Thoracic Trauma I and II:
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Introduction:
Traumatized small animal patients represent a population in which a standardized approach to diagnosis centered on thorough background knowledge of traumatic injuries coupled with a complete physical examination will allow for rapid therapeutic interventions and optimization of patient care. The following paragraphs will detail the pathophysiology, diagnostic methods, and emergency medical treatment for injuries sustained due to both blunt and penetrating thoracic trauma from an anatomically based approach.

Thoracic injury occurs most commonly as a result of blunt trauma. Common causes include being hit-by car, falling from a height (high-rise syndrome), big-dog-little-dog interactions, and human-animal interactions. Penetrating injury (projectile induced injury, big-dog-little-dog interactions, and impalement injuries) occurs with less frequency than blunt thoracic injuries, but it must be recognized that both can result in immediately life threatening problems.

Trauma Associated Pleural Space Disease:
Pneumothorax, Hemothorax, and Diaphragmatic Hernia make up the three acute trauma associated pleural space diseases. Patients with clinically significant trauma associated pleural space diseases will likely display signs of tachypnea, dyspnea, and muffled heart and lung sounds on auscultation of the thorax.

Pneumothorax is the accumulation of air in the pleural space between the parietal and visceral pleura. Pneumothorax is classified as “open” when air enters the pleural space from an external wound, or “closed” when air enters the pleural space due to pulmonary or mediastinal injury. Tension pneumothorax occurs when air accumulates within the pleural space via a one-way-valve effect allowing air to enter, but not leave the pleural space. The resultant accumulation of air (and thus pressure) within the pleural space limits pulmonary expansion (ventilation) and venous return resulting in severe compromise to both the cardiovascular and respiratory systems.1 Pneumothorax is the most common of the trauma-associated pleural space diseases occurring in up to 47% of all dogs and cats with thoracic trauma.2-4 During our initial assessment of the traumatized patient, if we assume that a pneumothorax is present, we will make extra effort to both document and treat the condition.

Diagnosis of clinically significant pneumothorax is based on thorough auscultation of the chest and observation of the patient for signs of dyspnea. Positioned in sternal recumbency, patients with pneumothorax will tend to have decreased lung sounds dorsally to diffusely. Pneumothorax may be unilateral or bilateral. If pneumothorax is suspected based on auscultation and clinical signs, or if the clinician is unsure of the presence or absence of pneumothorax, thoracocentesis should be performed. Thoracocentesis is both diagnostic and therapeutic for pneumothorax. Radiographs of the thorax are not necessary for the acute diagnosis of a clinically significant pneumothorax and they may jeopardize the stability of the patient. When performed, radiographic evidence supportive of pneumothorax includes retraction of the lung from the chest wall (loss of vascular markings in this space), consolidation of lung lobes, and on lateral radiograph, the appearance of the heart “floating” on a cushion of air. The latter radiographic finding is due to the falling of the heart to the side of the atelectatic “down” lung.

Clinical evaluation of the patient’s tolerance for its pneumothorax should guide treatment. Thoracocentesis may be performed with the patient in lateral or sternal recumbency. Most commonly, dyspneic patients will prefer to be sternal. Necessary equipment for thoracocentesis includes a 60cc syringe, three-way-stopcock, extension set and needle or catheter, or butterfly catheter. In sternal recumbency, the needle or catheter is inserted through the skin off of the cranial edge of a rib (to avoid the neurovascular bundle) approximately 1/3 of the distance from dorsal to ventral midline in the 8th – 11th interspaces. The needle or catheter is inserted perpendicular to the chest wall and advanced a few millimeters at a time with intermittent aspiration of the syringe until air is retrieved. If air is retrieved, the thoracic cavity should be completely evacuated until negative pressure is attained. When thoracocentesis is performed in lateral recumbency, the needle or catheter should be inserted at the highest point of the arch of the ribs. Most dyspneic animals will not tolerate being held in lateral recumbency. Numerous acceptable methods for thoracocentesis exist.
Once stabilized by restoring negative intrathoracic pressure and treating concurrent life threatening conditions, surgical exploration of the thorax is warranted in patients with open pneumothorax as damage to the internal structures, debris, and necrotic tissue are likely to be present. Closed traumatic pneumothoraces (most common situation) are often self-limiting with thoracocentesis or continuous pleural drainage (via thoracostomy tube) and rarely require surgical intervention.

Hemothorax is the accumulation of blood in the pleural space between the parietal and visceral pleura. Hemothorax may result from injury to the vessels of the thoracic wall, pulmonary vessels, great vessels, or the heart. The incidence of traumatic hemothorax based on radiographic evidence was found to be 8.7% in one series of dogs with fractures. The incidence of clinically significant hemothorax is lower and that of massive hemothorax is unknown.

Clinically significant hemothorax is suspected based on a thorough physical examination and confirmed through thoracocentesis or thoracostomy tube placement. Signs of shock (tachycardia, slow CRT, pale mucous membranes, weak pulses, cool extremities, etc.) will likely be seen early on in clinically significant hemothorax. Signs of respiratory tract compromise (tachypnea, dyspnea, dull lung sounds ventrally) may also be noted. Similar to cases of suspected pneumothorax, thoracocentesis is both diagnostic and therapeutic for hemothorax (see above). Thoracocentesis for suspected cases of hemothorax should be performed in the ventral third of the chest in the 6th – 8th interspaces with the patient positioned in sternal recumbency. Blood removed via thoracocentesis after blunt trauma may be re-administered via a blood administration set (auto-transfusion) as long as it is collected with a closed system.

Radiographs of the thorax are rarely necessary for the diagnosis of a clinically significant hemothorax and they may jeopardize the stability of the patient. Hemothorax will manifest radiographically as pleural fissure lines, retraction of the lung from the thoracic wall, and a positive silhouette with the heart and diaphragm (making identification of their specific borders difficult).

Most cases of hemothorax due to blunt trauma rarely require any management more aggressive than thoracocentesis. However, if >7mL/Kg of blood is retrieved via thoracocentesis or if there is other evidence of ongoing hemorrhage, a thoracostomy tube should be placed. If >30mL/Kg is retrieved, exploratory thoracotomy / sternotomy may be necessary. Surgical exploration of the thorax is always recommended in cases of penetrating thoracic injury.

Diaphragmatic hernia is the third of the acute trauma associated pleural space diseases. The pathophysiology surrounding diaphragmatic hernia in the dog and cat is thought to center on an acute rise in intra-abdominal pressure with the major energy dissipation directed cranially toward the diaphragm. Compared with other injuries identified in thoracic trauma patients, diaphragmatic hernia is relatively uncommon. Diaphragmatic hernia was reported in 5.8% of dogs sustaining fractures as a result of motor vehicle accidents. Diagnosis of diaphragmatic hernia is based on a thorough assessment of the respiratory system based on physical examination, and is aided by a variety of imaging techniques.

Clinical findings in dogs and cats with diaphragmatic hernia are varied and will depend on which organs are herniated, presence of concurrent injuries (in one study, 38% had concurrent thoracic injuries and 48% had no other clinical signs), and acuteness of the injuries. Acutely, signs of cardiovascular (shock) and respiratory compromise will predominate.

Imaging techniques including survey radiography, positional radiography, positive contrast celiography, upper gastrointestinal contrast study, ultrasound, and computed tomography may aid in the diagnosis of diaphragmatic hernia. Radiographic findings include gross evidence of liver lobes, bowel loops, spleen or stomach within the pleural space. Abdominal radiographs may be helpful to identify organs “missing” from the abdomen. Often in cases of diaphragmatic hernia, concurrent pneumo/hemothorax is present and pulmonary contusion may also be noted making definitive diagnosis challenging.

Some debate exists as to the optimal time for surgical intervention in cases of diaphragmatic hernia. One study found increased mortality in cases in which surgery was performed within 24 hours of the inciting trauma as well as after one year following trauma. However, a more recent study found excellent survival when patients were operated within 24 hours of trauma. Surgical management of patients with diaphragmatic hernia should be delayed if possible until patient stability is achieved. Indications for immediate surgery include the inability to stabilize patients medically (recognizing that surgical intervention may not improve the patients’ condition), those with evidence of strangulation of abdominal viscera, ongoing hemorrhage, concurrent injury for which emergency surgery is necessary, or those with a distended stomach within the thoracic cavity that cannot be decompressed via tube or trochar catheter. Mean mortality in cases of diaphragmatic hernia is approximately 10-20%.
Trauma Associated Pulmonary Disease:

Pulmonary contusion refers to a lesion of the lung that occurs after a compression-decompression injury to the chest wall that results in hemorrhage and edema leading to alveolar collapse and lung consolidation.\textsuperscript{10-11} Pulmonary contusion is the most common injury identified after blunt chest trauma in people and is very commonly recognized in animals that have undergone thoracic trauma.\textsuperscript{12-13} Pathophysiologic mechanisms for pulmonary contusion include the Spalling effect, inertial effect, and implosion effect.\textsuperscript{12} Various types of pulmonary contusion have been described.\textsuperscript{14}

All of the above forces and types of contusion culminate in the development of hypoxemia due to ventilation/perfusion mismatch, shunt, diffusion impairment, and hypoventilation.\textsuperscript{15} Diagnosis of pulmonary contusion should be based on strong suspicion in all cases of trauma supported by consistent physical examination findings, and confirmed radiographically. Pulmonary contusion should be suspected in all animals that have sustained thoracic trauma until proven otherwise. Thoracic radiography must not jeopardize the stability of the patient. Ventrodorsal radiographic views should NOT be performed on hemodynamically unstable or dyspneic patients.

Clinical signs of pulmonary contusion may be noted immediately after trauma or may not manifest for a number of hours. Clinical findings of tachypnea and dyspnea are most commonly recognized. Coughing and hemoptysis may also be noted. Auscultation of the chest in patients with pulmonary contusion may reveal a spectrum of findings ranging from mild increases in lung sounds to overt crackles. Conversely, in areas of the lung that are completely consolidated, decreased airflow may be noted. Each hemithorax may be differentially affected by pulmonary contusion. Auscultation must be interpreted in light of the likelihood that other thoracic lesions are present (pleural space diseases). If rib fractures are noted on physical examination, underlying pulmonary contusion should be expected.

Radiographic evidence of pulmonary contusion may not be present immediately after trauma, and may worsen over the first one-to-two days. Supportive radiographic evidence includes patchy interstitial or alveolar densities. Other radiographic evidence of thoracic trauma is commonly present.

Treatment of patients with evidence of pulmonary contusion is primarily supportive. Oxygen therapy should be administered to optimize oxygen saturation (minimum >94%) (as measured by a pulse oximeter) or \( \text{PaO}_2 >75\text{mmHg} \) as measured by arterial blood gas analysis. Patients that are not able to maintain oxygen saturation with moderate respiratory effort in the face of 50-60% inspired oxygen concentration will require ventilatory support. Fluid support should be directed to maintain mean arterial pressure at least 75mmHg in the face of a relatively normal heart-rate, adequate urine output (minimum 1ml/Kg/hr), normal lactate, normal base-excess, and normal cardiac output. There is much debate as to the optimal fluid resuscitation choice in patients with pulmonary contusion, but no firm conclusions. Crystalloids, blood products, and colloids all have their place in fluid resuscitation. We should strive to avoid excessive fluid therapy (volume overload) as such situations may worsen pulmonary contusion. In the absence of hypovolemic shock, fluids should be administered sparingly to patients with pulmonary contusion.\textsuperscript{11}

Pharmacologic agents used in the treatment of pulmonary contusion over the years include furosemide, corticosteroids, and antibiotics. Furosemide is not indicated unless fluid overload has occurred and the patient must be monitored such that hypovolemia does not develop. The only clinical study in veterinary medicine to evaluate the use of corticosteroids for treatment of pulmonary contusion showed no decrease in the duration of hospitalization or oxygen therapy.\textsuperscript{13} No benefits have been documented in humans. At the present time, corticosteroids are not recommended for the management of pulmonary contusion.\textsuperscript{12-13} The incidence of bacterial pneumonia after pulmonary contusion in dogs is quite low (1%)\textsuperscript{13}, however, this incidence is much higher in people. Because of the very low incidence of pneumonia, antibiotic therapy cannot be recommended. If a patient develops signs compatible with pulmonary infection, culture and sensitivity testing of endotracheal or bronchoalveolar lavage samples should be performed and antibiotic therapy begun immediately.

Survival after pulmonary contusion is excellent (82% in one study of dogs managed at a University Hospital)\textsuperscript{13}. Survival drops to approximately 30%-80% when ventilatory support is necessary.\textsuperscript{13,16,e}

Trauma Associated Thoracic Wall Injuries:

General Approach to the Initial Management of the Patient Presenting with Penetrating (or Suspected Penetrating) Thoracic Injury: The approach to diagnosis and treatment varies depending on the injuries present. Stabilization of the major body systems is the number one priority. Approaches vary depending on the type of initial presentation.
1. Obvious thoracic penetrating / sucking chest wound. Patients that present with obvious thoracic penetration must have negative intrathoracic pressure restored as soon as possible. The most proactive approach to these types of patients includes emergency intubation and ventilation with 100% oxygen (via an anesthesia machine) to allow for appropriate pulmonary expansion. In a referral center / facility equipped to perform thoracic surgery, stabilization of concurrent injuries followed by thoracic exploration is the necessary approach. However, many patients will need to be referred to other institutions. In those scenarios, restoration of negative intrathoracic pressure is vital. This involves temporarily closing the defect in the chest wall and then performing thoracocentesis or placing a chest tube. Closing the chest wound may involve simply closing the skin wound and then placing a dressing impermeable to air over that closure. This is followed by referral to a center capable of performing thoracic surgical procedures. Penetrating chest wounds are surgical emergencies. The external injuries are usually the “tip of the iceberg”. Full thoracic exploration via a thoracotomy or median sternotomy is necessary for debridement, lavage, and management of concurrent injuries. Early initiation of broad spectrum antibiotic therapy (see below) is critical to managing infectious complications. Drainage of the pleural space with chest tube(s) is also vital.

2. Wounds over the chest with dyspnea. Some patients present with wounds over the chest accompanied by dyspnea. Oxygen should be administered immediately. Physical examination evidence, TFAST, or other diagnostic testing supportive of pneumothorax or other evidence of thoracic penetration should trigger immediately covering the wounds with an air impermeable dressing and then performing thoracocentesis. Full thoracic exploration via a thoracotomy or median sternotomy is necessary for debridement, lavage, and management of additional injuries. Early initiation of broad spectrum antibiotic therapy is critical to managing infectious complications. Drainage of the pleural space with chest tube(s) is also vital.

3. Wounds over the chest without evidence of dyspnea or pneumothorax. The challenge in these patients is determining if there is evidence of penetration of the thoracic wall. After management of concurrent injuries, radiographs should be performed. Evidence of pneumothorax generally indicates penetrating thoracic injury and treatment should proceed as noted above in (1) and (2). Without evidence of pneumothorax, the wounds should be clipped free of hair, aseptically prepared for surgery, and lavaged. Simple probing with a sterile instrument may indicate the presence of thoracic penetration. However, if probing does not indicate penetration of the pleural space, then the wounds should be debrided and the tract of the wound should be followed performing debridement as needed until the wound either is identified to enter the pleural space, or to simply terminate in the tissues of the thoracic wall. In the former case (thoracic penetration), the treatment should proceed as noted in (1) and (2) above. In the latter case, copious lavage, culture, and establishment of drainage is indicated. Wounds that don’t penetrate the pleural space are almost never closed primarily. Early initiation of broad spectrum antibiotic therapy is critical to managing infectious complications.

Imaging of the Patient with Penetrating (or suspected penetrating) Thoracic Injury: Always remember that imaging is complimentary to a thorough history and physical examination. Furthermore, it is vital to stabilize major body systems prior to performing diagnostic imaging procedures. (If possible). In general, a thorough physical examination coupled with a TFAST scan allows for identification of most trauma associated thoracic injuries.

FAST Scan: After thorough physical examination, a thoracic FAST (TFAST) scan will help identify the presence of traumatic pleural effusion, pericardial effusion, and pneumothorax (through loss of the glide sign). Diaphragmatic hernia can also be diagnosed by FAST, but caution must be taken in making this diagnosis due to the impact of mirror image (duplication) artifact. The five sites for the TFAST are the pericardial sites (3rd-5th space bilaterally over the heart), the chest tube sites (8th-11th space 1/3 of the way from dorsal to ventral midline), and the hepaticodiaphragmatic view (subxyphoid).

Thoracic radiography: Thoracic radiography is useful in the diagnosis of subclinical pneumothorax, hemothorax or other pleural effusion, pulmonary contusion, and for the diagnosis of diaphragmatic hernia. Ensure that the patient is well stabilized prior to thoracic radiography. Judicious use of analgesic and sedation techniques is vital to performing thoracic radiography safely. Three radiographic views of the chest utilizing a DV projection if the patient is dyspneic are indicated. If the patient is not dyspneic, a VD projection
A series of trauma radiographs (cervical spine, chest, abdomen, pelvis) are always appropriate in a trauma patient.

**Computed Tomography (CT):** CT serves as a gold standard diagnostic for the presence of intrathoracic injuries. In the author’s practice, CT is performed in all patients where penetrating injury is suspected or proven.

**Antibiotic Therapy in Penetrating Thoracic Injury:** The bacterial population introduced as a result of penetrating injury is dependent on the type of injury sustained. Bite wounds will include flora common to the mouth. In these patients, empirical IV ampicillin/sulbactam is the antibiotic of choice followed by oral amoxicillin/clavulanic acid. The spectrum may be broadened with the addition of enrofloxacin and metronidazole if desired. Most other causes of penetrating injury will be treated empirically in a similar manner. If the wound encountered is old (pyothorax) and the patient has already received antibiotic therapy, changing the protocol is indicated.

**Rib fractures** are relatively common after blunt thoracic trauma. The canine thoracic wall is a relatively resilient structure. As a result, it takes relatively major trauma to result in rib fractures. Fractures of the rib invariably result in significant pain (that in the worst case scenario can cause ventilatory disturbances) and if displaced internally, may result in puncture of the lung and subsequent pneumothorax. Rib fractures noted on physical or radiographic examination should serve as a “flag” for underlying pulmonary contusion.

**Flail chest** is described as a “paradoxical movement of a floating thoracic segment” or “the fracture of two or more consecutive ribs in two places (ventral and dorsal).” Paradoxical movement results from the changes in intrapleural pressures. Upon inspiration, intrapleural pressure decreases and the lungs expand (move outward). Because of the instability of the flail segment, it will not move outward with the rest of the thoracic wall, instead, the flail segment will move inward (towards the more negative pressure). The reverse is true on expiration. The combination of pendulous airflow, underlying pulmonary trauma, concurrent pleural space injuries, and pain can predispose to hypoxemia and hypoventilation.

Diagnosis of a flail segment of the thoracic wall is based on physical examination through the observation of paradoxical movement of the flail segment. Radiographic evaluation may confirm the flail segment and identify concurrent injuries, but is not necessary for diagnosis.

Therapy for flail chest has changed significantly over the years and still remains under debate. Three main categories of management methods exist. Conservative management centers on the treatment of the concurrent thoracic injuries (pulmonary contusion, pleural space disease) and the provision of pain control in the form of intercostal nerve blocks and epidural opiates. Bupivicaine (0.75% solution diluted to 0.25%) can be infiltrated as a small bleb locally dorsal and ventral to rib fractures. The bleb should be placed caudal to the rib due to the anatomic location of the neurovascular bundle. It may be helpful to also block single nerves cranial and caudal to the injured rib or segment. Total dose should not exceed 1.5mg/Kg and extreme caution should be exercised so as not to compromise ventilation by blocking too many intercostals nerves. Parenterally administered opiates can result in significant compromise to ventilatory function in patients with impending respiratory failure (as indicated by a PaCO₂ of >50mmHg and significant respiratory effort). Surgical management can be performed if necessary once medical stabilization is achieved, but is rarely necessary on an emergency basis. Internal and external fixation methods are described. Management of flail chest patients with Positive Pressure Ventilation (PPV) techniques results in the generation of a “functional splint” by forcing the flail segment to move in concert with the thoracic wall. PPV also allows for the management of the underlying pulmonary trauma. Unfortunately, PPV is plagued with complications such as pneumonia and barotrauma and is difficult to perform in a non-referral institution. Prognosis for animals with a flail segment is often dictated by the severity of the underlying intrathoracic trauma.

**Trauma Associated Mediastinal Injuries:**

**Pneumomediastinum** is the accumulation of air within the mediastinal space. Pneumomediastinum can result from a variety of injuries in both the blunt and penetrating classifications of thoracic trauma. Possible causes of pneumomediastinum include large airway rupture, alveolar rupture (with subsequent tracking through the interstitium and back into the mediastinum), esophageal rupture, or cervical wounds (air can track along the airway and vascular structures of the neck back into the mediastinum).
Pneumomediastinum is most commonly a sign of other injuries rather than a problem itself. Diagnosis of pneumomediastinum is based on thoracic radiography. Presence of pneumomediastinum should prompt examination for the underlying cause through exploration for cervical wounds, endoscopy for evaluation of the esophagus, iodinated contrast studies of the esophagus, and tracheoscopy / bronchoscopy.

Tracheal avulsion is a rather uncommon result of thoracic trauma. Tracheal avulsion is more commonly reported in the cat than in the dog and is thought to occur due to rapid and extreme hyperextension of the head and neck. The trachea is most commonly avulsed within the thorax. Animals with tracheal avulsion may show evidence of pneumomediastinum on initial radiographic evaluation and may show signs of mild to severe dyspnea. A number of animals appear to recover over the first few weeks after trauma during which time the airway is maintained by a thin reflection of mediastinal tissue. However, affected animals then develop dyspnea secondary to fixed airway obstruction as the ends of the avulsed trachea begin to stenose. Subsequent radiographic evaluation often shows lack of continuity of the tracheal silhouette. Bronchoscopic evaluation leads to definitive diagnosis. Treatment is surgical correction of the stenosis and anastomosis of the tracheal ends.

Trauma Associated Cardiac Diseases:

The cause of the arrhythmias commonly detected 12-36 hours after trauma are likely multifactorial in nature. Direct contusion to the myocardium, decreased oxygen delivery to the myocardium secondary to shock, and ischemia reperfusion injury are all likely contributors to the problem. Common arrhythmias observed based on ECG monitoring include isolated premature ventricular contractions, accelerated idioventricular rhythms, and ventricular tachycardia. Treatment should subsequently be considered if the arrhythmia is compromising perfusion or if there are signs that it could degenerate to ventricular fibrillation. Prior to pharmacologic intervention, electrolytes, volume status, blood gas, and oxygenation should be assessed such that conditions that might predispose to ventricular arrhythmias can be corrected. Lidocaine is the most commonly utilized drug for treatment of such ventricular arrhythmias and can be administered at 2-4mg/Kg IV while an infusion is running at 50-80µg/Kg/min. Additional doses can safely be administered one to two more times. Tremors, seizures, and depressed mentation as well as gastrointestinal effects evidence lidocaine intoxication. Lidocaine therapy should be discontinued if signs of toxicity develop. Seizures secondary to lidocaine intoxication may respond to diazepam. Some arrhythmias refractory to lidocaine may respond to procainamide (6-8mg/kg IV) followed by an infusion of 10-40µg/Kg/min. Amiodarone (Nexterone) may also be effective.

Footnotes:

a. Monoject 60cc Syringe, Tyco Healthcare Group, Mansfield, MA
b. Three Way Stopcock, Medex, Hilliard, OH
c. Extension Set 30 inch, Abbott Laboratories, North Chicago, IL
d. B-D Precision Glide Needles, BD and Co, Franklin Lakes, NJ
e. Beal MW, Jutkowitz LA et al. Unpublished data.
f. Bupivicaine .75%, Abbott Laboratories, North Chicago, IL
g. Vacutainer Brand Tube for Activated Coagulation Time of Whole Blood, Becton Dickinson, Franklin Lakes, NJ
h. Vacutainer Brand Tube for Determinations Requiring Serum, Franklin Lakes, NJ
i. Lidocaine 2%, The Butler Co., Columbus, OH
j. Diazepam 5mg/ml, Abbott laboratories, North Chicago, IL
k. Procainamide 100mg/ml, Abbott Laboratories, North Chicago, IL

References