Tracheal and Pulmonary Injury

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Tracheal Injury

Tracheobronchial injuries are rare, occurring in less than 1% of all trauma patients, but carry a disproportionally high risk of morbidity and mortality [1]. They encompass a heterogenous group of injuries that are often concomitant with other injuries, making their diagnosis and management challenging. Therefore, a high index of suspicion and the ability to recognize the clinical signs and symptoms of such injuries early on are warranted. Although definitive indications for surgical intervention remain, minimally invasive techniques for a select group of patients or for patients who are poor surgical candidates have emerged.

Presentation

Tracheobronchial injuries can occur in the neck or in the chest. The cervical trachea is more likely to be injured in penetrating trauma, while the intrathoracic trachea is more often injured in blunt trauma, usually within 2.5 cm of the carina. In penetrating trauma, injuries are most likely due to missile or knife wounds, but can also be due to bony fragments secondary to blunt trauma. In blunt trauma, injury may occur by one of the three mechanisms: laceration from shear forces, rupture from compressive forces against the rigid vertebral column, or rupture from increased airway pressures against a closed glottis [2]. Associated injuries of the esophagus, great vessels, nerves, and thoracic duct must be ruled out [3].

Patients with tracheobronchial injuries typically present with dyspnea, tachypnea, hoarseness, stridor, or hemoptysis. Large amounts of subcutaneous emphysema may be present, with air bubbles seen in cases of open wounds. A distal tracheobronchial injury must be suspected in patients with a large pneumothorax and a massive continuous air leak that persists after tube thoracostomy placement. In severe cases, patients may present with respiratory distress requiring emergent definitive airway management.

Diagnostic Workup

Radiographically, the fallen lung sign on chest X-ray imaging may be present with mainstem bronchus transection. This sign describes an absent hilum, ipsilateral atelectasis, and pneumothorax with collapse of the lung toward the diaphragm (peripheral displacement). This is in contrast to the collapse of the lung toward the

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hilum seen in cases of pneumothorax without a tracheobronchial injury (central displacement) [4]. The fallen lung sign is pathognomonic for tracheobronchial injuries, but is evident only in cases of severe injury. Other more sensitive signs include abnormal mediastinal shadow, pneumomediastinum, subcutaneous emphysema, pneumothorax, or pleural effusion. Computerized tomography (CT) scan imaging may also demonstrate tracheobronchial wall discontinuity or mediastinal emphysema. This is of particular importance in penetrating trauma where the trajectory of the wound can give insight into possible tracheal injury. In physiologically stable patients, a 3-dimensional CT scan reconstruction of the tracheal surface and lumen can further delineate such injury.

The gold standard diagnostic modality for tracheobronchial injuries is bronchoscopy. Careful inspection of the entirety of the trachea is important for a thorough diagnosis. Flexible fiber-optic bronchoscopy can serve to determine the extent of the injury and aid in the intubation of critically ill patients in respiratory distress. However, a flexible bronchoscope can miss the injury if passed through an endotracheal tube that itself traverses the injury. Therefore, evaluation of the cervical trachea may necessitate withdrawal of the endotracheal tube to allow further visualization. The bronchoscope can then be used as a bougie to readvance the endotracheal tube. Rigid bronchoscopy can overcome that by allowing ventilation through the bronchoscope itself and also has the advantage of evacuating blood and debris.

Management

The first step in management of tracheobronchial injuries is securing the airway. Depending on the location of the injury, this may involve direct laryngoscopy, fiber-optic intubation, or a surgical airway. In severe cases, placing the endotracheal tube or tracheostomy directly through the injury may be necessary. Once the airway is secured, the full extent of the injury must be ascertained. This requires careful coordination with anesthesia. Cervical injuries can be managed with a single lumen tube, but more distal injuries require a double lumen endotracheal tube to facilitate repair. Due to the size and rigidity of double lumen tubes, care must be taken when intubating a patient to not worsen the situation by converting a partial injury into a circumferential one.

Tracheobronchial injuries that are large (usually greater than 2 cm) or full thickness are repaired primarily with the aim to restore airway continuity. Operative exposure of the trachea is determined by the location of the injury. A collar incision can be used to approach the proximal half of the trachea. The distal trachea as well as the right mainstem and proximal left mainstem can be approached using a right posterolateral thoracotomy. A distal left mainstem injury should be accessed with a left posterolateral thoracotomy. If severe mediastinal, parenchymal, or pleural injury requiring surgical intervention are also present, median sternotomy or clamshell incision can be considered. In cases of mainstem bronchus injury, lung-sparing repair procedures should be attempted before opting to proceed with the highly morbid pneumonectomy procedure [5].

Intubation of the contralateral bronchus during repair may prove helpful, with intermittent apnea and decreased tidal volumes also providing a more friendly operative field. Simple lacerations to the trachea are repaired with interrupted absorbable suture. More extensive injuries require debridement to healthy tissue before repair. If additional length is needed to facilitate repair, the trachea may be mobilized on the pretracheal plane. Tracheal hooks may be used to grasp a transected, retracted trachea, thereby allowing reapproximation and repair. If tracheal injury is not amenable of simple repair, tracheal resection may be necessary. In all repairs, care must be taken to avoid involving the endotracheal tube or the cuff. If separate repairs of the surrounding vascular structures or esophagus are done, an intercostal, sternocleidomastoid, or strap muscle may be placed between the suture lines to help prevent fistula formation.

Small tracheobronchial injuries (usually less than 2 cm) that are only partial thickness can be managed nonoperatively. Conservative management may involve tube thoracostomy, covered stent placement, selective intubation beyond the injury, or even observation alone. However, close monitoring for any signs and symptoms of clinical deterioration is mandatory to allow for prompt surgical intervention. Red flags may include respiratory compromise even when on mechanical ventilation, signs of mediastinitis, or rapid progression of subcutaneous or mediastinal emphysema.

Complications

Aside from the overall complications of tracheobronchial-associated injuries of polytrauma patients, anastomosis-related complications are the most common. The rates of anastomotic dehiscence and stricture formation following repair have been reported to exceed 5% [6]. Initial management is recurring the airway with delayed reconstruction or multiple dilations. Fistula formation is another potential complication. Tracheoesophageal fistula is managed by gastric decompression, supplemental nutrition, and treatment of pneumonia. Once the patient has stabilized, then operative repair or resection can be pursued. A trachea-innominate fistula is a surgical emergency that is often fatal [7]. Other delayed complications may include bronchiectasis, post-obstructive pneumonia, mediastinitis, and cervical abscess.

Pulmonary Injury

Because of the anatomic design of the lungs, pulmonary injuries can be classified as either pneumatic or hemorrhagic. Pneumatic injuries are injuries to the lung parenchyma with rupture of alveoli that lead to a pneumothorax. These may range from the sometimes occult simple pneumothorax to the life-threatening tension pneumothorax. Conversely, hemorrhagic injuries are injuries to the bronchial, pulmonary, or intercostal vessels that lead to a hemothorax. Because of limited tissue to provide tamponade, these vessels can bleed extensively when injured. Central injuries to the lung hilum and associated major pulmonary vessels are technically challenging and often fatal if not addressed promptly.

Presentation

Lung injury should be suspected in any patient with blunt or penetrating chest trauma. History from patients must be sought whenever possible; otherwise, field history must be obtained from prehospital providers. This includes details of mechanism of injury, type of impact, type of weapon, vital signs, transport times, neurologic status, and fluid resuscitation, if any.

In patients with a pneumothorax, initial presentation can vary depending on the size and type of the pneumothorax. Patients with a simple pneumothorax may present with minimal complaints, if any. However, care must be taken not to miss such cases because a simple pneumothorax can evolve into a tension pneumothorax. Classical findings of patients with tension pneumothorax are respiratory distress, decreased or absent breath sounds on the affected side with hyperresonance on percussion, distended neck veins, tracheal deviation away from the affected side, chest wall crepitus, and paradoxical chest wall motion. Elevated intrathoracic pressure causes decreased venous return, decreased cardiac output, and ultimately cardiac arrest. Patients may also develop hypoxia, which manifests as dyspnea, confusion, anxiety, and use of accessory muscles. In patients with vital sign instability or profound hypoxia, the physical exam should suffice, and further investigation with imaging should not delay intervention with a tube thoracostomy.

The combined pathology of hemopneumothorax is not uncommon, given the shared traumatic etiology. Therefore, in patients with a suspected pneumothorax, evaluation for a possible concomitant hemothorax is warranted. Clinical presentation is usually similar, but with dullness on percussion. Hemodynamic instability is an additional factor that is contingent upon the size of the hemothorax and the rate of bleeding into the thoracic cavity. In general, hemodynamically unstable patients require immediate intervention, but stable patients may benefit from further diagnostic imaging.

Pulmonary contusions are common following blunt trauma and are highly associated with rib fractures, especially flail chest. Such injuries can be clinically silent and not apparent on initial chest X-ray. In more severe forms, patients may present in respiratory distress and increased work of breathing. Pulmonary contusions are unique in that clinical symptoms and radiographic findings worsen over the first few days, before resolving in a 1-week period.

Diagnostic Workup

Arterial blood gas analysis must be sent for initial laboratory studies, as it yields critical information on oxygenation, ventilation, and degree of shock. Portable chest X-ray may reveal a pneumothorax or hemothorax, although controversy exists about the utility of this exam in the stable patient. In supine patients, liquid blood will spread along the posterior border of the thorax appearing as a subtle haziness that can be missed if the blood volume is small. In upright chest X-ray, liquid blood will manifest as fluid at the costovertebral angle and, depending on the volume, may displace lung tissue. Extended Focused Assessment with Sonography for Trauma (EFAST) exam with ultrasound (US) is a rapid, radiation-free alternative that is highly sensitive and specific in detecting a pneumothorax with the absence of lung sliding [8]. EFAST also offers the advantage of concomitantly evaluating the heart. In the hemodynamically stable patient, CT scan will allow greater inspection of the thoracic cavity. Hemopneumothoraces not seen on chest X-ray may be revealed, whether because of their small size or anterior nature. Further evaluation of the lung parenchyma is also achieved, revealing pulmonary contusions, lacerations, and pneumatoceles. CT scan also allows further evaluation of the great vessels and aorta [9].

Management

Initial management of traumatic pulmonary injury is guided by the principles of advanced trauma life support (ATLS). Injuries to the chest are prioritized and are addressed early in the evaluation of the trauma patient. Many thoracic injuries, such as pneumothorax, hemothorax, or pulmonary contusion can often be managed nonoperatively with a tube thoracostomy which allows re-expansion of the lung and drainage of the surrounding air and blood. Thoracic trauma patients with decreased breath sounds, hypoxia, and hypotension are presumed to have a tension pneumothorax until proven otherwise and require immediate decompression. In the field, needle decompression through the fourth or fifth intercostal space at the anterior axillary line or through the second intercostal space at the midaxillary line was found to have the lowest predicted failure rates [10]. In the hospital, most patients with a pneumothorax can be definitively treated with a tube thoracostomy, but some will have a persistent air leak requiring surgical intervention through either a thoracotomy or the less invasive video-assisted thoracoscopic surgery (VATS).

In patients with a hemothorax or a hemopneumothorax, 14 French pigtail catheters have been shown to be as effective as large bore chest tubes [11]. If the retained hemothorax is large, a second chest tube may prove helpful. However, a massive hemothorax, defined as more than 1500 mL of initial chest tube output or 200 mL/h for the first 3 h, should prompt evaluation for operative intervention. Thoracic exploration for hemorrhage control should not be delayed, as early intervention is associated with improved outcomes [12]. Emergent exploration should be done via a sternotomy or a thoracotomy. In a select group of stable patients with pulmonary vascular tree injury, or patients who are poor surgical candidates, transcatheter embolization is a feasible alternative to thoracotomy. When evaluating chest tube output, care must be taken not to confuse resolved intrathoracic bleeding with organized blood clots or tube mispositioning causing drainage cessation.

For stable patients with pulmonary contusions, treatment usually consists of adequate analgesia, ventilatory support in the form of supplemental oxygen, frequent pulmonary toilet, and judicious volume administration. In cases of respiratory failure refractory to less invasive therapies, mechanical ventilation is indicated.

In unstable patient, operative management must not be delayed. Choice of operative approach is dictated by the patient's overall clinical condition and hemodynamics, presence of concomitant injuries that will also necessitate repair, and findings of imaging studies. In the hemodynamically unstable patient, a median sternotomy, and an anterolateral thoracotomy, which can be extended as bilateral anterior thoracotomies (clamshell), provide adequate exposure to the pleural space and anterior mediastinum. Additionally, such approaches can be continued as a laparotomy for abdominal exploration, but offer little exposure of the posterior compartment. This is in contrast to the posterolateral thoracotomy most often used in elective thoracic surgery, which provides adequate exposure of the posterior compartment and is therefore the preferred approach for intrathoracic tracheal and esophageal injury repairs.

If tolerated by the patient, a double lumen instead of a single lumen endotracheal tube is preferred to improve the exposure and the intended repair or resection of the injured lung. However, in emergent settings, single lung ventilation may not be tolerated by the hemodynamically unstable patient, and lung isolation should therefore be avoided. In such cases where a single lumen tube is used, holding ventilation intermittently or manual compression of the adjacent lung can aid in optimizing exposure.

Once in the chest, blood and clots must be evacuated, and the lung is mobilized by incising the inferior pulmonary ligament and lysing any adhesions. Bleeding from the hilum can be controlled with digital pressure, a vascular clamp, or placing a Penrose drain around the hilum as a tourniquet. In cases of massive hemothorax, sources of bleeding may include a large parenchymal laceration, pulmonary vessel injury, or great vessel injury, especially in cases of penetrating trauma. If bleeding persists, a hilar twist may be performed. This should be attempted as a last resort as it can lead to further decompensation and precipitate rapid heart failure secondary to the rapid increase in pulmonary arterial pressure.

After exsanguinating hemorrhage is controlled and the patient's hemodynamics are improved, lung injuries can be attended to. Similar to the decision for operative approach, the choice of repair technique is dictated by the type and severity of the parenchymal injury, chest wall, cardiac and vascular injuries, and the patient's overall status. Simple lung injuries can be primarily repaired via pneumonorrhaphy. In more complex injuries, pulmonary tractotomy must be attempted, as tissue sparing techniques have consistently shown to improve outcomes and thus remain the mainstay for management [13]. The stapler is placed through the tract of the injury and fired, thereby exposing any injured blood vessels and airways that can be oversewn. Extensive injuries that involve unsalvageable lung tissue should be treated with a wedge resection or lobectomy. When attempting a lobectomy, the arterial and venous lobar branches should be dissected and either stapled or ligated. The lobar bronchus must also be identified and stapled prior to resection. To ensure the correct bronchus is to be transected, the lung is inflated while the bronchus is occluded by the stapling device. The lobe to be resected must not inflate. When proceeding with the resection, care must be taken not to fire the stapler through major pulmonary artery branches, especially in cases of more central lesions. Proximal hilar injuries are extremely difficult to manage and may necessitate the often fatal pneumonectomy. To further strengthen the bronchial stump following lobectomy, and especially pneumonectomy, a viable tissue flap can be used for reinforcement. This may include an intercostal muscle flap, diaphragmatic flap, or pericardial fat pad.

Growing interest and experience with minimally invasive techniques have made VATS an important part of the trauma surgeon's armamentarium in managing patients with chest injuries. VATS can be useful both as a diagnostic tool in the assessment of continued hemorrhage and air leaks and as a therapeutic tool in the repair of small diaphragmatic injuries, control of bleeding from intercostal vessels, and empyema decortication. However, the greatest utility of VATS has been in the evacuation of retained blood clots. Ideally, patients need to be placed in the lateral decubitus position with the injured side facing up. A double lumen endotracheal tube is almost always required to allow deflation of the affected lung. The operative field must be widely prepped and draped in case a conversion to thoracotomy is warranted. The thoracoscope can be inserted through the existing chest tube site after tube removal. Otherwise, it can be inserted in the fifth intercostal space with the tip of the scapula serving as a convenient landmark. This would permit excellent visualization of the inferior and posterior portions of the thoracic cavity where blood clots are most likely to accumulate. Additional ports can then be added as needed under direct visualization. By means of high-pressure pulse irrigation and suctioning, the blood clot can be broken up and evacuated. Therefore, the success of VATS in evacuating blood clots is contingent upon the earlier timing of the procedure, i.e. before the clot becomes organized with adhesions and loculations.

Complications

The most common complication following pulmonary injury is pneumonia. Patients requiring intubation and mechanical ventilation in the field were 12 times more likely to develop pneumonia compared to those who did not. Patients with pulmonary contusion, aspiration, or hemothorax were also at an increased risk for pneumonia and acute respiratory distress syndrome [14]. There are also the complications of the chest tube insertion itself, which not uncommonly requires readjustment or reinsertion. In addition, patients with an inadequately drained hemothorax have been shown to develop an empyema in 26.8% of the cases [15]. A retained hemothorax may also lead to a fibrothorax and an entrapped lung. In general, hemothorax volumes of 300 mL and less estimated on CT scan can be safely observed if not complicated by infection. Volumes greater than 300 mL will likely require evacuation. If a lobectomy was performed, a bronchial stump dehiscence may also occur. The risk of this may be lessened by using a flap, such as an intercostal flap, to buttress the site of resection. Other uncommon complications in patients with pulmonary injury include persistent air leak, bronchopleural fistulae, and chylothorax.

Conclusion

Learning the principles in diagnosis and management of tracheal and pulmonary injuries is incumbent on all trauma surgeons and surgical residents, as such injuries can be challenging and often fatal. Tracheobronchial injuries are infrequent, but remain a serious event with significant associated morbidity and mortality. Pneumatic and hemorrhagic pulmonary injuries are commonly encountered injuries in the trauma patient and must be addressed early on to restore adequate ventilation and circulation.

1. Bronchoscopy remains the gold standard diagnostic modality for tracheobronchial injuries.
2. Small (<2 cm) partial thickness tracheobronchial injuries can be managed nonoperatively.
3. Extensive tracheal injuries require debridement to healthy tissue before repair.
4. In cases of hemothorax or hemopneumothorax, 14 French pigtail catheters are as effective as large bore chest tubes.
5. Massive hemothorax (>1500 mL of initial chest tube output or >200 mL/h for the first 3 h) warrants operative intervention.
6. Uncomplicated small volume (<300 mL) hemothorax can be observed.
7. If lung resection is necessary, preference remains to the tissue sparing techniques.
8. Choices of operative approach and repair technique are to be dictated by the injury type, injury location, and overall patient status.

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