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EMERGENCY RADIOLOGY (J YU, SECTION EDITOR)

Blunt Chest Trauma: A Radiologic Approach and Review

James Cassuto[1] · Nisreen Ezuddin[1] · Gary Danton[1]

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Abstract Blunt chest trauma, a frequent component of trauma admissions, is the second leading cause of death in motor-vehicle accidents. Additionally, it may be associated with significant morbidity in those who survive. Radiography, ultrasonography, and computed tomography (CT) have a widespread role in evaluating blunt chest trauma, importantly aiding in the diagnosis and management of injury. Herein, we discuss the most common salient injuries, imaging protocol considerations and imaging findings associated with acute blunt chest trauma.

Keywords Blunt chest trauma · Pleural injury · Blunt aortic injury · Cardiac injury · Diaphragmatic rupture

Introduction

Blunt chest trauma is frequently a component of trauma admissions, is the second leading cause of death in motor-vehicle accidents, and may be associated with significant mortality [1]. It most commonly results from a sudden high-speed deceleration with impact to the anterior thorax, causing injury to the underlying vessels, bone, soft tissue, and organs. Radiography, ultrasonography, and CT have a widespread role in evaluating blunt chest trauma given its universal presence, with conventional angiography and magnetic resonance imaging (MRI) serving as important adjunct modalities in more stable patients. This chapter will discuss the salient injuries and their associated imaging findings following acute blunt chest trauma.

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✉ Gary Danton
Gdanton1@med.miami.edu

1 Department of Radiology, Jackson Memorial Hospital/University of Miami Miller School of Medicine, 1611 NW 12th Ave, Miami, FL 33136, USA

Imaging Technique

Chest radiographs are part of the standard initial acute trauma workup. Most commonly, these are performed anteroposterior (AP), supine, while the patient remains on the trauma backboard. X-ray technologists should be considered part of the trauma team and included as part of a trauma alert. This facilitates acquisition of the radiograph as quickly as possible. Digital equipment with immediate display of the acquired image allows initial interpretation by the trauma team in the resuscitation unit.

CT angiogram (CTA) either alone or as part of a full body scan would be the next imaging test if additional workup was required. CTA is preferred in both blunt and penetrating trauma to allow evaluation of vascular injuries. Delayed images of the chest can be helpful to properly characterize vascular injury or active bleeding if found on initial screening.

MRI is not commonly used in the acute setting, but can be useful for a more thorough evaluation after the patient is stabilized. Examples include MR angiography (MRA) for vascular injury, cardiac MRI for cardiac injury, thoracic spine MRI for spine and cord injuries, and dedicated MRI of the bones and joints for conditions such as sternoclavicular dislocation and acromioclavicular joint injury.

Bedside ultrasound is being utilized more often by the clinical services to assess a variety of conditions, including pneumothorax, hemopericardium, hemothorax, and rib/sternal fractures, with recent evidence showing that ultrasound has a higher sensitivity for detecting pneumothoraces than plain radiograph [2]. The drawback of bedside ultrasound, however, is its operator variability.

Pleural Space

Traumatic Pneumothorax

A traumatic pneumothorax is defined as air in the pleural space and may occur secondary to alveolar over pressurization and subsequent rupture from blunt trauma (Fig. 1) [3]. A chest radiograph is the initial imaging modality of choice and classically demonstrates the visceral pleural line (e.g., *free lung edge*) with a lack of peripheral lung markings. On an upright film, a pneumothorax will be present in the apical pleural space; on a decubitus film, it may be present in the non-dependent pleural space; on a supine film, a "deep sulcus sign may be seen," indicative of a basilar pneumothorax causing deepening of the costophrenic recess (Fig. 2). While tension or large pneumothoraces will be visible on the low volume supine exams available acutely, it is important to recognize that overall sensitivity will be reduced. Historically, expiratory views have been suggested as being better able to detect pneumothoraces, but there is a paucity of evidence for this practice [4]. We no longer recommend our ordering providers request expiratory views. Subtler radiologic findings that are useful in the diagnosis of an anterior pneumothorax include a hyperlucent hemithorax and increased definition of the mediastinal border. A tension pneumothorax will show a contralateral mediastinal shift and ipsilateral flattening of the hemidiaphragm.

In the setting of acute trauma, a chest CTA or, less commonly, a plain CT is ordered depending on the mechanism of injury or if concerning findings are noted on radiograph. CT can also help distinguish trauma pathology from underlying cystic lung disease or bullous emphysema, which should be considered if the diagnosis of pneumothorax is uncertain prior to chest tube placement.

A common pitfall in the diagnosis of a pneumothorax is mistaking a skin fold as the visceral pleural line (Fig. 3). Skin folds occur on supine radiographs when the technologist slides the detector behind the patient who is lying down in bed. The detector pushes the skin into a fold such that the patient effectively becomes thicker laterally until the fold ends. Misdiagnosed pneumothoraces have unfortunately resulted in otherwise normal patients receiving chest tubes. Overlying bed sheets, the scapula and/or machines and devices located outside the chest wall can be distinguished from a pneumothorax by identifying lung vessels between the mimicker and thoracic wall and extension of the mimicker overlying the soft tissues, outside of the border of the lung.

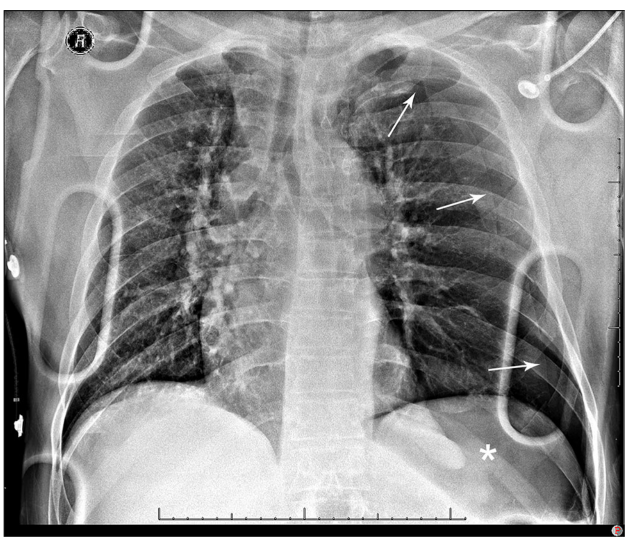

Fig. 1 This single AP radiograph of the chest is typical of the supine radiographs obtained with overlying leads and on a backboard. The large ovals projecting over the chest are due to the handles of the trauma board. A visceral pleural line is seen towards the lateral aspect of the left thorax (arrows). The left lung base appears hyperexpanded with increased lucency seen overlying the left upper abdomen (asterisk) and the left heart border appears sharp indicating a large basilar component to the pneumothorax. The patient is rotated to the right which makes it difficult to assess the extent of tension but the expansion of the left thorax with the shift in the cardiomediastinal silhouette indicates a component of tension pneumothorax is present. While this large pneumothorax is readily visible, small pneumothoraces may be easily missed on these supine, AP radiographs with overlying backboards

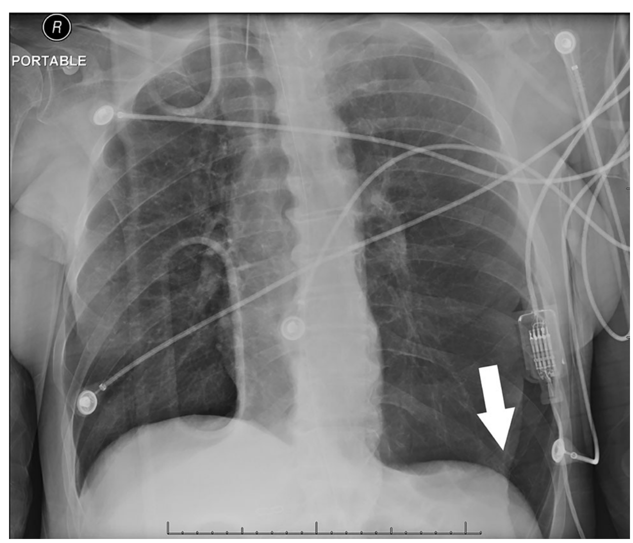

Fig. 2 A single supine AP radiograph with the patient on a trauma backboard shows depression of the left diaphragm with a "deep sulcus sign" (arrow) indicating a basilar pneumothorax in a supine patient

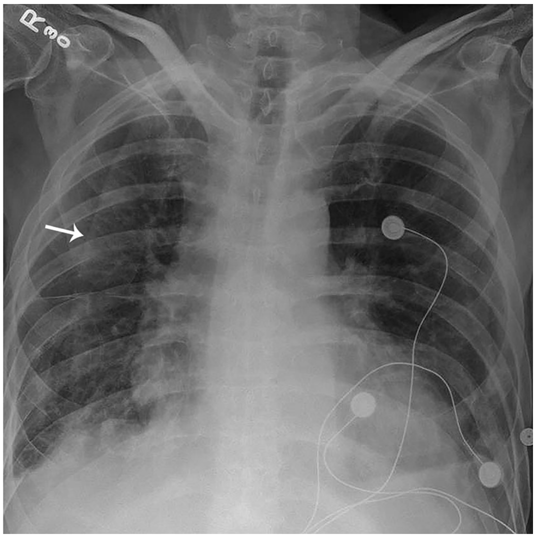

Fig. 3 Single supine radiograph demonstrates the typical pattern of a skin fold. Note that the free edge is not a sharp thin line, but rather there is a gradual transition from less to more radiopacity until the increased density ends which creates the appearance of a line (arrow). This is the typical appearance of a skin fold and should not be mistaken for a pneumothorax

The most inferior edge of the lung just above the diaphragm may also be a source of false positives and negatives (Fig. 4). On axial images, the edge of the lung just above the liver can appear devoid of vascular markings and overcalled as a small pneumothorax. Conversely, a small pneumothorax lying in the anterior costophrenic recess just anterior to the liver may be dismissed or go unobserved. While these pneumothoraces usually resolve on their own, they could expand and present clinically later on, making it important to make the diagnosis. When a pneumothorax is present, the area of air density frequently extends lower than what is normally expected for the edge of the lung, which is best appreciated on sagittal and coronal images. Comparison with the contralateral side can be helpful as well. Sagittal and coronal images will also help distinguish between pneumothorax and small pneumoperitoneum or soft tissue air dissecting in the lower chest and upper abdominal wall. Looking carefully for the presence of pneumoperitoneum or subcutaneous emphysema and looking carefully at the muscle planes can help make this distinction.

Hemothorax

A hemothorax is the presence of blood in the pleural space and is commonly seen in the setting of blunt trauma. It rarely presents as an isolated finding and may be concomitant with rib fractures, pneumothorax, lung contusion, or other visceral injuries. Patients may be hemodynamically unstable from lacerated vessels. Supine and upright chest radiographs may demonstrate fluid within the pleural space. This finding is often mislabeled as a pleural effusion. In the setting of trauma, however, unless the patient appears to have radiographic features of comorbid conditions or is elderly, these are more likely to be hemothorax. Hounsfield attenuation values can help differentiate simple fluid from blood and CTA images may be helpful in identifying the source of vascular injury. Large hemothoraces may show contralateral mediastinal shift and atelectasis of the affected lung. A large amount of fluid in the thorax warrants further evaluation with CTA to distinguish

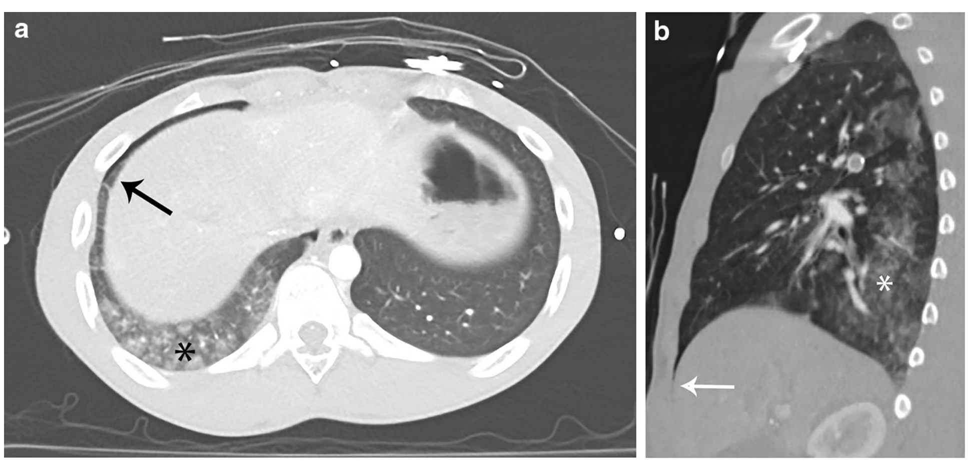

Fig. 4 **a** Axial CTA image of the chest shows a lucency just anterior to the liver. A visceral pleural line is seen at the junction of the lucency and the adjacent lung confirming this as a pneumothorax. The edge of the lung can sometimes appear lucent in this region and may be a reason for a false positive identification of pneumothorax. Careful scrutiny of sagittal views (**b**) are very helpful to look for lucency extending anteriorly along the liver more inferiorly than what is normally expected (arrow). This can help confirm or exclude the presence of a small pneumothorax. The asterisk in (**a**) and (**b**) demonstrate ground-glass opacities of a pulmonary contusion in this patient with blunt thoracic trauma

hemothorax from incidental pleural effusion, esophageal rupture, or thoracic duct tear, which will present with a chylothorax. Patient management may change depending on the volume and type of fluid suspected.

Rib Fractures/Flail Chest

The most common mechanism causing rib fractures is blunt trauma (i.e., motor-vehicle accidents, falls from height, assault, excessive coughing) [5]. Roughly 10% of patients who experience blunt chest trauma have one or more rib fractures [6]. Patients may present with chest wall pain, dyspnea with deep breathing, and severe local rib tenderness, swelling, and crepitus. The presence of rib fractures is more common with advancing age, with a significantly increased mortality associated with 1st and 2nd rib fractures, given the relation to great vessel injury. Flail chest is defined as 3 or more segmental rib fractures or greater than 5 adjacent rib fractures with the flail segment showing paradoxical motion with respiration. Clinical findings may not be evident in about 30% of cases and may be masked in patients receiving positive pressure ventilation.

A chest radiograph is often the initial imaging modality obtained and may detect displaced rib fractures and identify associated injuries, such as pneumothorax, hemothorax, and pulmonary contusion. Initial radiographs may not show non-displaced fractures and these may only be evident when the fracture begins to heal by producing periosteal reaction and callus. With mild thoracic trauma, a rib series may be obtained, which increases sensitivity to detect rib fractures.

The presence of a rib fracture adjacent to the liver or spleen should raise the suspicion for solid organ injury. Occasionally a finding in the liver or spleen poses a challenge as to whether it is a traumatic injury, incidental finding, or normal variant. The presence or lack of adjacent rib fractures can be a useful factor in distinguishing between these entities. [7•] Routine use of chest CT is institution and practitioner dependent, but may identify subtle fractures. While mild fractures may seem trivial, they can be painful. This is particularly important in the lower ribs, as unexplained pain could herald delayed presentation of abdominal injury. The presence of non-displaced rib fractures may explain the pain and reassure the clinical team that the patient is indeed stable.

Fractures due to blunt trauma frequently occur along multiple ribs in adjacent locations. Pathologic fractures often do not occur on multiple adjacent ribs and may occur with minimal trauma. They are less likely to present with associated injuries.

Cardiac Injury and Contusion

The incidence of blunt cardiac injury is estimated at 30,000 cases per year in the United States, and ranges from benign etiologies such as cardiac contusion to lethal injuries, such as chamber rupture [8]. In the setting of trauma, cardiovascular injures are second to neurological injuries as the primary cause of death [9]. Valvular involvement during initial patient presentation to the hospital is rare, as most of these patients die on scene [8]. Motor-vehicle accidents account for 81% of cardiac trauma, followed by crush injuries (5.7%) [9]. The primary mechanism of injury is a consequence of compressive forces on the heart from the sternum anteriorly and the thoracic spine posteriorly. This mechanism of injury preferentially affects the right atrium, given its anterior location within the chest. Additional mechanisms of injury are a result of the “ram effect” of increased abdominal pressure causing cephalad herniation of viscera and rapid changes in atmospheric pressure during blast injury.

Cardiac concussion (lack of myocardial cell damage) is the mildest form of blunt cardiac injury and may manifest as segmental wall motion abnormalities on echocardiogram without increase in acute phase cardiac markers, such as troponins. Chest wall ecchymosis is seen in 30% of patients with cardiac contusion (Fig. 5), pathologically defined by sharp contrast between normal and injured myocardial cells (compared to infarction, where the transition is gradual). In addition to electrocardiogram changes and elevated cardiac enzymes, cardiac contusion may manifest as increased myocardial echogenicity with wall motion abnormalities on echocardiography [9], decreased perfusion on myocardial scintigraphy [10], and decreased perfusion on contrast enhanced helical CT [11]. In a study involving 42 patients with documented blunt cardiac injury, Hammer, et al, documented 33% of patients presenting in cardiogenic shock, 33% of patients demonstrating arrhythmia, 50% of imaged patients having wall motion abnormalities on echocardiography, 73% having associated rib fractures, 64% having pulmonary contusion, and 40% demonstrating pericardial effusion [11]. The most serious myocardial injury in the setting of blunt trauma is free-wall rupture, which is typically fatal. For patients who survive, pericardial tamponade is often present. Importantly, rupture may occur up to 2 weeks following the initial insult. CT findings of myocardial wall rupture include discontinuity of the ventricular wall, communication of the ventricle or atrium with the pericardium, hemopericardium, and/or contrast extravasation into the pericardium [12]. A complication of free-wall rupture includes the development of pseudoaneurysm—a consequence of pericardium sealing of the myocardial defect with the development of an organized thrombus.

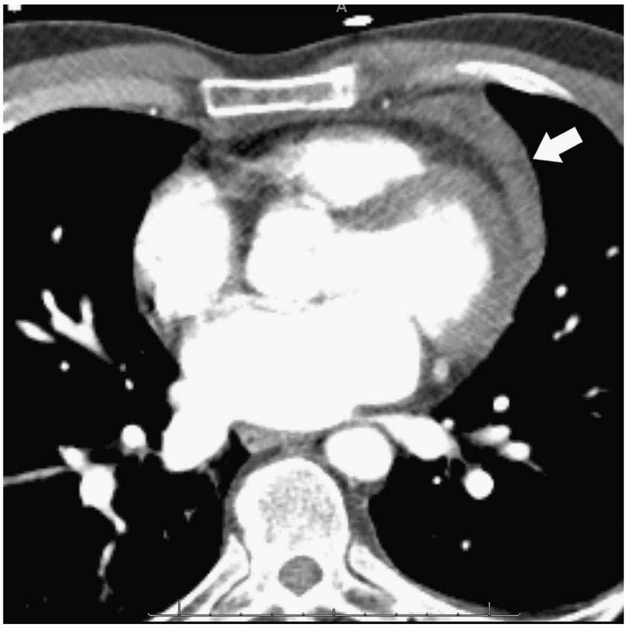

Fig. 5 A focal pericardial hematoma (arrow) was seen in this patient with a history of coronary artery disease after severe blunt chest trauma. Echocardiographic wall motion abnormalities and EKG changes were documented shortly after presentation. The patient was clinically and echocardiographically diagnosed with a severe cardiac contusion which was believed to precipitate a myocardial infarction from contusions to the already diseased coronary arteries. Focal pericardial hematomas should raise the possibility of cardiac contusion when seen on CT

Pericardial tear with cardiac herniation is a rare complication of blunt cardiac injury, occurring in 0.4% of patients with pleuropericardial tearing occurring on the left in 50% of patients (Fig. 6). Pericardial tears in the 8–12 cm range may facilitate cardiac luxation. The mortality for this injury is high, with survival rates for those who present alive to the hospital only ranging from 57 to 64%. Diaphragmatic surface tear of the pericardium may result in herniation of abdominal contents into the pericardial sac. Associated injuries include cardiac contusion, dysrhythmia, rib fractures, pneumothoraces, spine injury (32%), abdominal injury (27%), pelvic and long bone fracture (49%) [13]. Radiograph findings may be normal or demonstrate abnormalities, including boot-shaped cardiac silhouette, elevation of the heart off the left hemidiaphragm, pneumopericardium, herniation of bowel contents into the pericardial sac, herniation of the heart into either hemithorax, rotation of the heart, or a "waist" surrounding the heart, which may reflect herniation. CT findings include pericardial dimpling, pneumopericardium, interposition of lung between the great vessels, empty pericardial sac with heart luxation into a hemithorax, constriction of the heart by the pericardium resulting in the *collar sign*, and indirect signs such as enlargement of or contrast reflux into the vena cava [14, 15].

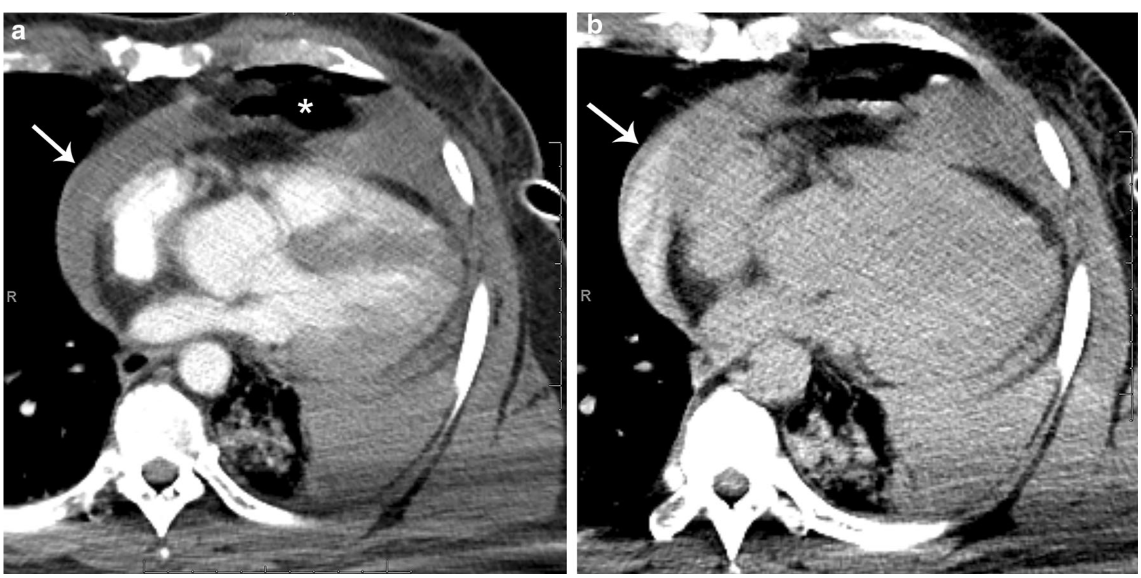

Fig. 6 **a** CT following blunt thoracic trauma demonstrates a large pericardial effusion (arrow) and twisting of the cardiac axis towards the left lateral chest wall. The AP diameter of the heart is narrowed and the heart is shifted to the left. Anterior to the heart is components of pneumothorax and pneumomediastinum (asterisk). Pulmonary contusion and hemothorax are seen posterior to the left ventricle. **b** The heart was observed on delay images and showed contrast density (arrow) in the pericardial hematoma. This suggested active bleeding into the pericardium. This was confirmed in the OR as being due to a pericardial tear with rupture of the anterior, intrapericardial portion of the IVC. Pericardial tears may result in luxation of the heart with torsion of the cardiac axis to the left and associated hemodynamic instability

Lung

Pulmonary Contusion

Lung contusion is the most common type of lung injury in blunt chest trauma [16] and is a focal parenchymal injury caused by a disruption of the capillaries in the alveolar walls and septa, which cause a leakage of blood into the alveolar spaces and interstitium [17]. Initial imaging with chest radiographs may not reveal signs of lung parenchymal injury, but edema and hemorrhage may be noted 24 h after initial insult (Fig. 7). On CT, a consolidation may be indicative of pulmonary contusion, aspiration, or fat embolism [18]. Contusions are not restricted to lobar boundaries and can appear as geographic, non-segmental areas of ground-glass, nodular opacities, or consolidation on CT [19]. Often described with pulmonary contusions is a 1–2 mm area of lucent subpleural sparing between the opacity and the visceral pleura. Uncomplicated contusions may completely resolve after 3–14 days; a lack of resolution should raise concerns for pneumonia, abscess, or acute respiratory distress syndrome. Even small contusions are important to describe, as trauma patients with an otherwise benign clinical appearance may be admitted for observation

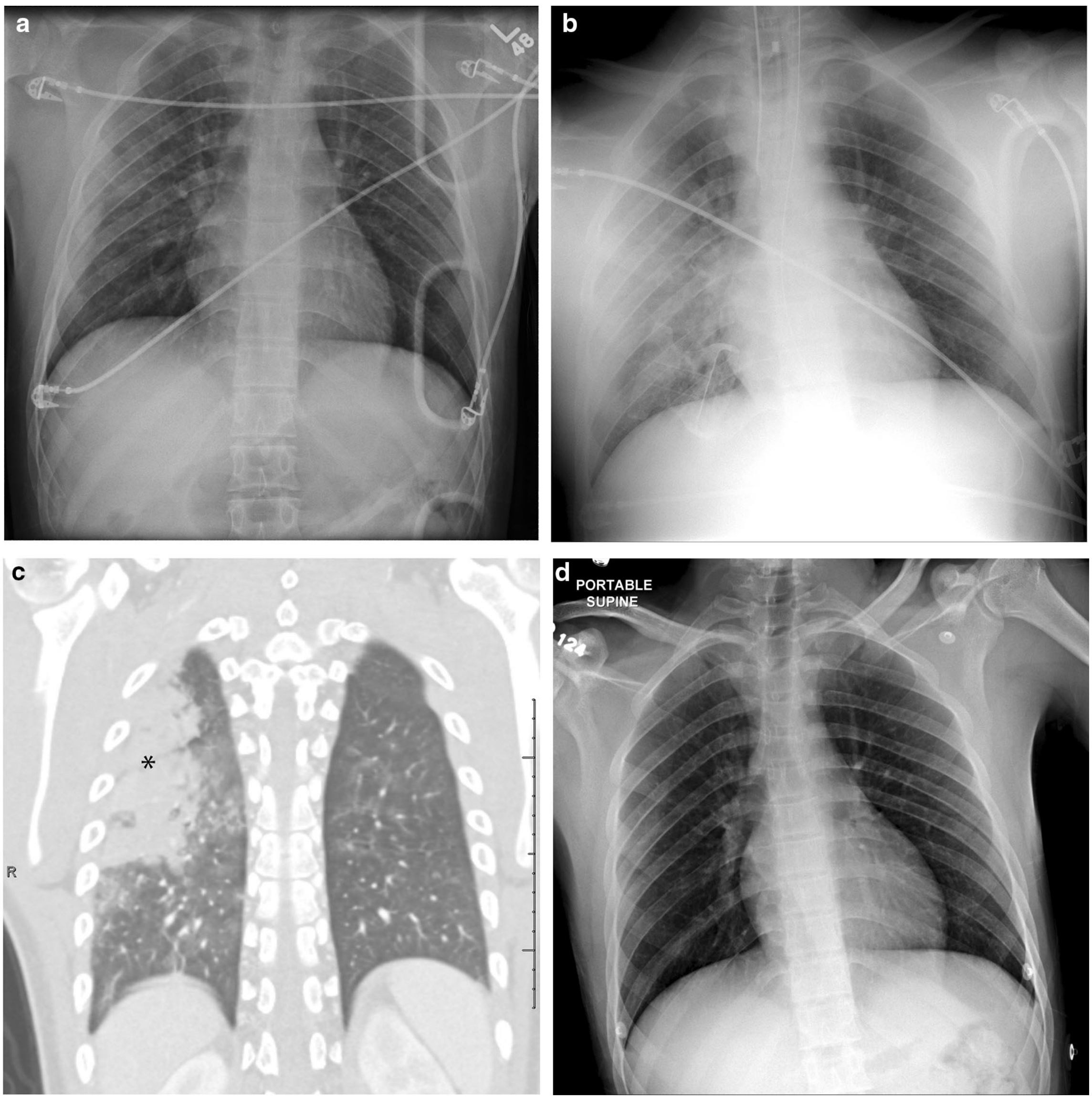

Fig. 7 **a** Initial chest radiograph immediately upon arrival in the trauma resuscitation unit revealed fairly clear lungs with some peripheral opacity along the right lateral chest wall and hazy opacities of the lateral right upper lobe. **b** At 90 min the pulmonary opacities significantly worsened, revealing pulmonary contusions throughout the right lung. **c** The extent and appearance of the contusions were confirmed on CT performed just after the 90 min chest radiograph. **d** By 3 days, the radiograph had almost normalized. While the timeline for resolution may vary, pulmonary contusions frequently worsen initially after presentation and then begin to resolve

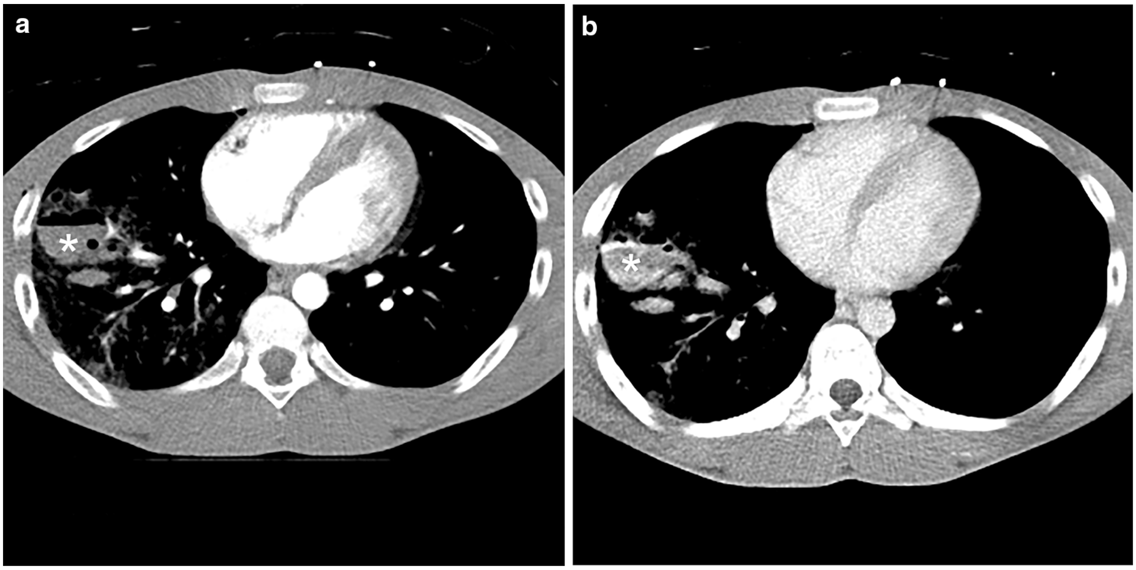

Fig. 8 Pulmonary lacerations appear as air or blood filled focal areas usually round or oval in shape surrounded by pulmonary contusions. This large laceration (asterisk) was filled with intermediate density fluid on early images but on delayed images (**b**) was seen filling with higher attenuation contrast (asterisk). This indicates active bleeding into the pulmonary laceration

if a contusion is identified. Large pulmonary contusions over 20% of the total lung volume carry an increased risk for acute respiratory distress syndrome and poor outcome [20].

Pulmonary Laceration

Pulmonary laceration results when damage to the lung parenchyma occurs following shearing forces from direct impact, compression, or inertial deceleration [21] (Fig. 8). Due to the elastic recoil of lung parenchyma, tissue surrounding the laceration will retract from the injury itself. There are four types of lung lacerations, based on the mechanism of injury. The most common is a type I laceration that occurs when the compression injury is centrally located with compression of the lung against the tracheobronchial tree. Type II is an injury that results from the lower lobes compressing against the spine and occurs paraspinally. A type III injury is due to a rib penetration tear, is peripherally located, and is usually associated with a pneumothorax. A type IV injury is caused by an adhesion tear adjacent to a previous pleuropulmonary adhesion and is generally found during surgery or on post-mortem survey. CT findings of pulmonary laceration are a round or oval cavity filled with air, blood, or both. In the acute setting, contusions may be seen surrounding the laceration limiting its identification on radiographs.

Esophagus and Tracheobronchial Injury

Esophageal Injury

Esophageal injury is more prevalent in penetrating or iatrogenic injury (i.e., esophageal perforation) and occurs in 1% of blunt chest trauma cases [22]. The mechanism of injury is a direct blow to the neck, namely the cervical esophagus, burst-type force or hyperextension injury, or rupture secondary to a vertebral body fracture [22, 23]. On imaging, CT will show associated injuries as a result of esophageal rupture, such as pneumomediastinum and periesophageal air or abnormal mediastinal contour, due to leakage of fluid, hematoma, or mediastinitis. The diagnosis may be confirmed with water-soluble esophagography, which may show leakage of contrast medium into the mediastinal or pleural space [24].

Tracheobronchial Injury

Tracheobronchial injury (TBI) is a rare, but serious condition that occurs from high-speed motor-vehicle accidents [25] (Fig. 9). While injury to the tracheobronchial tree is common, tracheobronchial laceration or bronchial avulsions secondary to blunt chest trauma are rare, with a prevalence of 3.0–4.4% and 1–2% of all blunt trauma cases, respectively [26, 27]. Most blunt injuries occur in the distal trachea or in the right mainstem bronchus [28], as a result of direct trauma or hyperextension. Patients may present with dyspnea, respiratory distress, hoarseness, dysphonia, and stridor. Given that TBIs are not diagnosed immediately in 25–68% of patients, a high index of suspicion is necessary for quick diagnosis [29].

Initial chest and cervical C-spine x-rays may show deep cervical emphysema and pneumomediastinum in around 60% of patients [25]. A complete separation of the mainstem bronchus will result in lung collapse. When the collapse occurs away from the hilum and towards the

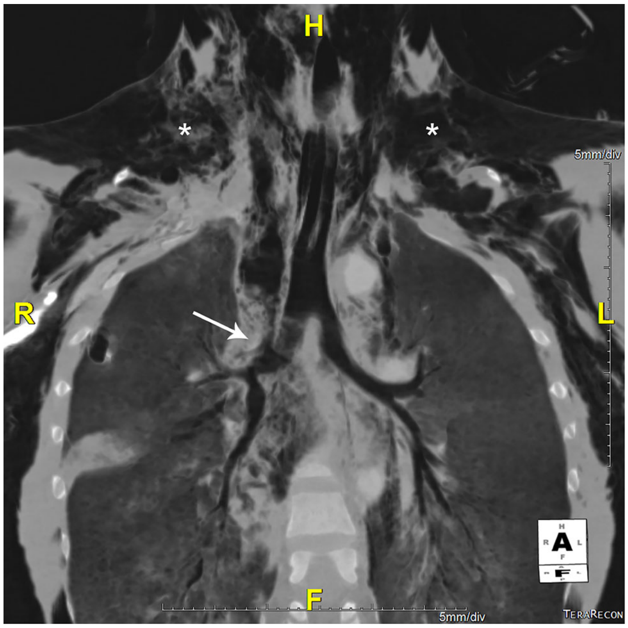

Fig. 9 This coronal minimum projection image (Minip) demonstrates irregularity of the right main stem bronchus (arrow) when compared to the left. There is extensive soft tissue, mediastinal and subcutaneous emphysema (asterisks) bilaterally but worse around the right main bronchus and right paratracheal soft tissues. Frothy material is also seen in the right main stem bronchus. A right bronchus injury was diagnosed by CT and confirmed at surgery. Characteristics of this uncommon injury include the extensive soft tissue air that dissects through the mediastinum and into the subcutaneous soft tissues

diaphragm it is known as the *falling lung sign of Kumpe* [30]. A chest CT is crucial in evaluating great vessel injuries and mediastinal hematomas and may reveal pneumomediastinum, separation in the tracheobronchial air column, respiratory tract deviation, or simply an irregular appearance of the bronchus with frothy material in the airway. Other CT findings include: disruption of the tracheal and bronchial cartilage rings, thickening of the tracheal or bronchial wall, or laryngeal disruption.

Bronchial injuries are more common than tracheal injuries. Bronchial lacerations classically parallel the cartilaginous rings of the bronchi. Pneumomediastinum and pneumothorax are commonly seen, with persistent pneumothorax after chest tube placement. This observation warrants consideration for a bronchopleural fistula. Tracheal lacerations are typically vertical in alignment and occur at the junction of the cartilaginous and membranous portions of the trachea. Cervical subcutaneous emphysema and pneumomediastinum are common radiologic findings. If chest CT demonstrates injury to the tracheobronchial tree, definitive diagnosis and better evaluation of the extent of disease with bronchoscopy are recommended.

Diaphragm and Chest Wall

Chest Wall Fractures

Sternal fractures (Fig. 10) and dislocations (Fig. 11) are typically associated with two primary mechanisms of

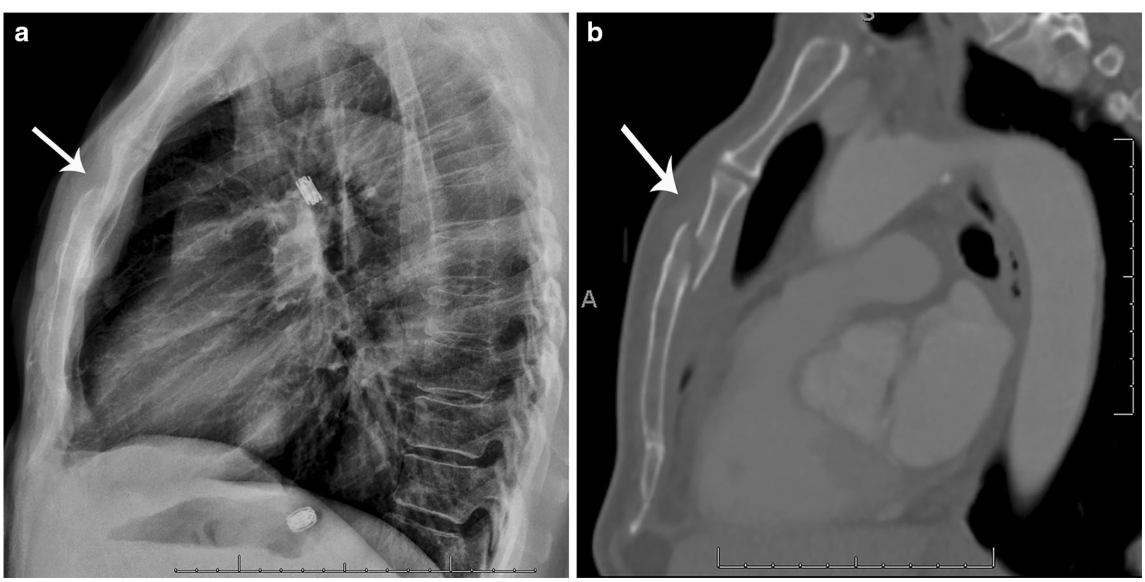

Fig. 10 Sternum fractures can be missed on radiograph and on CT if the sternum is not carefully inspected. Without dedicated sternal views, the lateral chest radiograph (**a**) can reveal the presence of a sternal fracture by following the anterior and posterior cortex looking for discontinuity (arrow) and retrosternal soft tissue attenuation from a hematoma. On CT, the sagittal images (**b**) are very helpful for detecting subtle sternal fractures but the sternum should be inspected in all three planes. A small retrosternal hematoma on CT may be the initial clue to a subtle sternal fracture

injury, (1) direct blow to the anterior chest wall such as in a front-end automobile collision with steering wheel/airbag impact or (2) significant flexion-compression movement of the trunk with concomitant rib or spine fractures. The incidence of sternal fracture in the setting of blunt chest trauma ranges from 1.5 to 18%. Organ injuries associated with the force necessary to fracture the sternum may carry up to a 45% mortality. When associated with rib and spine fractures the thorax may become unstable with resultant shallow respirations, alveolar collapse, arteriovenous shunting, hypoxemia, and pulmonary insufficiency. Accordingly, pulmonary contusion, rib fractures/flail chest, spine fractures, and cardiac contusions need to be evaluated when imaging findings demonstrate sternal fracture or dislocation [31•].

Scapula fractures in the setting of blunt chest trauma are uncommon, with an incidence ranging from 0.5 to 3.7%. Importantly, these fractures portend associated thoracic injury in almost 50% of patients, including rib fracture (46%), lung contusion (31%), and pneumothorax (39%). Additionally, intra-abdominal and head injuries are also common in this setting, occurring in 13 and 54%, respectively [32]. As nearly 90% of scapular fractures are non-displaced, identification on plain radiographs, particularly with overlying injury and radiodense trauma equipment, is difficult. Thus, CT is often necessary to identify scapular fracture in this setting with particular attention paid to sagittal and coronal reconstructions [33].

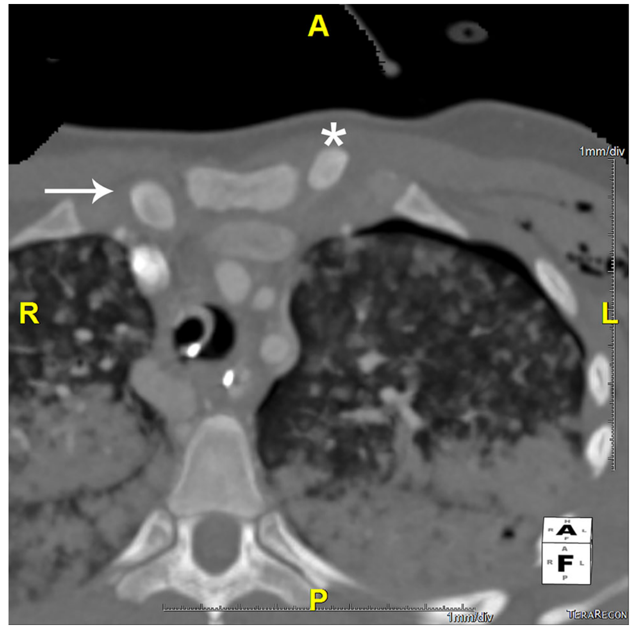

Fig. 11 Directed inspection of the sternoclavicular joint is important to avoid missing a sternoclavicular dislocation. Subtle signs of sternoclavicular joint injury include adjacent excess fluid, hematoma, or air. Dislocation or subluxation of the clavicle with respect to the manubrium confirms the injury. Sometimes an indentation of the skin superficial to the clavicular heads heralds the injury. The asterisk marks the anteriorly dislocated left clavicular head. The skin bulge is seen as well and these findings were confirmed on clinical exam. The easiest way to make the diagnosis on CT is to note the asymmetry between the left (asterisk) and right (arrow) clavicular heads and note their vastly different positioning with respect to the joint. Sagittal and 3D images may be helpful as well. Also present are airspace opacities worse in the posterior portions of the upper lobes due to extensive pulmonary contusions and a left anterolateral pneumothorax is seen in the pleural space along with adjacent subcutaneous emphysema

Diaphragmatic Injury

Major blunt abdominal and chest wall injury is associated with a 1–8% incidence of diaphragmatic rupture (Fig. 12). The proposed mechanism of injury is a sudden increase in intra-abdominal-thoracic pressure against a fixed diaphragm [22]. While plain chest radiographs are abnormal in up to 77% of patients, less than 50% of cases are suspected of having diaphragmatic injury [34]. The sensitivity of CT for detecting diaphragmatic injuries is controversial with mixed data. Sprunt et al, concluded that CT was not reliable for diagnosis of diaphragm injury with only 57% of scans demonstrating injury [35]. Hammer et al, found that 77% of diaphragm injuries in blunt trauma were identified prospectively, with over 90% being identifiable retrospectively with careful evaluation [36]. Panda et al, found that 94% of patients with blunt diaphragmatic injury demonstrated discontinuity of the diaphragm [37]. Discrepancy in the literature may be in part due to small sample sizes and experience of the interpreters. Diaphragm injuries in our experience are very easy to miss if they are not actively sought. A number of CT signs have been described to help identify diaphragmatic injuries. They can be divided into direct observations of the injured diaphragm, observations of the hernia resulting from the injury and observation of the injury pattern. Segmental diaphragm defects, diaphragm thickening or seeing a detached piece of the diaphragm (*dangling diaphragm sign*) are highly specific signs with moderate to low sensitivity. Signs of the visualized hernia include the *collar sign,* where the diaphragm is wrapped tightly around the herniated bowel creating a collared or strictured appearance. There is also the dependent viscera sign where the bowel loops are observed lying adjacent to the posterior ribs without any intervening lung. The *hump sign* is seen as a protruding bump of liver extending into the right thorax. The contiguous injury sign is classically described with penetrating trauma, but if there is extensive blunt injury above and below the diaphragm (contiguous injury), a diaphragm injury could be considered and the diaphragm should be more carefully evaluated. CT demonstrates 70–90% sensitivity and 90% specificity for diaphragm tear [38]. Herniation of abdominal organs, including bowel, fat, liver, colon, and kidney have been reported. Diaphragm injuries missed at initial

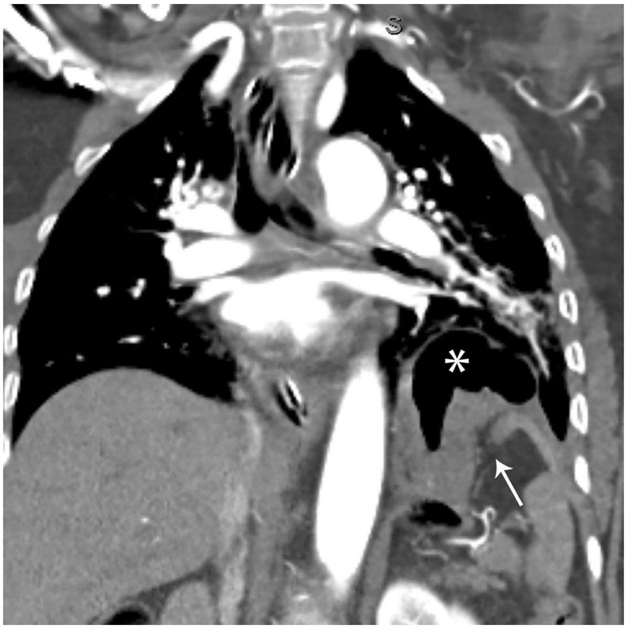

Fig. 12 Following severe blunt trauma to the chest and abdomen, CT identified herniation of the stomach (asterisk) through a tear in the diaphragm. The diaphragm is thickened, with a segmental defect and a "dangling diaphragm sign (arrow)

screening may present years later with herniation and strangulation of abdominal contents. Ventilators may mask a diaphragmatic injury as the positive pressure forces the diaphragm and its contents towards the abdomen. When the patient is eventually extubated, the bowel contents may expand through the diaphragmatic defect. An "elevated diaphragm" on follow-up radiographs may be the only clue of worsening injury.

Compliance with Ethical Guidelines

Conflict of interest James Cassuto, Nisreen Ezuddin, and Gary Danton each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Recently published papers of particular interest have been highlighted as:

- Of importance

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