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Pulmonary Contusions

Pulmonary contusions are a frequent complication of chest trauma and may have serious morbidity and mortality associated with them. Early recognition, aggressive management, and a targeted diagnostic approach may optimize outcomes for these patients. The authors present a concise, comprehensive review of the current status of identification and management of pulmonary contusions.

—The Editor

Case Scenario

A 25-year-old man presents to the emergency department three hours after being in an all-terrain vehicle accident in which he was thrown from the vehicle and landed on his back on a concrete surface. He complains of chest and back pain and has a laceration to the back of his head. He is awake and alert, moves all four extremities without pain, has no abdominal pain or bruising, and denies difficulty breathing. His vital signs on arrival are a temperature of 98.8°F, pulse of 134, blood pressure of 142/76, respiratory rate of 28, and oxygen saturation of 94% on room air. His FAST exam is negative. He has abrasions on his entire back, with contusions over the upper back and shoulders. The patient is transported to the radiology suite for a two-view chest radiograph. While in radiology, he begins vomiting and complains of difficulty breathing. On repeat examination, his oxygen saturations are in the low 80s on 4 liters oxygen by nasal cannula.

The patient's chest X-ray reveals bilateral pulmonary contusions encompassing 50% of each lung. He is immediately intubated, but his oxygen saturations fail to improve. A chest computed tomography (CT) scan is obtained and reveals 70% bilateral pulmonary contusions without rib fractures, pneumothorax, or hemothorax. As you arrange transfer to the nearest trauma center, which is 30 minutes away by helicopter, the patient continues to be hypoxic, tachycardic, and hypotensive, and you wonder what else you can do to optimize his condition prior to transfer.

Introduction

Blunt thoracic trauma can lead to many serious outcomes. Of these, pulmonary contusion can lead to significant morbidity and mortality if not recognized early and managed appropriately. While other immediately life-threatening injuries may be initially apparent, the clinical course and radiographic abnormalities of pulmonary contusions may present in a delayed manner. Although morbidity and mortality rates for pulmonary contusion have not varied greatly in the past few decades, early recognition of the risk factors, symptoms, and signs, as well as aggressive treatment can reduce harm to the individual patient. Recently, there has been some debate regarding the best way to manage the ventilator-dependent contused lung, and the disposition options for the patient whose contusions can only be seen on computerized tomography.

This discussion will focus primarily on the most up-to-date recommendations for diagnosis and treatment of pulmonary contusions. The authors performed a literature search of PubMed, Medline, Web of Science, and Cochrane databases

Executive Summary

- Children have a more elastic thoracic cage and do not always present with rib fractures in the setting of pulmonary contusions.
- Evidence suggests that a flail chest is associated with 75% risk of having an underlying pulmonary contusion that can double the risk of mortality.
- CT is easily obtained, highly accurate, and readily available in most emergency departments; it is considered the gold standard for diagnosing pulmonary contusions.
- The primary goal in the management of pulmonary contusions is the maintenance of adequate oxygenation. Treatment modalities include noninvasive and invasive ventilation, high-frequency ventilation, surfactant replacement, and others.

using the terms “pulmonary contusions,” “blunt thoracic trauma,” and “blast lung injury,” yielding 132 relevant articles. Pertinent articles and various practice guidelines were reviewed, and further references were pulled from those articles, with a total of 55 articles cited for this review.

Epidemiology

Pulmonary contusions were first described in the medical literature by Morgani in 1761, when he noted extensive underlying parenchymal lung damage without evidence of chest wall trauma in a young man who was crushed under a carriage. Pulmonary contusions are the most common parenchymal lung injury seen in blunt thoracic trauma, present in 25-35% of cases.¹ They are a significant source of morbidity and mortality, occurring in up to 200,000 victims per year, with up to 15,000 adult deaths.^{2,4} Up to 25% of deaths from blunt chest trauma are in patients with pulmonary contusions.⁴ While many of these deaths may be attributed to polytrauma, pulmonary contusions are evidence of a severe mechanism of injury and contribute to a poor clinical course. In the pediatric population, pulmonary contusions occur in up to 50,000 children annually in the United States, with associated mortality in 8,000 patients.⁵

Pathophysiology

Pulmonary contusions are typically the result of blunt trauma to the chest wall. Motor vehicle and

motorcycle crashes are the most common causes of this injury pattern,⁶ but it can also be seen with blast trauma. Approximately 25-35% of blunt chest traumas involve injury to the lung itself.^{5,7} The lungs are the second most common organ injured in blast injuries.⁶

Pulmonary contusions result in lung consolidation and alveolar collapse secondary to hemorrhage and interstitial edema.^{2,4,8} While the pathophysiology is poorly understood, Wagner et al. proposed four potential causes and types of pulmonary contusions to assist with physician understanding of the risks and etiology of this disease process. (*See Table 1.*)⁹

Lung tissue is frequently injured by direct impact with the ribcage. If rib fractures or flail chest are present, the likelihood that there is underlying trauma to the lung tissue itself is between 5% and 13%,⁶ although there can be significant lung injury without thoracic fractures.^{1,7} The external mechanical forces of the bony thorax can cause laceration or tearing of the lung parenchyma.^{1,7} Pulmonary contusions associated with rib fractures are often more localized than pulmonary contusions without clear areas of bony injury.⁴ Children have a more elastic thoracic cage and do not always present with rib fractures in the setting of pulmonary contusions. A 100-patient, retrospective study found that children were 18% less likely than adults to have an associated rib fracture with their pulmonary contusion.¹⁰

Direct blunt trauma and blast

trauma can produce similar patterns of pulmonary contusion without outward signs of injury. The physics behind the causes of a pulmonary contusion can be divided into three components that are based on shock wave passage through the lung parenchyma. The first component is referred to as the “Spalling effect” and involves the initial disruption between the gas and liquid interface at the level of the alveolus. This disruption occurs at the time of impact and is secondary to a shearing or bursting effect on the alveolus itself. The second component is the inertial effect, which occurs during tissue acceleration and deceleration. As hilar tissues are denser than alveolar tissues, they will accelerate at different rates. During this phase, there is further disruption between the tissue planes. The third stage is the implosion effect that results from overexpansion of gas bubbles, which can also disrupt the alveoli.¹

After the initial blunt or blast thoracic trauma, the edematous phase is notable for worsening interstitial edema and infiltrates, occurring within the first 1-2 hours after injury.⁷ The air spaces become inundated with blood, inflammatory markers, and tissue debris, as there is an increase in alveolar and capillary permeability along with a reduction in surfactant production. Within 24-48 hours after the onset of injury, there is alveolar collapse and further consolidation due to the extravasation of blood into the alveoli.^{1,7-9} Lung consolidation can lead to increased vascular pressures causing

Table 1. Types of Pulmonary Contusions⁹

Type I Due to direct chest wall compression against the lung parenchyma; this accounts for the majority of cases.
Type II Due to shearing of lung tissue across the vertebral bodies
Type III Localized lesions due to fractured ribs, which directly injure the underlying lung
Type IV Due to underlying pleuropulmonary adhesions from prior lung injury tearing the parenchyma

pulmonary hypertension and retention of blood. The resulting ventilation/perfusion mismatch, increased pulmonary shunting, decreased gas exchange, and decreased compliance can predispose patients to clinically apparent symptoms such as hypoxia, hypercarbia, tachypnea, hemoptysis, and wheezing. It is also these mechanisms of consolidation, shunting, and mismatch that predispose patients with pulmonary contusions to pneumonia and acute respiratory distress syndrome (ARDS).¹¹ Pulmonary vasoconstriction and ensuing pulmonary hypertension in the affected tissue can occur in response to pulmonary contusion as a protective mechanism. The blood is then shunted away from areas of parenchymal injury to areas of better oxygenation, but this response does not occur in all patients.¹¹

Hypoxia is frequently encountered with pulmonary contusions, and it is believed to primarily be due to hypoinflation and atelectasis, as opposed to widened gas exchange barriers.¹² Hypoxia will often worsen over the initial 48 hours post-injury as ventilation decreases to the injured area, atelectasis worsens, and infection may occur.¹³

The first signs of pulmonary contusion on chest X-ray are focal or diffuse lung opacities, which classically appear within the first six hours after

injury, but may take 24-48 hours to demonstrate maximum consolidation.¹¹ During that time, the acute phase inflammatory response is driving the underlying cellular and sub-cellular injury with activation of the coagulation and complement cascades and release of multiple inflammatory mediators such as cytokines, chemokines, and free radicals.⁸ Much of the acute phase mechanisms have yet to be fully elucidated, but researchers believe that inflammation is responsible for much of the morbidity and mortality associated with pulmonary contusions. These markers are likely present with any lung parenchymal injury and predispose patients to delayed complications such as pneumonia, ARDS, and long-term disability.⁸ Despite these effects to the lung parenchyma from pulmonary contusions, most resolve within 7-14 days with overall minimal long-term effects.^{6,11}

Clinical Presentation

Any blunt thoracic trauma patient who presents to the emergency department in respiratory distress should be considered to have a significant pulmonary contusion, after first excluding a tension pneumothorax or hemothorax. The patient may show evidence of chest wall injury such as obvious rib fractures or flail chest. Evidence of these

injuries should increase one's suspicion for underlying parenchymal lung injury. However, as mentioned, many pulmonary contusions present without evidence of localized chest wall trauma. Patients with pulmonary contusions often have multiple injuries from severe mechanisms of trauma. Other injuries may be more obvious and life-threatening, as respiratory symptoms and the radiographic findings of a pulmonary contusion can be delayed from the time of initial injury. Therefore, it is essential to monitor and frequently reassess chest trauma patients to identify pulmonary contusions that may have a delayed presentation.

Mechanism/History

The patient with a pulmonary contusion will present following an injury notable for a mechanism in which there was significant blunt force applied from a high energy transfer, such as rapid deceleration, compression, shear, and inertial forces.¹⁶ Motor vehicle collisions are the most common cause of pulmonary contusions because of the high-velocity acceleration/deceleration. This can also occur with falls from a significant height, a fast moving object striking the chest wall, vehicle versus pedestrian accidents, as well as from blast injuries. It has been suggested that front-end collisions, near-side collisions, collisions with a fixed object, and motor-vehicle collisions greater than 45 miles per hour place patients at higher risk for pulmonary contusions.^{11,14} As is typical of trauma patients in general, many of these patients will be young adults and male. Children have similar mechanisms of injury but are also at risk due to falls from a height of more than five feet.^{6,11,14}

“Blast lung” is a well-known complication of blast injuries noted among military and civilian survivors of explosive attacks. In blast lung injuries, the shock wave from the high-velocity explosion can lead to significant injury to the lung parenchyma, in particular, by disrupting the alveoli at the point of initial shock wave impact due to the

Figure 1. Significant Chest Trauma



Figure 2. Chest Radiograph of Pulmonary Contusion



Spalling effect.^{11,16} One retrospective Israeli study of blast injuries among survivors of suicide bomb attacks showed that patients with multiple areas of injury (4-5 body areas) or penetrating head injury were at a much higher risk of blast lung injury.¹⁷

Symptoms and Clinical Presentations

Signs and symptoms of pulmonary contusions at presentation in the emergency department are consistent with respiratory distress. It is important to note that these symptoms will likely worsen over time, so reassessment is essential to determine the need for airway protection.

Outward physical signs of potential pulmonary contusions are bruising

to the chest wall or back, localized tenderness or crepitus, tenderness over the site of a rib fracture, or flail chest. (See Figure 1.) If a patient is noted to have multiple rib fractures or flail chest on evaluation, one must maintain a high index of suspicion for underlying parenchymal contusions to the lungs, as these are clear indications of a dangerous mechanism of injury. Evidence suggests that a flail chest is associated with a 75% risk of having an underlying pulmonary contusion that can double the risk of mortality.^{12,18,19} Other injuries suggestive of significant blunt force trauma, such as scapular fractures,⁴ first or second rib fractures, and cardiac contusions, should prompt one to be alert for pulmonary contusions as well. Lung auscultation is a non-specific test, as some patients will simply have decreased breath sounds from splinting, while others may present with increased work of breathing, rales, ronchi, and even wheezing.

Vital signs also must be monitored closely in those suspected of a pulmonary contusion. Patients should be watched closely for hypoxia, hypercarbia, tachycardia, and other signs of end organ dysfunction. It is important to note that these findings initially may be absent soon after the primary injury. They may develop rapidly in some, but in others may take up to 48 hours to manifest. Symptoms that worsen over the 24 hours after injury portend a worse short-term and long-term prognosis.^{19,20}

Imaging

A chest X-ray is the first-line test to obtain in blunt thoracic trauma to assess for pulmonary or thoracic injury. Because an initial flat anterior-posterior chest X-ray is typically obtained in the trauma evaluation to quickly recognize injuries such as pneumothorax, hemothorax, aortic injury, or pulmonary contusions, many of these injuries will be identified early in the workup of the trauma patient. In the case of pulmonary contusions, they tend to be present on initial plain film if they

are already severe and symptomatic. Some reports have suggested that pulmonary contusions that cannot be seen on initial chest X-ray in patients who have minimal symptoms are of little clinical significance, and that those contusions only seen on chest CT are less likely to result in significant morbidity.^{3,5,21-24} Patients with moderate to severe symptoms often receive a chest CT early in the course of resuscitation to determine the severity of disease, but deciding which patients with mild symptoms require further imaging beyond chest X-ray can be challenging because the clinical relevance and management of occult pulmonary contusions is currently unclear based on the available literature.

Chest Radiograph

It is classically taught that the size of pulmonary contusions found on chest X-ray directly correlates with severity of the clinical symptoms and the overall prognosis.¹¹ (See Figure 2.) The chest X-ray can be misleading, missing up to 58% of pulmonary contusions on initial radiograph.^{21,22} Patients who have persistent or worsening symptoms of tachypnea, hypoxia, and respiratory distress may have a normal chest X-ray in the initial hours following injury, but subsequent films may demonstrate evolving interstitial injury seen with pulmonary contusions.^{2,19,20} This underscores the need for repeat examinations and further imaging if symptoms persist. A retrospective chart review by Tyburski et al demonstrated that up to 25% of patients initially diagnosed with a pulmonary contusion in the emergency department had both clinical and radiographic worsening of their contusions within 24 hours.²⁰ Findings on chest X-ray suggestive of a pulmonary contusion include focal or diffuse homogenous opacification on multiple lung segments and lobes, particularly when the opacities are outside the bounds of normal anatomical limits.^{2,5}

Chest X-ray is the initial imaging selection in the blunt thoracic trauma patient and should not be dismissed,

but if initial X-ray findings are negative or respiratory symptoms persist, a repeat X-ray may show evolving injury. In certain cases, further radiographs may not be obtained until 24 hours after initial imaging, leaving a large window open for worsening findings to become apparent and affect clinical course. A retrospective review by Pape showed that only 47% of pulmonary contusions were seen on initial chest X-ray, while 92% were evident by 24 hours after injury.²⁵ Pulmonary contusions may take time to manifest on radiograph, and, at a minimum, a repeat chest X-ray should be obtained in 12-24 hours for the stable patient with mild to moderate symptoms. If respiratory symptoms worsen, computed tomography of the chest is the best choice for further imaging to visualize the injured lung and should be considered the next imaging modality employed after chest X-ray when assessing for pulmonary contusions.

Computed Tomography

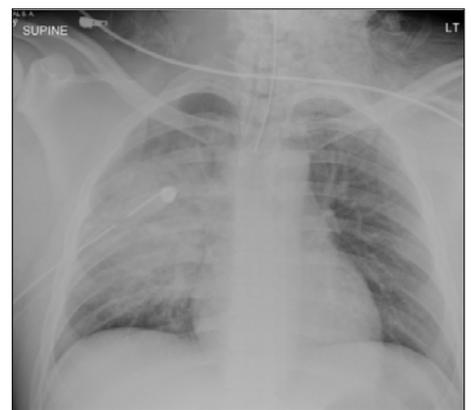
Computed tomography can visualize lung injury and contusions not seen on initial chest X-ray. Because CT is easily obtained, highly accurate, and readily available in most emergency departments, it is considered the gold standard for diagnosing pulmonary contusions. However, in patients with mild pulmonary contusions diagnosed by chest X-ray and few clinical symptoms, CT may not be necessary. Kwon's three-year retrospective review of a pediatric trauma database showed that of 46 patients with pulmonary contusions requiring hospitalization, only 31 were positive for contusions on the initial chest X-ray. Overall, those patients with initially positive X-rays had longer lengths of stay in the hospital, a greater need for intensive care unit admissions, and a higher incidence of mechanical ventilation than those injuries that were not present on initial chest X-ray and only discovered on chest CT. (See *Figure 3*.) Of note, no patient in this study had a chest X-ray that was positive for pulmonary contusion with a negative CT scan. This suggests that

pulmonary contusions present only on CT (occult pulmonary contusions) have minimal clinical significance and are associated with better outcomes and fewer complications than pulmonary contusions visualized on initial chest X-ray.⁵

Other studies have suggested that occult pulmonary contusions found only on CT can still have serious morbidity and even mortality.³ A prospective study by Exadytklos et al also showed that in blunt thoracic trauma, 50% of patients with initial normal chest X-rays had clinically significant intra-thoracic injuries noted on chest CT.²⁶ Although initial evaluation by chest X-ray in the acute trauma patient is warranted, CT can allow the physician to diagnose a pulmonary contusion earlier in the course of the disease than a chest X-ray and is more accurate at determining the extent of the injury by measuring the volume of lung injured.²⁶⁻³¹ Initial chest X-ray has been found to be only 82% sensitive and 57% specific when compared to chest CT.³¹ Multiple studies have found that CT can detect other blunt thoracic injuries such as rib fractures, hemothoraces, pneumothoraces, and aortic injuries that may be of clinical significance when compared to initial chest X-ray. There is debate, however, about how these occult CT findings alter the overall clinical course.^{3,11,27-39}

A retrospective chart review by Deunk and colleagues evaluated patients diagnosed with pulmonary contusions by CT alone compared to those patients who had pulmonary contusions evident on both chest X-ray and CT of the chest. Of 255 patients with pulmonary contusions, 98 (38%) were found in the dual imaging group and 157 (62%) were found only on CT. Of those found on CT alone, there was an 8% mortality compared to 16% in the chest X-ray and CT group.³ Kaiser et al assessed blunt trauma patients with overt thoracic injuries seen on chest X-ray alone compared to those with occult blunt thoracic injury (seen only on CT) and those with no injuries. They found that overt injuries

Figure 3. Chest Radiograph of Intubated Trauma Patient with a Significant Pulmonary Contusion



required increased mechanical ventilatory support and had higher mortality.¹⁵ Patients with occult and no injury had similar rates of mortality and ventilator support, but those with occult injuries had longer hospital stays. Importantly, they found that no patients with only occult thoracic injuries subsequently required intubation or tube thoracostomy.¹¹

While the above studies show that occult pulmonary contusions had less morbidity and mortality, they still had a high rate of serious complications and death, suggesting that occult injuries may lead to clinical decompensation and require aggressive treatment.

The primary value of CT lies in its ability to quantify the amount of lung injured, as this can help to predict overall hospital course. CT will aid in diagnosing the disease earlier in the course when compared to chest X-ray, and CT may improve visualization of other serious intra-thoracic injuries. However, there is still debate over the clinical significance of occult pulmonary contusions found on CT without other serious injuries or clinical symptoms.

Ultrasound

As ultrasound has become a more common imaging modality, lung ultrasound has been found useful in bedside imaging of various lung injuries such as pneumothorax,

Table 2. Severity of Pulmonary Contusions³⁴

Mild
<ul style="list-style-type: none">• < 18% of lung volume affected• None required intubation
Moderate
<ul style="list-style-type: none">• 18-28% of lung volume affected• Intubate on a case-by-case basis
Severe
<ul style="list-style-type: none">• > 28% of the lung volume affected• All required intubation

pulmonary edema, and pneumonia. It has been suggested by several studies and case reports that ultrasound may be a useful adjunct to diagnose pulmonary contusions, with a sensitivity of 94.6% and a specificity of 96.1%.^{7,32} Soldati and Ball both demonstrated that ultrasound may reveal alveolar-interstitial syndromes in the setting of trauma suggestive of pulmonary contusions. A recent case report by Stone described using ultrasound to diagnose a pulmonary contusion by visualizing the presence of lung sliding (to prove a pneumothorax was not present) and the presence of A-lines and B-lines on ultrasound suggestive of the alveolar-interstitial pattern.³³ While ultrasound may not give definitive evidence of pulmonary contusions, it is a useful adjunct to assist in the diagnosis when chest X-ray is indeterminate, CT is unavailable, or the patient is too unstable to transport to the radiology suite.

Clinical Correlation

The amount of injured lung on the imaging test of choice often correlates directly with short-term and long-term prognosis.^{20,34} Both Wagner et al and Miller et al have determined that pulmonary contusion size can be divided into mild, moderate, and severe based on the size of the contused portion of the lung.³⁴ A mild contusion on imaging studies suggests that less than 18% of the lung has been injured,

and Wagner found that none of these patients required intubation. A moderate-sized contusion is between 18% and 28%, and a severe contusion has greater than 28% of the lung volume involved. Moderate contusions may require intubation, while those with severely contused lungs (> 28% of the lung volume) all eventually required mechanical ventilation.³⁴ (See Table 2.) Severe pulmonary contusions have been shown to correlate with a 10-20% risk of mortality,² and those with contusions greater than 22% were shown by Miller et al to have a much higher risk of ARDS than smaller contusions.³⁵ This study divided patients slightly differently in to moderate size (< 20%) and severe (> 20%), and found that the average size was 18% of lung volume contused.

Management

Pre-hospital Care. Blunt chest trauma is a frequent injury in developed countries, with motor vehicle accidents being the most common cause. There is an estimated 7% risk of a serious thoracic injury with motor vehicle collisions (MVC). Lung contusions occur in 35% of these MVC patients without any bony thoracic injury.⁶ It is essential, therefore, that pulmonary contusion be considered in all patients with blunt chest trauma, as the absence of obvious chest wall injury does not eliminate the risk of having severe pulmonary dysfunction and

respiratory compromise.

Resuscitation. After arrival to the hospital, the patient should be rapidly examined and treated in accordance with ATLS (Advanced Trauma Life Support) protocols. The primary treatment of pulmonary contusion is supportive, and initial efforts should focus on diagnosing and treating critical concordant chest injury and providing supplemental oxygen to treat hypoxia. Prophylactic intubation in the setting of a pulmonary contusion without signs of impending respiratory failure is contraindicated.

The ATLS course manual states, "Patients with significant hypoxia, i.e., $paO_2 < 65$ mmHg, $SaO_2 < 90\%$, should be intubated and ventilated within the first hour of injury."³⁶ Intubation should be provided with the goal of reducing parenchymal edema, thereby decreasing shunting, improving functional residual capacity, and decreasing hypoxemia. Hamrick et al conducted a retrospective chart review of all patients sustaining blunt chest injury who presented to a trauma center in Georgia. Patients who sustained greater than 20% lung contusion were more likely to require assisted ventilation 40% of the time in their initial 48 hours post trauma in comparison with only 8% of those patients who sustained less than 20% pulmonary contusion. They did not find a linear relationship between contusion size and early respiratory failure.³⁷ Two older retrospective chart reviews by Wagner et al and Clark et al suggested that the severity of contusion on imaging correlates well with the need for intubation and ventilator support, and those with bony thoracic injuries, such as flail chest, have an increased need for intubation and a higher mortality rate.^{18,34}

Fluid Resuscitation. There is persistent controversy surrounding the issue of fluid management in patients with pulmonary contusions. The disagreement started in World War II when the "wet lung" was described in soldiers with thoracic injuries who had undergone extensive

fluid resuscitation. Later investigation found that fluid accumulation increased in injured lung tissue and that it was more difficult to remove the excess fluid.² Results of animal models have failed to substantiate the claim that crystalloid fluids exacerbate the hypoxia associated with pulmonary contusions. Maintenance of euvolemia and judicious use of crystalloids and colloids are considered standard of care, although there are no prospective trials that can substantiate this claim.⁶

Oxygenation and Ventilation.

Pulmonary contusions are a result of parenchymal hemorrhage, interstitial edema, and decreased surfactant production resulting in alveolar collapse and consolidation. These factors contribute to the ventilation/perfusion mismatch, pulmonary shunting, and decreased lung compliance. The primary goal in the management of pulmonary contusions is the maintenance of adequate oxygenation. Treatment modalities include noninvasive and invasive ventilation, high-frequency ventilation, surfactant replacement, and others. The following are several methods that have been studied in an effort to improve survival in patients with pulmonary contusion.

PEEP/NIPPV. Positive end expiratory pressure (PEEP) via mechanical ventilation or noninvasive positive pressure ventilation (NIPPV) remains controversial as the optimal treatment of pulmonary contusion patients. NIPPV may offer an alternative to intubation in the alert patient who can tolerate it, as it is used for other causes of pulmonary edema, but studies have yet to definitively show improved clinical outcomes with pulmonary contusions. A retrospective analysis involving ICU trauma patients with ARDS secondary to pulmonary contusions showed benefit from increasing average PEEP values from 10 cm H₂O to 21 cm H₂O. This small study showed improved PaO₂/FiO₂ ratios, higher lung volumes, and decreased atelectasis.³⁸ The “open lung” concept may be a reasonable mode of ventilation for patients with ARDS from

pulmonary contusions after trauma, but the investigation was not powered to assess overall mortality. PEEP can be associated with high peak inspiratory pressures, which can be harmful in patients with pulmonary contusions, because it can increase pulmonary edema, cause barotrauma through alveolar rupture, and may facilitate both pulmonary venous and pulmonary air embolisms. It should be used with caution and on a case-by-case basis when treating patients with known pulmonary contusions.

While no studies have specifically targeted pulmonary contusions and the use of NIPPV, Antonelli and colleagues examined the use of NIPPV in 2,770 patients with hypoxia and acute respiratory failure and found that of those meeting their criteria for NIPPV, up to 70% did not require subsequent mechanical ventilation, and only 18% of those specifically with pulmonary contusions required intubation. More severely injured patients and those with pneumonia or already with ARDS present were more likely to fail and require intubation.³⁹ NIPPV for pulmonary contusions requires further study, but it may prove to be a useful alternative to intubation in select patients.

Optimal Positioning. Placing the “good” lung in a dependent position to improve oxygenation and selectively intubating the unaffected lung have also been suggested as a ventilatory strategy in pulmonary contusions to improve oxygenation. While these have not been rigorously examined, they do offer further potential respiratory management strategies in patients who are difficult to oxygenate.

Surfactant. The role of surfactant is thought to have a stabilizing effect on the alveoli, which may improve recruitment of non-ventilated alveoli or prevent end-expiratory collapse. Surfactant abnormalities have been demonstrated in animal models with lung contusions and in trauma patients with lung contusions and ARDS. A prospective, randomized clinical trial in Greece demonstrated improved PaO₂/FiO₂ ratios,

compliance, and decreased ventilatory support with the addition of a natural bovine surfactant (Alveofact). This study included 16 patients and was not powered to measure a change in survival.⁴⁰ Previous adult studies with acute lung injury (ALI) have also demonstrated improved oxygenation following surfactant replacement but were not linked to an outcome benefit.

Researchers in Italy used saline and a porcine-derived surfactant (Curosurf) in combination with broncho-alveolar lavage (BAL) to remove breakdown products and blood components from contused lung areas. The study found a statistically significant decrease in the duration of intubation, but this study was also unable to assess mortality benefit due to a small number of patients.⁴¹ While there may be a role for surfactant administration for pulmonary contusions, it has yet to be studied or widely utilized in the emergency department setting.

Prostacyclin. A double-blind, randomized, placebo-controlled trial in the Netherlands investigated whether aerosolized prostacyclin (epoprostenol sodium) compared to aerosolized normal saline improved oxygenation in children with acute lung injury. Fourteen children were included in the study and in the treatment group. There was a significant (26%) improvement in oxygenation compared to placebo after three escalating doses of nebulized prostacyclin in a one-hour time-frame. The number needed to treat was 1.8 without any adverse side effects.⁴² Further studies are needed to determine whether this treatment will provide a mortality benefit in patients with pulmonary contusions.

High-Frequency Oscillatory Ventilation. Pulmonary contusions may lead to severe hypoxia and hypercarbia, which cannot be adequately controlled using conventional mechanical ventilation. High-frequency ventilation is a type of mechanical ventilation that uses very high respiratory rates (more than 60 per minute) and very small tidal volumes. High-frequency ventilation

is thought to decrease the incidence of ventilator-associated lung injury (VALI), especially in the setting of ARDS and ALI. High-frequency ventilation is sometimes called lung-protective ventilation. There are several types of high frequency ventilation, but two in particular have been used in trials of trauma patients with pulmonary contusions.

One type of high-frequency ventilation that has been examined in patients with pulmonary contusions is high-frequency oscillatory ventilation (HFOV). This mode of ventilation is commonly used in premature neonates to improve gas exchange, reduce ventilator lung injury, and reduce levels of inflammatory mediators. HFOV uses a constant mean airway pressure over which small tidal volumes are superimposed at a high respiratory frequency. Using a constant mean airway pressure allows the patient to maintain alveolar recruitment with lower peak airway pressures that limit barotrauma and avoid low end expiratory pressures, which can cause the alveoli to collapse. This mode of ventilation is consistent with the ARDSNet (Acute Respiratory Distress Syndrome Network) low tidal volume strategy and has been validated to provide a beneficial impact on overall mortality.⁴³

A study by Funk et al conducted a retrospective chart review of all patients who received HFOV for severe pulmonary contusions. Patients were placed on HFOV when mean airway pressures were higher than 30 cm H₂O and the FIO₂ was greater than 0.6. Seventeen patients were included in this study at Duke Medical Center (mean ISS 36 and mean time until HFOV was 2.0 days). PaO₂/FiO₂ ratios after 72 hours significantly increased after HFOV was initiated, although this study was underpowered to detect a difference in outcome.⁴³

High-frequency Jet Ventilation. Another mode of high-frequency ventilation used in trauma patients with pulmonary contusions is the high-frequency jet ventilation (HFJV). Unlike the HFOV, in which

air is pushed into the lungs and then pulled out, in HFJV exhalation is passive. HFJV is known to induce an increase in functional residual capacity by an auto-PEEP mechanism (trapping intrapulmonary gases because of incomplete exhalation). At a hospital in France, HFJV has been used for years in the treatment of ARDS in patients with severe bilateral pulmonary contusions refractory to conventional mechanical ventilation.⁴⁴

Over a six-year period (1990-1996), nine trauma patients (ISS 20-75) who received HFJV during the first 24 hours were included in this study. The decision to perform HFJV was made by the senior anesthesiologist in the emergency department. All patients had a PaO₂ < 100 mmHg with FiO₂ of 100%, progressive decrease in PaO₂ during the last few hours without any indication of stabilizing, a failure of PEEP to improve status, and bilateral pulmonary contusions. HFJV was always started in the ED. HFJV increased PaO₂ in all patients (four of the nine died, all from head injury). It is suspected that alveolar recruitment was the cause of the improved PaO₂. HFJV enabled control of PaCO₂ and PaO₂ in patients with life-threatening pulmonary contusions. This study was also underpowered to determine mortality benefit.⁴⁴

Pain Control. Optimal pain control is an important management consideration in patients with significant thoracic injuries and pulmonary contusions. Patients need to be able to perform effective deep breathing and coughing. Combining different modes of analgesia, such as epidurals, opioid PCA, nonsteroidal anti-inflammatory drugs (NSAIDs), and acetaminophen, improves ventilation and physiotherapy.³⁶ Epidural anesthesia and even intercostal nerve blocks may also be useful in patients with persistent pain.¹⁴

Antibiotics and Steroids. There is no indication in the literature for the prophylactic use of antibiotics or steroids in patients who have developed pulmonary contusions after sustaining chest wall trauma.¹¹

Outcomes

The asymmetric lung pathology in pulmonary contusions leads to under-ventilation of the injured (noncompliant) areas and over distension of the non-injured areas of lung, which can result in barotrauma. Asymmetry in lung mechanics can include decreased compliance, increased dead space, and elevated shunt fraction. In an attempt to ventilate the poorly compliant injured lung, elevated mean airway pressures, PEEP, peak pressures, and oxygen concentrations are usually necessary. The resulting mismatch can lead to refractory hypoxemia that may only respond to nonconventional ventilatory strategies, such as one lung ventilation or even lobectomy.

Lung Function Long Term

Most pulmonary contusions heal within one to two weeks.^{2,6} Patients who have larger contusions and additional traumatic injuries may have increased morbidity. In patients who survive the initial trauma and the hospitalization period, many complain of frequent dyspnea, decreased exercise tolerance, and persistent chest pain on the side of injury. Several investigators have studied patients diagnosed with pulmonary contusion with post-recovery pulmonary function testing. Patients with severe chest injury (abbreviated injury score of 4-5) had pulmonary dysfunction at 50% of their predicted values at two weeks after hospital discharge. By four months, the patients began to improve, and at 18 months following discharge, only 5% of patients met criteria for pulmonary disability.¹⁶

An Israeli study evaluated 13 patients who survived blunt chest trauma during 2005 and 2006. At 12-48 months post-injury, all patients underwent complete pulmonary function tests and cardiopulmonary exercise tests. The study included nine men and four women with an average age of 44 years. Six patients smoked, and most had more than three fractured ribs and hemo/pneumothorax at the time of injury.⁴⁵ The results show that most survivors

of severe chest trauma have a good chance of recovery, with near normal pulmonary function tests and fair exercise capacity. Smokers, on average, have worse spirometry results, which might be related to disease of smoking or incomplete recovery after pulmonary contusion.

There is some controversy in the literature regarding long-term respiratory disability from pulmonary contusions. In agreement with the above study, Kishikawa et al and Leone et al both found that patients with significant pulmonary contusions had long-term problems with chronic dyspnea, lung fibrosis, and reduced pulmonary function that ultimately decreased their quality of life.^{46,47} In contrast, two Israeli studies found that survivors of blast injuries with pulmonary contusions had good lung function and no long-term sequelae one year after the sustained injury.^{48,49} Children, likewise, have been shown to have excellent recovery with normal pulmonary function and chest X-rays up to one year after injury.⁵⁰

Complications

Most pulmonary contusion symptoms peak by 72 hours from the time of injury, and the injured lung resolves within seven days of the injury. Small contusions often resolve without any complications and with minimal intervention. However, serious complications can and do still occur despite the relatively short course of the injury. The seriousness of the complications from pulmonary contusions is typically related to the size of the pulmonary contusions as diagnosed at 24 hours from the time of injury. The short-term negative outcomes include death and the requirement for mechanical ventilation, but there are several short-term and long-term complications that can occur from pulmonary contusions.

ARDS. Acute respiratory distress syndrome (ARDS) is a well-known and frequent complication of significant pulmonary contusions that may affect up to 38% of polytrauma patients.⁵¹⁻⁵⁴ The development of

ARDS is associated most commonly with the more severely contused lung and, importantly, those patients with multiple areas of injury or higher Injury Severity Scores.^{35,51}

Pneumonia. Pulmonary contusions decrease the lung's ability to clear secretions and bacteria, thus increasing the risk of pneumonia. Up to 50% of patients with pulmonary contusions will develop a bacterial respiratory infection.^{11,18,19} While early intubation of pulmonary contusions has decreased the rate of early mortality, those patients who require intubation have an increased risk of ventilator-associated pneumonia, especially those requiring a prolonged ventilator course. Evidence also suggests that pulmonary contusions increase the likelihood of post-traumatic empyema by an odds ratio of 3.06.⁵⁵ One of the major causes of mortality late in the course of pulmonary contusion is sepsis, which may be due to a variety of factors, most notably mechanical ventilation and nosocomial infections.

Summary

In years past, mortality occurred in up to 40% of pulmonary contusions; the mortality has greatly improved to approximately 10%.^{4,5,11} Although medicine has greatly advanced our understanding of pulmonary contusions and management issues, this disease still carries a high risk of significant morbidity and mortality. Failure to recognize pulmonary contusions in a timely manner and manage them aggressively can greatly influence the short- and long-term outcomes. Because there is often a delay in presentation of respiratory symptoms, diligent attention to worsening vital signs and physical exam findings, and consideration of repeat imaging are important to the physician caring for the blunt thoracic trauma patient.

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CNE/CME Objectives

Upon completing this program, the participants will be able to:

- a.) discuss conditions that should increase suspicion for traumatic injuries;
- b.) describe the various modalities used to identify different traumatic conditions;
- c.) cite methods of quickly stabilizing and managing patients; and
- d.) identify possible complications that may occur with traumatic injuries.

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5. Which is the best fluid for resuscitation of trauma patients?
 - A. normal saline
 - B. lactated Ringers
 - C. hypertonic saline with Dextran
 - D. All IV fluids cause a dose-related dilutional coagulopathy.
6. What is the mortality risk for a pulmonary contusion involving more than 30% of the lung parenchyma?
 - A. 10%
 - B. 20%
 - C. 30%
 - D. 40%
 - E. 50%
7. What is considered the gold standard for determining the volume of injured lung?
 - A. chest CT
 - B. chest X-ray
 - C. ultrasound
 - D. pulmonary angiography
8. What is the most common thoracic injury associated with blunt thoracic trauma?
 - A. pneumothorax
 - B. pulmonary laceration
 - C. cardiac contusion
 - D. pulmonary contusion
9. Why are pediatric patients less likely than adult patients to have rib fractures associated with a pulmonary contusion?
 - A. Children have a more compliant thoracic cage.
 - B. Children have lung parenchyma that bruises more easily than adult lung tissue.
 - C. Most thoracic injuries to children are from blows to the back/scapula than to the ribs directly.
 - D. Adults have less protective muscle and soft tissue over their trunk than children.
10. What percentage of lung injury is associated with a very high likelihood for intubation?
 - A. 10%
 - B. 15%
 - C. 20%
 - D. 30%

CME/CNE Questions

1. A patient with chest wall trauma and pulmonary contusions after a motor vehicle accident survived the initial injury and hospitalization. What is the patient's long-term prognosis?
 - A. About 50% of patients will have persistent pulmonary dysfunction of more than 50% predicted values on pulmonary function testing.
 - B. Less than 5% of patients will meet criteria for pulmonary disability after one year.
 - C. In the second year after injury, 30% of patients are unable to walk one mile.
 - D. Most patients are oxygen-dependent after their injury.
2. In what situation are steroids indicated in a patient with a pulmonary contusion?
 - A. Steroids are indicated in patients with greater than 20% lung contusion.
 - B. Steroids are indicated in all patients with pulmonary contusions.
 - C. Steroids are not indicated in patients with pulmonary contusions.
 - D. Steroids are indicated in patients with less than 20% lung contusion.
3. Why is high-frequency ventilation (HFV) called "lung-protective ventilation?"
 - A. HFV uses very high respiratory rates and very small tidal volumes.
 - B. HFV has been shown to decrease mortality in patients with lung contusions.
 - C. HFV uses high respiratory rates and high tidal volumes.
 - D. HFV decreases the use of steroids and antibiotics in patients with ARDS.
4. What is the proposed role of surfactant replacement in lung injury?
 - A. Surfactant increases lung volume.
 - B. Surfactant replacement will wash away debris from the injured lung.
 - C. Surfactant is thought to have a stabilizing effect on the alveoli.
 - D. Surfactant may decrease recruitment of non-ventilated alveoli.

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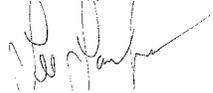
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