or those with acute cor pulmonale, or complex combination carinal injuries, these can be lifesaving adjuncts.

Postoperative Care:

- Noninvasive positive pressure ventilation can be tried on an individual basis.
- The VDR is helpful for patients who must be ventilated, as VDR without PEEP can clear bronchial secretions and blood, and not cause air leaks.
- Ideally, get baseline pulmonary function tests and flow volume loops. These are used in follow up to help assess for stenosis.

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Figure 1: CXR in a patient with a tracheal injury demonstrating a large amount of subcutaneous emphysema.

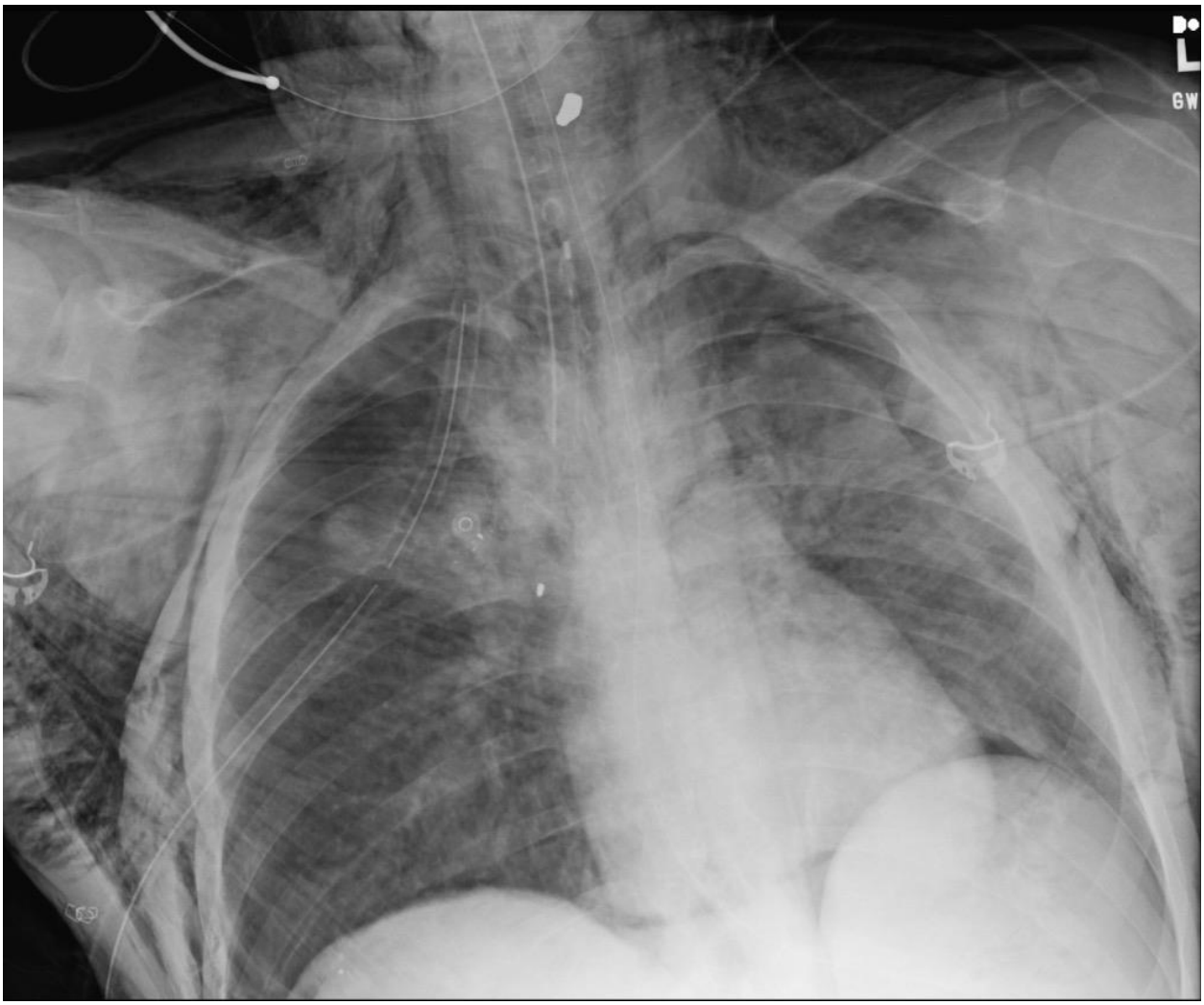

Figure 2: Chest CT of a patient with a tracheal injury demonstrating large amount of deep emphysema and a persistent pneumothorax after chest tube placement.

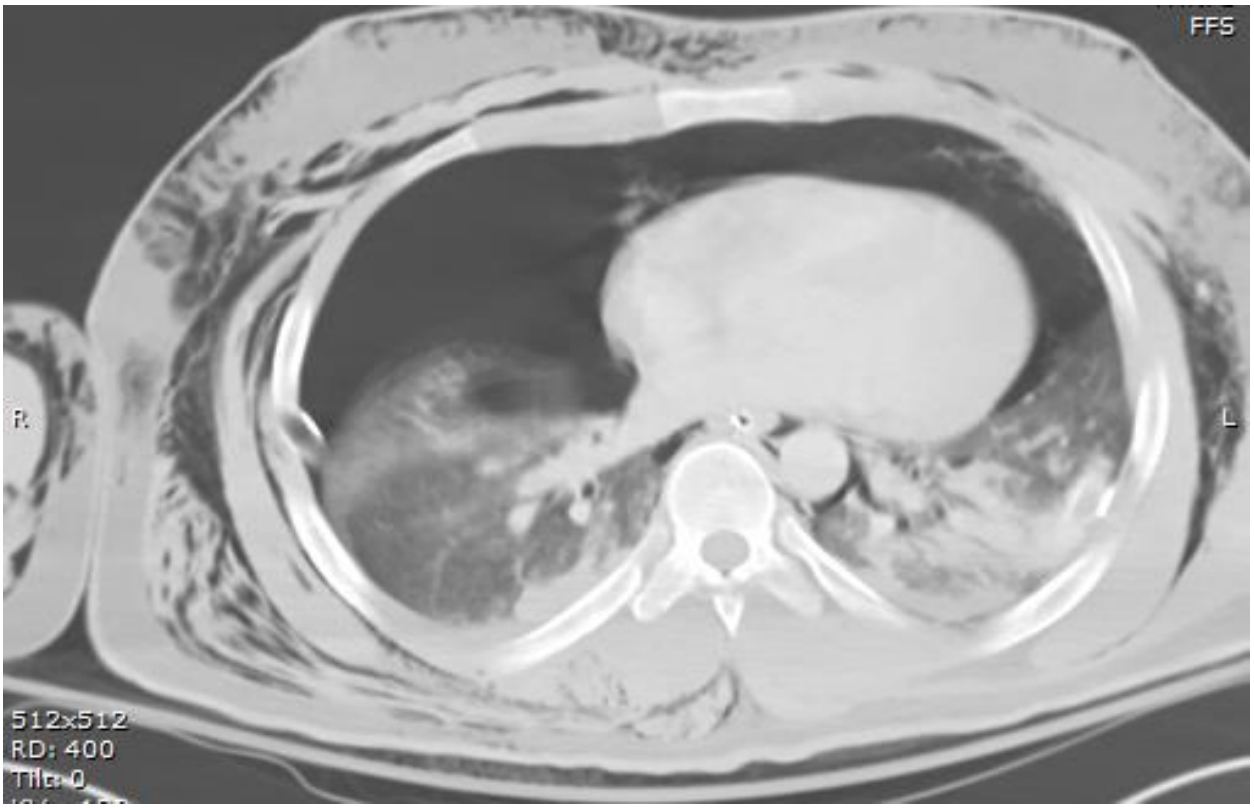

Figure 3: Operative photo of patient with a stab wound to the neck that sustained an anterior and posterior tracheal injury (with endotracheal tube visible) as well as an associated esophageal injury (held by three Allis clamps).