Lung Contusion: A Clinico-Pathological Entity with Unpredictable Clinical Course

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ABSTRACT

Lung contusion is an entity involving injury to the alveolar capillaries, without any tear or cut in the lung tissue. This results in accumulation of blood and other fluids within the lung tissue. The excess fluid interferes with gas exchange leading to hypoxia. The pathophysiology of lung contusion includes ventilation/perfusion mismatching, increased intrapulmonary shunting, increased lung water, segmental lung damage, and a loss of compliance. Clinically, patient's presents with hypoxiemia, hypercarbia and increase in laboured breathing. Patients are treated with supplemental oxygen and mechanical ventilation whenever indicated. Treatment is primarily supportive. Computed tomography (CT) is very sensitive for diagnosing pulmonary contusion. Pulmonary contusion occurs in 25–35% of all blunt chest traumas.

Keywords: Pulmonary contusion; Blunt chest trauma; Computed tomography (CT) ventilation

Introduction

In 1761, an Italian anatomist Giovanni Battista Morgagni was the first to describe lung injury not accompanied by chest wall injury [1]. The term pulmonary contusion is thought to have been coined by French military surgeon Guillaume Dupuytren in the 19th century [2]. This injury is an independent risk factor for development of Acute Respiratory Distress Syndrome (ARDS) [3], pneumonia [4], long-term respiratory dysfunction, and is associated with 10 to 25% mortality rate [5]. Lung contusion (LC) is caused by blunt chest trauma, explosion injuries or a shock wave associated with penetrating trauma. These injuries damage alveolar capillaries, so blood and other fluids accumulate in the lung tissue, but it does not involve a cut or a tear of the lung tissue. The excess fluid interferes with gas exchange leading to hypoxia. The pathophysiology of lung contusion includes ventilation / perfusion mismatching, increased intrapulmonary shunting, increased lung water, segmental lung damage, and a loss of compliance [6]. Clinically, patients have hypoxiemia, hypercarbia and increase in labored breathing of varying severity and duration [7]. Patients are treated with supplemental oxygen and mechanical ventilation as necessary. There is often varied correlation between the anatomic extent of contused lung and the degree of hypoxemia [1]. The contusion mostly heals by its own with supportive care, supplemental oxygen and close monitoring, but intensive care may be required. Fluid replacement is required to ensure adequate blood volume, but

this should be done carefully as fluid overload can worsen pulmonary edema, which may be damaging. No pharmacologic therapy is effective, treatment is primarily supportive. Intubation and mechanical ventilation are often required to ameliorate the derangements in gas exchange, lung compliance and work of breathing. Multiple mechanical ventilation strategies have been tried to determine the optimal method to maximize gas exchange with minimal lung damage in patients with acute lung injury [8]. The use of low tidal volumes with appropriate levels of positive end expiratory pressure (PEEP) to ensure lung recruitment (ARDSNet) is the common method of mechanical ventilation of patients with ARDS [9]. Biphasic positive airway pressure ventilation (BiPAP) is increasingly used as an alternative procedure to conventional assisted control ventilation for patients with acute respiratory distress syndrome and acute lung injury. BiPAP permits spontaneous breathing throughout the ventilatory cycle, offers several advantages over conventional strategies to improve the pathophysiology in these patients, including gas exchange, cardiovascular function and reducing or eliminating the need for heavy sedation [10]. There is a significant inflammatory reaction to blood components in the lung, and 50-60% of patients with significant pulmonary contusions develop bilateral ARDS. Most significant pulmonary contusions are diagnosed on plain chest X-ray, but the chest X-ray often underestimate the size of contusion and usually lags behind the clinical picture. Sometimes the true extent of contusion is not apparent on plain film until 24-48 hours following injury. Computed tomography (CT) is very sensitive for diagnosing pulmonary contusion, its size and 3-dimensional assessment. CT differentiates pulmonary contusion from areas of atelectasis or aspiration. Most contusions that are visible only on CT scan are not clinically relevant, in that they are not large enough to impair gas exchange and worsen the outcome. Patients initially have minimal respiratory compromise due to the injury, but may progress to respiratory dysfunction and adult respiratory distress syndrome (ARDS) [3] pneumonia [4], and long-term respiratory dysfunction, with 10 to 25% mortality rate [5]. A pulmonary contusion score incorporating the number of lobes with contusion has been reported to determine prognostication [11].

Etiology

Pulmonary contusion occurs by rapid deceleration when the moving chest strikes a fixed object [12]. Pulmonary contusion occurs in 25-35% of all blunt chest traumas [13] Lung tissue is crushed when the chest wall bends inward on impact [14]. Other causes are falls, assaults and sports injuries.

Clinical Presentation

Impaired gas exchange at alveolar level, leads to decreasing blood oxygen saturation, reduced concentration of oxygen in arterial blood, cyanosis and dyspnoea [15]. There is decreased exercise tolerance [16]. Patient may become tachypnoic and may have tachycardia [17,18] with more severe contusions. On auscultation, patient may have rales and decreased breath sounds in severe contusion [15,19]. There may be wheezing, coughing, bronchorrhea and blood streaked sputum in up to half of cases [12,20]. There may be hypotension and reduced cardiac output. [15,20] Respiratory distress due to hypoxia and hypercarbia peaks at around 72 hours [21].

Mechanism

Disruption of the capillaries of the alveolar walls and septa causes leakage of blood into the alveolar spaces and interstitium [22]. It is the most common type of lung injury in blunt chest trauma [20]. The accumulation of blood and edema becomes apparent at 24 h, making contusion radiographically more evident, although it is detected by CT from the initial imaging [23]. The appearance of radio-opacity on chest radiography after 24 h should raise suspicion of other pathologies like aspiration, pneumonia and fat embolism [24]. Three possible mechanisms of development of contusion are:

1. Inertial effect: The lighter alveolar tissue is sheared from the heavier hilar structures [25], due to different tissue densities at different areas of lung and therefore different rates of acceleration or deceleration [19].

2. Spalling effect: Lung tissue bursts or is sheared where a shock wave meets the lung tissue, at interfaces between gas and liquid [1]. The spalling effect occurs in areas with large differences in density; particles of the spalled denser tissue are thrown into the less dense particles [26].

3. Implosion effect: It occurs when a pressure wave passes through a tissue containing bubbles of gas: the bubbles first implode, then rebound and expand beyond their original volume [27]. The overexpansion of gas bubbles stretches and tears alveoli [28].

Pathophysiology

The pathophysiology of pulmonary contusion and

blunt chest trauma includes inflammation, increased alveolo-capillary permeability and pulmonary edema, ventilation/perfusion mismatching increased intrapulmonary shunting, and a loss of compliance [29]. Clinically, patients with pulmonary contusion manifest in hypoxemia, hypercarbia, and intensified labored breathing [1]. Pulmonary contusion results in bleeding [30] and fluid leakage into lung tissue, which becomes rigid and loses its normal elasticity. The water content of the lung increases over the first 72 hours after injury, and may lead to frank pulmonary edema in more serious cases [1]. The membrane between alveoli and capillaries is torn, and damage to small blood vessels causes both blood and fluid to leak into the alveoli and the interstitial space of the lung [20]. Pulmonary contusion is characterized by micro-hemorrhages that occur when the alveoli are traumatically separated from airway structures and blood vessels [31]. The contused lung is commonly surrounded by an area of edema [31]. Fluid accumulation in alveoli interferes with gas exchange [32] and causes alveoli to be filled with proteins and collapse [31].

Acute Inflammatory Response to Acute Lung Injury

The innate inflammatory response due to direct or indirect insults to the lungs involves recruitment of blood leukocytes, tissue macrophage activation, and the production of a series of mediators including cytokines, chemokines, oxygen radicals, arachidonic acid metabolites and components of the complement and coagulation cascades [33,34]. The physiological dysfunction in this condition is related to existing significant acute inflammation [35].

Lung Contusion and Role of Neutrophils

Neutrophil-induced lung injury is oxidant-mediated, and may also involve impaired alveolar fluid transport function [36]. Oleic acid-induced lung injury is not neutrophil-dependent despite their presence in large number in the lungs [37]. Increased neutrophils in the lungs following LC as reported by Seitz et al., [38] are not associated with increased apoptosis of type II cells that is observed following blunt trauma [39].

Roles of Alveolar Macrophages and Peripheral Blood Monocytes in Lung Contusion

In first 24 hrs following LC injury neutrophilic response predominates, but progresses largely to monocytic response by 48 hr post-contusion [35,40]. Liener et al., [39] suggested that increase in alveolar macrophage in 48 hrs following thoracic trauma is associated with increased type II cell apoptosis, indicating a possible role of alveolar macrophage in the initiation or maintenance of LC injury.

Lung Contusion and Cellular Apoptosis

It is believed that decreased neutrophilic apoptosis and increased alveolar epithelial apoptosis are important for maintenance/progression of acute lung injury/acute respiratory distress syndrome (ALI)/ARDS in lung contusion [41]. Leiner et al., [39] reported growing alveolar epithelial apoptosis following blunt chest trauma, and Seitz et al., [38] documented increased type II cell apoptosis 48 hrs following LC injury.

Toll-like receptors (TLRs) in lung contusion

TLR-2 and TLR-4 have recently been shown to involve in the pathogenesis of pulmonary contusion in murine models [42,43]. A deficiency of TLR-4 appears to be protective in LC injury. The mechanisms underlying these varied effects of TLR receptors on this type of lung injury have not been completely elucidated.

Role of Inflammatory Mediators in Lung Contusion

In closed chest LC-induced injury in rats, levels of cytokine-induced neutrophil chemo-attractant (CINC-1/GRO/CXCL1), macrophage inflammatory protein - 2 (MIP-2)], monocytic chemokine macrophage chemo-attractant protein-1 (MCP-1/CCL2) and IL –1β elevated significantly in BAL at around 24 hrs post-contusion which correlates with rising neutrophil accumulation in the lung parenchyma [35]. They all decline to baseline on day 7 post-contusion [35].

Sub-Acute Pathological Changes in Lung Contusion

In sub-acute pathological changes, relevant to LC injury, bronchiolitis obliterans organizing pneumonia (BOOP) is characterized by the proliferation of granulation tissue within small airways and alveolar ducts [44]. BOOP has been observed in rats 7 days after contusion [35], and has also been reported in other forms of sub-acute lung injury in humans [44,45]. T-cells have been implicated to be important in BOOP-associated fibrosis [46], and these immune cells might be contributing to pathology and resolution of isolated lung contusion.

Lung Contusion and Surfactant Dysfunction

Aufmkolk et al., [47] reported some abnormalities in surfactant lipid composition in bronchoalveolar lavage (BAL) from trauma patients with elevated alveolar plasma protein concentrations [48], which reflect type II cell injury or dysfunction. Such surfactant activity deficits were most severe 24 hrs after contusion, and returned to normal state over 48-96 hr in parallel with improving lung injury parameters [48]. Tracheal instillation of bovine surfactant (Infasurf®) in rats with blunt trauma-induced LC improve pulmonary

function at 24 hr post-injury [48], and surfactant therapy was to be found beneficial in swine with unilateral LC injury [49].

Contributory Factors to Lung Contusion

Concurrent gastric aspiration in trauma can exacerbate permeability of the lung injury and its associated inflammation, and that gastric aspiration unwittingly has the potential to complicate LC injury and progress to ALI/ARDS and pneumonia in patients with thoracic trauma [50].

Consolidation and Collapse

Pulmonary contusion can cause parts of the lung to consolidate, alveoli to collapse, and atelectasis to occur [51]. An inactivation and reduction in the amount of surfactant increase alveolar surface tension which subsequently may cause collapse and consolidation of the alveoli [13,28]. The different blood components entering the lung tissue cause the release of multiple inflammatory factors, increasing the likelihood of respiratory failure [52]. This inflammatory response leads to rising mucus production, plugging parts of the lung and resulting in their collapse [31]. The inflammatory response may also cause uninjured contra lateral lung [52] to develop edema, thickening of alveolar septa [53]. Severe inflammatory response can bring about pulmonary dysfunction as in acute respiratory distress syndrome [54].

Ventilation/Perfusion Mismatch

Normally, the ratio of ventilation to perfusion is about 1:1. This ratio is reduced in pulmonary contusion. As the mismatch between ventilation and perfusion grows, blood oxygen saturation is reduced [55]. Pulmonary hypoxic vasoconstriction, due to the constriction of blood vessels near the hypoxic alveoli in response to the lowered oxygen levels, can occur in pulmonary contusion [56]. The underlying pathology increases vascular resistance in the contused part of the lung, decreasing the amount of blood inflow [53], directing blood to more-ventilated areas [56], a way to compensate the blood passing unventilated alveoli and not getting oxygenated [56]. The oxygenation of the blood remains lower than normal [57], which causes high mortality in trauma patients [55].

Diagnosis

The following aspects are considered for the diagnosis of pulmonary contusion: mode of injury, physical examination, radiography [58], arterial blood gasses showing insufficient oxygen and excessive carbon dioxide even on receiving supplemental oxygen [51].

a) X-ray: Chest X-ray (CXR) is the most common method used for diagnosis [52]. Contusion is not restricted by the anatomical boundaries of the lobes or segments of the lung [56,59,60]. The presence of hemothorax or pneumothorax may obscure the contusion on a radiograph [61]. Signs of contusion that progress after 48 hours of injury are due to aspiration, pneumonia, or ARDS [19]. It takes an average of six hours for the characteristic white region to show up on a chest X-ray, and sometimes contusion may not become apparent for 48 hours [16,56,59].

b) Computed tomography: Findings on chest radiography vary from irregular, patchy areas of consolidation to diffuse and extensive homogeneous consolidation. Radiographic changes of contusion are evident within 6 hours after trauma to the chest, and resolve rapidly, typically within 3 to 10 days. CT findings of contusion consist of non-segmental areas of consolidation and ground-glass opacification that predominantly involve the lung and directed deeply into the area of trauma, often sparing 1 to 2 mm of sub-pleural lung parenchyma adjacent to the injured chest wall [62]. CT is highly sensitive in detecting pulmonary contusions and the volume of lung involvement on CT scanning correlates with clinical outcomes [63-66]. Unlike X-ray, CT scanning can detect the contusion almost immediately after the injury [59].

c) Ultrasound: Portable bedside ultrasound can be equated to visual stethoscope of the 21st century. A lung contusion is diagnosed by the presence of: (a) an irregularly delineated tissue image, which could be a moderately hypo-echoic blurred lesion with no change during respiration or hyper-echoic punctiform images corresponding to air bronchogram; (b) multiple B-lines. The overall sensitivity of 94.6% for ultrasound and 27% for initial CXR [67] to diagnose lung contusion proves sufficient evidence for ultrasonography to diagnose lung contusion in emergency settings. Thoracic ultrasonography as a bedside diagnostic modality is a better diagnostic test than CT and CXR. In comparison with CT scanning, it is a better bedside diagnostic modality when evaluating supine chest trauma patients in the emergency situations, particularly for diagnosing pneumothorax and lung contusions [68]; c) Sub-pleural, echo-poor, irregular bordered lesions without air-inlets and lacking a large focal effusion [69]; d) alveolo-interstitial syndrome defined by increased number of comet tail artifacts/B-lines [69-71]; e) moderate hypo-echoic blurred lesions with indistinct margins of constant dimension even during breathing [69].

d) Histopathological changes: Histopathological evaluation of the lung tissue at 8 min, 4 hr, and 12 hr post-contusion revealed diffuse intra-alveolar hemorrhage with alveolar disruption, along with interstitial hemorrhagic injury that frequently involve peri-hilar areas and extended to the visceral surface of the pleura. At 24 hr post-contusion, atelectasis is pronounced, and there is neutrophilic predominance within the alveoli and interstitium. At 48 hr, neutrophilic infiltration still predominates, while alveolar lining tissue is thickened with an increase in alveolar macrophage and cellular debris [35]. Post-contusion fibrosis around bronchioles predominates after 7 days [35].

Complications Inherent to Contusion and Ventilator Associated

Pulmonary contusion usually resolves spontaneously in 3 to 5 days, provided no secondary insult occurs. The main complications of pulmonary contusion are ARDS and pneumonia. ARDS develops in 17% of patients with isolated pulmonary contusion, while 78% of those with additional injuries develop ARDS [15]. Lung trauma, alveolar hypoxia and blood in the alveolar spaces all activate the inflammatory pathways that result in acute lung injury. Blood in the alveolar spaces provide an excellent medium for bacteria. Clearance of secretions from contused area is decreased which is augmented by any chest wall injury and mechanical ventilation. Good tracheal toilet and pulmonary care is essential to minimize the incidence of pneumonia in this susceptible group. Pneumonia, another potential complication, develops in 20% of people with pulmonary contusion [72].

Pulmonary shunt

A pulmonary shunt is a physiological condition which normally occurs when the alveoli are perfused with blood, while the ventilation fails to supply this perfused area. In other words, the ventilation/perfusion ratio decreases and may reach zero level [73]. A pulmonary shunt occurs when the alveoli are filled with fluid; causing parts of the lung to be unventilated even if they are still perfused [72]. In pathological conditions like pulmonary contusion, the shunt fraction is significantly greater and even breathing 100% oxygen does not fully oxygenate the blood [59]. Pulmonary vasoconstriction often occurs after pulmonary contusion. The pulmonary vasoconstriction is probably a compensatory mechanism to limit perfusion of traumatized parenchyma, but some patients (nonreactors) not demonstrating this response have unchecked increases in shunt fraction [74].

Prevention

Airbags in combination with seat belts distribute impact in the motor crashes more evenly across the body [15]. Child restraints such as car seats protect children from pulmonary contusion in vehicle collisions [75]. Special body armor for military personnel at high risk of sustaining blast injuries, prevent shock wave propagation across the chest wall to the lung, and thus protect wearers from blast lung injuries [76]. These garments contain materials with alternate layers of high and low acoustic impedance in order to "decouple" the blast wave, thereby preventing its propagation in the tissues [76].

Management

Most contusions will require no specific therapy as such. The modality of care in lung contusion is to prevent additional injury, provide supportive care while waiting for the contusion to heal [54]. Treatment helps prevent respiratory failure and to ensure adequate blood oxygenation [13,77]. But large contusions may affect gas exchange and result in hypoxemia. As the physiological impact of the contusion tends to develop over 24-48 hours, close monitoring is required along with administering supplemental oxygen. Tracheal intubation and mechanical ventilation may be necessary if there is difficulty in oxygenation or ventilation. Usually ventilatory support can be discontinued once the pulmonary contusion has resolved, irrespective of the chest wall injury. When the contusion does not respond to other treatments, extracorporeal membrane oxygenation may be used [78]. Lung volume and compliance decrease marginally at 24 h post-contusion injury [35].

Ventilation

Noninvasive positive pressure ventilation including continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BiPAP) may be used to improve oxygenation and treat atelectasis [54]. However it may cause gastric distension by forcing air into the stomach or cause aspiration of stomach contents, especially when level of consciousness is decreased [30]. People with signs of inadequate respiration or oxygenation may need to be intubated [16] and mechanically ventilated [79]. Ventilation can re-open collapsed alveoli, but their repeated opening will be harmful, and positive pressure ventilation can also damage the lung by overinflation [80]. ARDS as a complication of traumatic lung contusion may cause lungs to lose compliance, so higher pressures may be needed to give normal amounts of air [30]. When the

compliance of the injured lung differs significantly from that of the uninjured one, the lungs can be ventilated independently with two ventilators in order to deliver air at different pressures; this provides adequate ventilation and prevents the injury of uninvolved lung from overinflation [81].

A recruitment maneuver is a sustained increase in airway pressure typically performed by increasing the PEEP setting on the ventilator to 30 to 40 cms H_2O for 30 to 40 minutes, followed by applying a sufficient amount of PEEP to keep the lungs open. This strategy is being presumed to be helpful in traumatic lung contusion. Quasistatic pulmonary inflation volumes were severely reduced at 8 min post-contusion, and abnormalities in inflation mechanics persisted at 12 to 24 h [35]. The presence of very early decreases in lung inflation volumes with a lower point of inflection in the inflation P-V curve suggests that recruitment of alveoli with optimal PEEP might play an important therapeutic role in lung contusion [35]. Early positive pressure ventilation with PEEP has been shown to be beneficial in some patients with lung contusion [82-84]. Peak abnormalities in deflation P-V mechanics occurred at 24 h post-contusion [35].

Fluid Therapy

The administration of fluid therapy in individuals with pulmonary contusion is controversial [55]. Measuring pulmonary artery pressure allows the clinician to give enough fluids to prevent shock without exacerbating edema [85].

Diuretics

Diuretics decrease fluid overload in the body system [82] and may be used in the treatment of pulmonary contusion to relax the smooth muscle of the pulmonary veins, thereby lowering pulmonary venous resistance and reducing pressure in the pulmonary capillaries [83].

Supportive Care

Pulmonary toilet, use of suction, deep breathing, coughing, and other methods to remove mucus and blood from the airways [16], chest physiotherapy using methods such as breathing exercises, stimulation of coughing, suctioning, percussion, movement, vibration, and drainage to rid the lungs of secretions, increase oxygenation, and expanding collapsed parts of the lungs [84].

Outcome

The mortality rate of pulmonary contusion is estimated to range from 14–40%, depending on the severity of the contusion and associated injuries [20].

Another study reported, 11% mortality with isolated pulmonary contusion, whereas the number rose to 22% in those with additional injuries [15]. Clearance of an uncomplicated contusion begins at 24 to 48 h with complete resolution after 3 to 14 days [16].

Discussion

Blunt trauma thorax is more common in males than in females [86]. Patients with blunt trauma chest causing pulmonary contusion usually have injury severity score (ISS) greater than 15 [87,88]. Pulmonary contusion is the parenchymal injury characterized by hemorrhage and edema in the alveoli causing failure of the respiratory functions [86,87]. This condition develops 24 hours after blunt trauma to the lungs, decreasing perfusion/ventilation gradient by increasing the pulmonary vascular resistance and decreasing pulmonary compliance [88]. Severe inflammatory reaction in patients with significant pulmonary contusion leads to ARDS in 50 to 60% of cases [89]. Chest radiograph is the first evaluative investigation in chest trauma, but its sensitivity is low in the early period of injury [51]. The length of hospital stay, percentage of patients requiring mechanical ventilation and intensive care unit stay was significantly longer in patients with pulmonary contusion diagnosed with CXR than in those detected by chest CT ($p<0.001$) [88]. Effective treatment of lung contusion includes supportive treatment with monitoring respiratory functions, oxygen saturation and hydration. Complications occur in the form of pneumonia and ARDS [88]. The goal of treatment is to prevent respiratory failure and hypoxia [87]. Lung protective ventilation processes frequently lead to hypercarbia and acidosis. This often limits the ability to apply strict low volume, low pressure strategies. One technique that has been shown to be promising in military casualties is extracorporeal removal of carbon dioxide [90], but there is limited evidence to support its efficacy. A comparison between ECMO and ECMO plus partial liquid ventilation showed a greater improvement in lung compliance and reduction in physiological shunt in the liquid ventilation group, but the benefits of perfluoro-carbon liquid ventilation are not substantiated [91]. Pulmonary contusion develops in 30 to 75% of blunt chest traumas [92]. In a recent European epidemiological study, mortality of patients with ALI/ARDS due to lung contusion exceeds 20% [93]. In a retrospective analysis of patients with ARDS due to pulmonary contusion Schreiter and co-workers showed that mechanical ventilation, according to the open lung concept, dramatically improved oxygenation and lung aeration [94]. Current clinical

ventilation strategies demonstrate that volume-limited device can reduce mortality in these patients [95]. The inflammatory response in pulmonary contusion may be either compartmentalized in the alveolar space or in the systemic circulation [96-99]. Loss of pulmonary compartmentalization could result in the development and progressive multi-organ failure [100], the leading cause of mortality in ARDS patients [101]. Intra-alveolar hemorrhage can progress to ALI/ARDS which can increase mortality due to severe hypoxia [102]. Despite advances in pulmonary care and ICU management, pulmonary contusion has higher mortality and morbidity in patients with other severe injuries. The elderly patient does not tolerate major chest trauma as mean age of survivors (36.6 yrs) was statistically lower than non-survivors [103]. It has been reported that lung isolation procedures may be required in 33% of patients with airway bleeding [104]. Pulmonary contusion occurs in about 17% of people with multiple injuries and an injury severity score of over 15 [1].

Future Directions

Current work established a functional role of neutrophils in the inflammatory response to LC injury. The important aspect for future involves studies to define in more detail the mechanistic importance of other cell types like alveolar epithelial cells and the alveolar macrophages. Future studies are warranted to address and clarify the importance of signaling via TLR-2 and TLR-4 in LC injury, and extend interpretations to other receptors such as TLR-3 and associated ligands. Further investigations are also needed to elucidate the role of fibroblast proliferation and the pathogenesis of fibrosis during healing/resolution phase of inflammatory LC; they may have broader applications to fibro-proliferative ALI/ARDS and chronic lung disease outside the trauma field. Improvements with intravenous corticosteroids, antioxidants and exogenous surfactants in LC have been noted in animal models [48], but this has not been extrapolated to clinical studies in patients with LC. New synthetic surfactant preparations contain phospholipase-resistant components [105,106]. T cells have been associated with BOOP-associated fibrosis, and these immune cells may contribute to the pathology and resolution of isolated lung contusion [35,46].

Conflict of Interest: None declared.

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