RadioGraphics

Multidetector CT of Blunt Thoracic Trauma[1]

CME FEATURE

See accompanying test at http://www.rsna.org/education/rg_cme.html

LEARNING OBJECTIVES FOR TEST 2

After reading this article and taking the test, the reader will be able to:

- Discuss the significance of blunt thoracic trauma, as well as the prevalence, pathophysiologic features, and mortality-morbidity associated with various related injuries.
- Recognize the typical radiologic manifestations of blunt thoracic trauma.

TEACHING POINTS

See last page

Rathachai Kaewlai, MD • Laura L. Avery, MD • Ashwin V. Asrani, MD
Robert A. Novelline, MD

Thoracic injuries are significant causes of morbidity and mortality in trauma patients. These injuries account for approximately 25% of trauma-related deaths in the United States, second only to head injuries. Radiologic imaging plays an important role in the diagnosis and management of blunt chest trauma. In addition to conventional radiography, multidetector computed tomography (CT) is increasingly being used, since it can quickly and accurately help diagnose a wide variety of injuries in trauma patients. Furthermore, multiplanar and volumetric reformatted CT images provide improved visualization of injuries, increased understanding of trauma-related diseases, and enhanced communication between the radiologist and the referring clinician.

Abbreviation: 3D = three-dimensional

RadioGraphics 2008; 28:1555–1570 • **Published online** 10.1148/rg.286085510 • **Content Codes:** CH CT ER

[1]From the Division of Emergency Radiology, Department of Radiology, Massachusetts General Hospital, 55 Fruit St, FND-210, Boston, MA 02114.
Presented as an education exhibit at the 2007 RSNA Annual Meeting. Received February 7, 2008; revision requested March 19 and received April 23; accepted May 7. All authors have no financial relationships to disclose.
Address correspondence to R.K. (e-mail: *rathachai@gmail.com*).

Introduction

Injuries to the thorax are the third most common injuries in trauma patients, next to injuries to the head and extremities (1). Thoracic trauma has an overall fatality rate of 10.1%, which is highest in patients with cardiac or tracheobronchial-esophageal injuries (1). Furthermore, the presence of thoracic injuries in the setting of multisystemic trauma can significantly increase patient mortality. Injuries such as "flail chest," lung contusion, hemothorax, and pneumothorax can complicate overall case management (2). More than two-thirds of cases of blunt thoracic trauma in developed countries are caused by motor vehicle collisions. The remaining cases are the result of falls or of blows from blunt objects (3). Imaging plays an important role in the diagnosis of blunt thoracic trauma. Conventional radiography is typically used for the initial imaging investigation, even if computed tomography (CT) is to be performed. Portable chest radiography can show a tension pneumothorax, a large hemothorax, tube and line malpositioning, and other conditions that require immediate treatment. CT has been increasingly used for trauma. Studies have shown that CT may demonstrate significant disease (eg, thoracic aortic injury) in patients with normal initial radiographs (4). Furthermore, CT has been credited with changing management in up to 20% of chest trauma patients with abnormal initial radiographs (5). CT is more accurate than radiography for the evaluation of pulmonary contusion, thereby allowing early prediction of respiratory compromise (6). It is also valuable in the diagnosis of fractures of the thoracic spine, especially at the cervicothoracic junction, which is difficult to evaluate with conventional radiography. In addition, CT has helped exclude thoracic aortic injury, thereby limiting the number of catheter aortographic examinations (7).

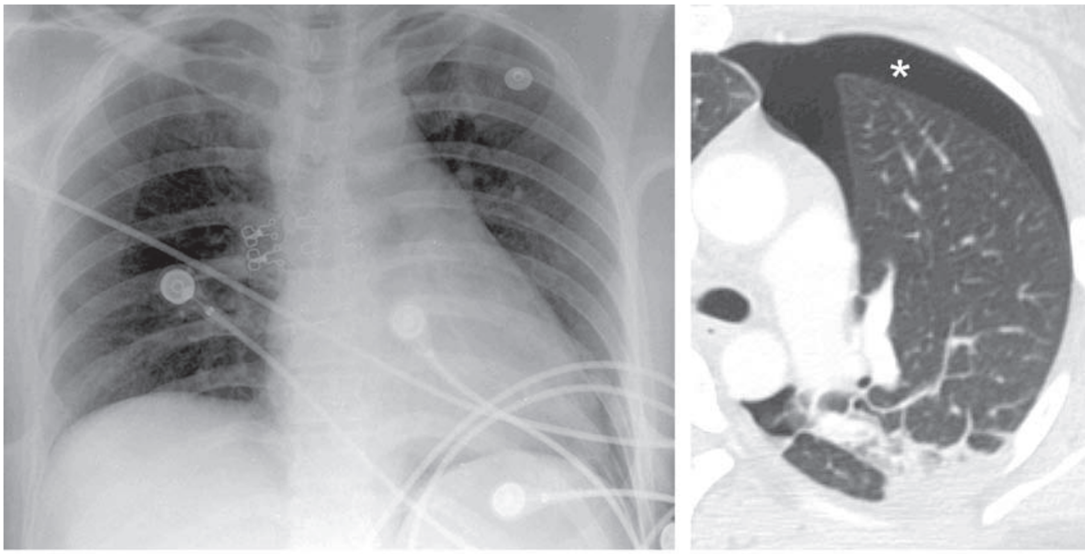
In this article, we discuss and illustrate a spectrum of abnormalities encountered in blunt thoracic trauma at multidetector CT with multiplanar (two-dimensional) and volumetric (three-dimensional [3D]) reformation. These abnormalities include injuries of the pleural space (pneumothorax, hemothorax), lungs (pulmonary contusion, pulmonary laceration, traumatic lung herniation), airways (bronchial lacerations, tracheal lacerations, Macklin effect), esophagus, heart (pericardial injuries, injuries to the heart valves and chambers), aorta and great vessels (thoracic aortic injury, injury to the internal mammary artery, injuries to the aortic arch branches), diaphragm, and chest wall (rib fracture, flail chest, fractures of the scapula, sternal fractures, sternoclavicular dislocations). It should be noted that multiple injuries may coexist in a single patient.

Injuries of the Pleural Space

Pneumothorax

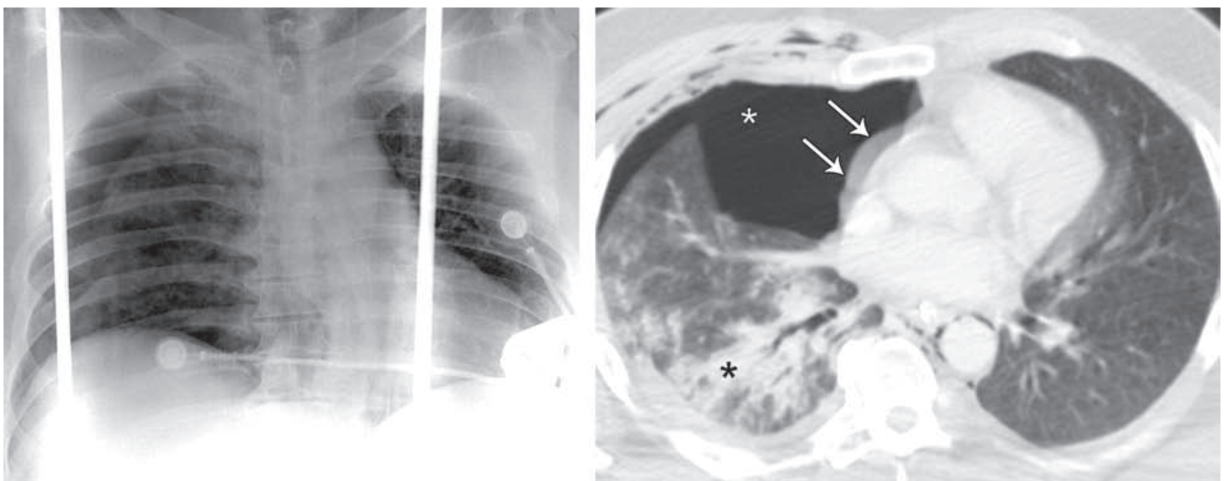
Pneumothorax, an air collection in the pleural space, is a very common traumatic condition that is seen in 15%–40% of all blunt chest trauma patients (6,8,9). Pneumothoraces may be caused by ruptured alveoli due to a sudden increase in intrathoracic pressure or to blunt crushing force or deceleration force to the chest, with or without rib fractures. The diagnosis of pneumothorax is usually made at chest radiography. However, 10%–50% of pneumothoraces from blunt trauma are not visualized at chest radiography performed in supine patients but can be seen at CT (6,9,10); pneumothoraces seen only at CT are called "occult pneumothoraces" (Fig 1). Air in the pleural space accumulates anteriorly and medially in supine patients. As a result, a pneumothorax may be occult on chest radiographs obtained with the patient supine, even though it may be seen on a chest radiograph obtained with the patient upright. Even a small occult pneumothorax may become clinically symptomatic when it enlarges in patients who are placed on positive mechanical ventilation or undergo general anesthesia with endotracheal tube placement. The diagnosis of an occult pneumothorax on a "supine" radiograph relies on several signs, including *(a)* increased lucency at the affected lung base, *(b)* the "deep sulcus" sign, *(c)* the "double diaphragm" sign, and *(d)* better definition of mediastinal contour. With the increased use of CT in trauma patients, pneumothoraces are well recognized and do not present a diagnostic difficulty. However, determining which patients should receive treatment with chest tube drainage does pose a clinical dilemma (10). Measuring the distance from a collapsed lung edge to the chest wall to estimate the amount of pneumothorax is usually inaccurate; therefore, urgent treatment of pneumothorax currently relies on symptoms and physiologic responses (6) in an individual patient.

When air collects in the pleural space to the point where the intrapleural pressure exceeds that of the atmosphere, a tension pneumothorax occurs (Fig 2). Mediastinal shift, compromised venous return to the heart, and collapse of the ipsilateral lung may follow. Tension pneumothorax is



a. b.

Figure 1. Occult pneumothorax. **(a)** Chest radiograph shows a subtle area of increased lucency in the left lung base with increased sharpness of the left hemidiaphragmatic contour. **(b)** Subsequent CT scan helps confirm a left pneumothorax (∗).



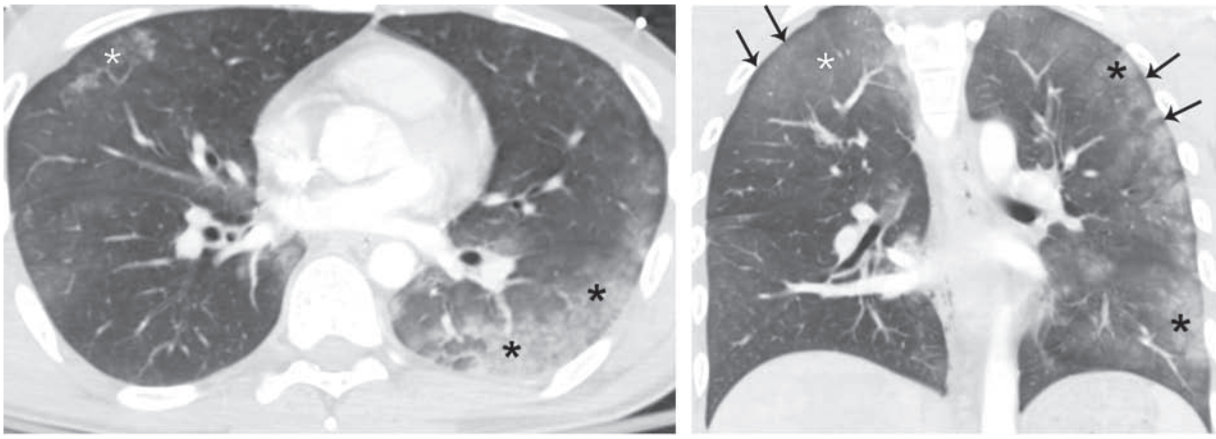
a. b.

Figure 2. Tension pneumothorax. **(a)** Chest radiograph shows a right pneumothorax. **(b)** CT scan shows the right pneumothorax (white ∗) with leftward displacement of the heart (arrows). Black ∗ = pulmonary contusion.

a clinical diagnosis; however, it may be suggested at imaging when the following signs are present in addition to the pneumothorax: *(a)* mediastinal shift to the contralateral side, *(b)* flattening or inversion of the ipsilateral hemidiaphragm, and *(c)* hyperexpanded ipsilateral chest. On the other hand, these signs may be seen in a large pneumothorax unaccompanied by hemodynamic compromise. This is probably due to loss of negative intrapleural pressure on the affected side rather than the presence of positive intrapleural pressure impairing venous return.

Hemothorax

Hemothorax represents blood in the pleural space, which may originate from a variety of thoracic injuries (eg, involving the lung, chest wall, heart, or great vessels) or abdominal injuries (liver and splenic injuries with diaphragmatic rupture). Massive hemothorax is defined as a hemothorax exceeding 1 liter with clinical signs of



a. b.

Figure 3. Pulmonary contusion. Axial **(a)** and coronal reformatted **(b)** CT images show the characteristic features of pulmonary contusion: nonsegmental patchy airspace opacities in the lung periphery (*) with thin subpleural sparing (arrows in **b**).

shock and hypoperfusion (6). CT readily characterizes pleural fluid in the setting of trauma with determination of the attenuation value. Blood in the pleural space typically has an attenuation of 35–70 HU. Measurement of pleural fluid attenuation should be routine in the interpretation of chest trauma CT to distinguish simple fluid from acute blood.

Teaching Point

Injuries of the Lungs

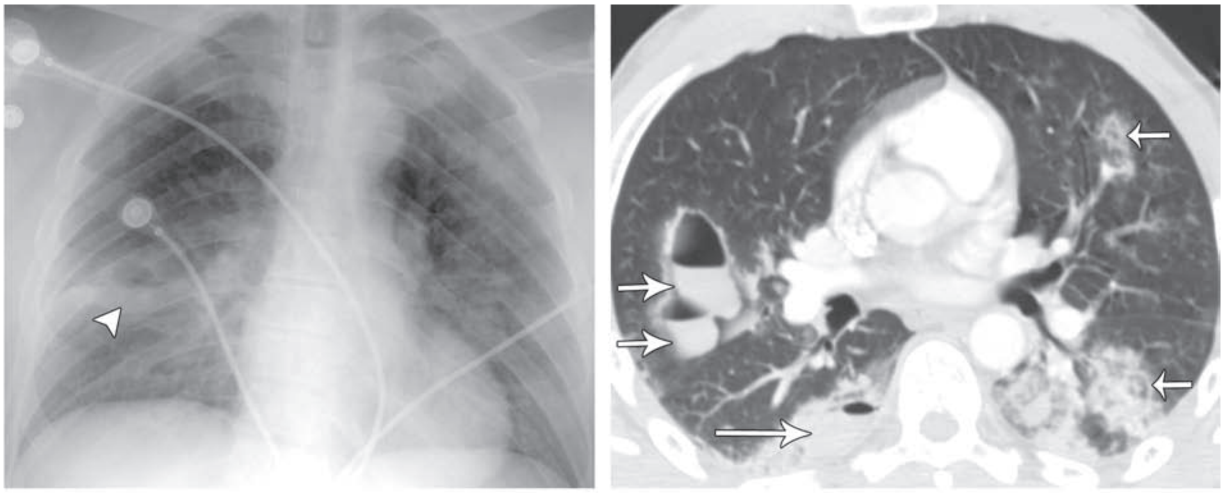
Pulmonary Contusion

Pulmonary contusion is the most common lung injury from blunt chest trauma, with a prevalence of 17%–70% (11,12). It represents traumatic injury to the alveoli with alveolar hemorrhage, but without significant alveolar disruption. Pulmonary contusion occurs at the time of injury, usually at the site of impact. Contusion in the opposite portion of the lung (contrecoup contusion) may be seen. The typical imaging appearance consists of patchy airspace opacities or consolidations with ill-defined borders that are distributed irrespective of bronchopulmonary segmental anatomy (nonsegmental distribution). At CT, subpleural sparing (1–2 mm of clear parenchyma beneath the pleural surface) may be observed (Fig 3). CT can often help detect pulmonary contusion immediately after injury, whereas visualization at conventional radiography may not be possible until up to 6 hours later. Resolution of pulmonary contusion typically begins within 24–48 hours, with complete clearing in 3–10 days (13). The timing of the development of pulmonary contusion is often helpful in determining the cause of areas of pulmonary opacity in trauma patients. Focal areas of pulmonary opacity appearing 24 hours or more after injury suggest diagnoses other than contusion, including aspiration, pneumonia, and fat embolism. However, patients who have pulmonary contusion are at increased risk for developing pneumonia and respiratory distress syndrome.

Teaching Point

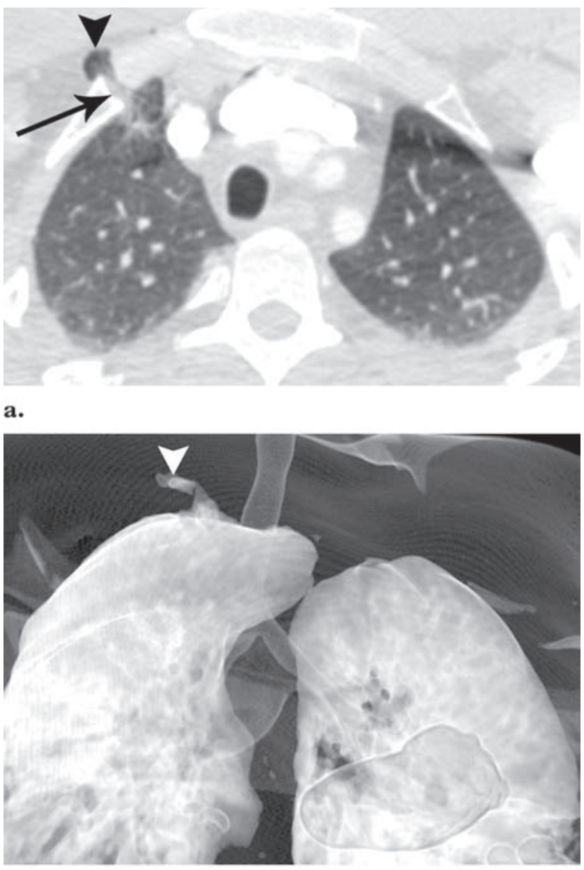
Pulmonary Laceration

Pulmonary laceration occurs when there is a disruption (tear, laceration) of the lung parenchyma, resulting in a cavity in the lung. Because of the normal pulmonary elastic recoil, lung tissues surrounding a laceration pull back from the laceration itself. This results in the laceration manifesting at CT as a round or oval cavity, instead of having the linear appearance typically seen in other solid organs. The traumatic cavity may be filled with air (traumatic pneumatocele), blood (traumatic hematocele or pulmonary hematoma), or both air and blood (traumatic hematopneumatocele) (Fig 4). Pulmonary lacerations heal more slowly than contusion and may last up to several months. Over time, they become increasingly filled with blood and then regress. In the acute setting, lacerations are usually surrounded by contusion and are therefore often obscured at conventional radiography. However, nearly all acute lacerations can be detected with CT. They may be single or multiple and unilocular or multilocular in appearance. Four types of lung laceration have been described according to mechanism of injury, CT pattern, and location of associated rib fractures (11). Type 1 laceration (compression rupture injury) is the most common type of pulmonary laceration, wherein direct compressive force results in lacerations in a deep portion of the lung. Type 2 laceration (compression shear injury) is caused by a severe, sudden blow to the lower hemithorax, resulting in a sudden shift of the lower lobes of the lungs across the spine. These lacerations are seen in the



a. b.

Figure 4. Pulmonary lacerations. **(a)** Chest radiograph shows multifocal patchy airspace opacities in both lungs with an air-fluid level in the midportion of the right lung (arrowhead), findings that represent pulmonary contusions and a laceration, respectively. **(b)** CT scan reveals multiple pulmonary lacerations (large arrows) in the central portion of the right upper lobe (compression rupture injury) and in the paraspinal portion of the right lower lobe (compression shear injury). Small arrows indicate pulmonary contusions in the left lung.



a. b.

Figure 5. Traumatic lung herniation. **(a)** CT scan shows the herniation of lung tissue (arrowhead) through a fracture of the right third costochondral junction (arrow). **(b)** Three-dimensional CT image clearly depicts the lung herniation (arrowhead).

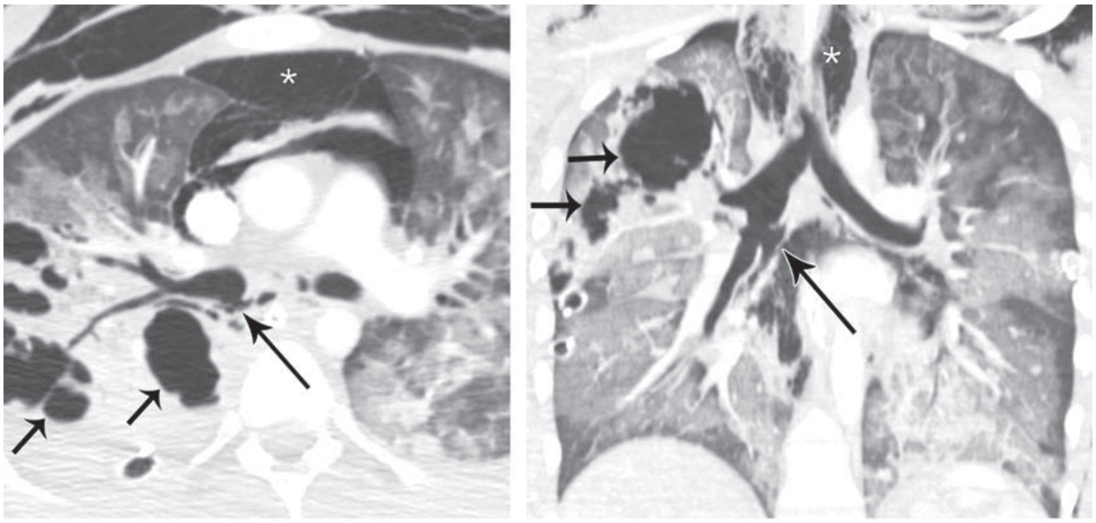
paraspinal regions. Type 3 laceration (rib penetration tear) is located in the periphery of the lungs where a rib has been fractured and is generally associated with pneumothorax. Type 4 laceration (adhesion tear) is a laceration in the region of preexisting pleuropulmonary adhesion and is usually diagnosed at surgery or autopsy. Pulmonary laceration is common in children and young adults because they have greater flexibility of the chest wall, resulting in a higher likelihood of lung injury with blunt trauma.

Traumatic Lung Herniation

Traumatic lung herniation occurs when a pleura-covered part of the lung extrudes through a traumatic defect in the chest wall (Fig 5). This condition is usually associated with rib fractures. Because lung herniation may increase with positive-pressure ventilation, patients may require treatment before undergoing intubation and general anesthesia.

Injuries of the Airways

Tracheobronchial injuries are rare in clinical practice because most patients die before arriving at the emergency department, from either associated injuries to vital structures, hemorrhage, tension pneumothorax, or respiratory insufficiency from an airway injury. In clinical series, blunt tracheobronchial trauma has been reported as accounting for 0.2%–8% of all cases of blunt chest trauma (14,15). Airway trauma with deceleration



a. b.

Figure 6. Bronchial laceration. Axial **(a)** and coronal reformatted **(b)** CT images show a tear (long arrow) in the posterior wall of the right intermediate bronchus with an air leak into the mediastinum (*) and a small right pneumothorax. Short arrows indicate multiple pulmonary lacerations in the right lung against a background of extensive bilateral pulmonary contusions. Note also the tubes in the right side of the chest.

injuries may result from compression of the airways between the sternum and thoracic spine, shearing at fixation points, or elevated intrathoracic pressure against a closed glottis. Tracheobronchial injuries usually occur within 2.5 cm of the carina.

Bronchial Lacerations

Bronchial lacerations are more common than tracheal lacerations and are typically parallel to the cartilage rings of the bronchi. Common imaging manifestations of bronchial injuries are pneumomediastinum and pneumothorax (Fig 6). The latter occurs if an injury extends to the pleural space. The presence of a persistent pneumothorax, even with chest tube placement and suction, should raise concern for possible bronchial injury. When there is complete transection of a bronchus, the lung on the side of the bronchial injury may fall posterolaterally away from the hilum ("fallen lung" sign). The lung falls inferiorly if the patient is upright and posteriorly if the patient is supine, as would be seen on a CT scan.

Teaching Point

Tracheal Lacerations

Tracheal lacerations are usually vertical and longitudinal and located at the junction of the cartilaginous and membranous portions of the trachea. Common findings of tracheal lacerations are cervical subcutaneous emphysema and pneumomediastinum (Fig 7). In intubated patients, overdistention or herniation of an endotracheal balloon may be seen if the balloon is at the same level as the tracheal laceration. CT may help identify the site of tracheal laceration in 70%–100% of cases (16,17).

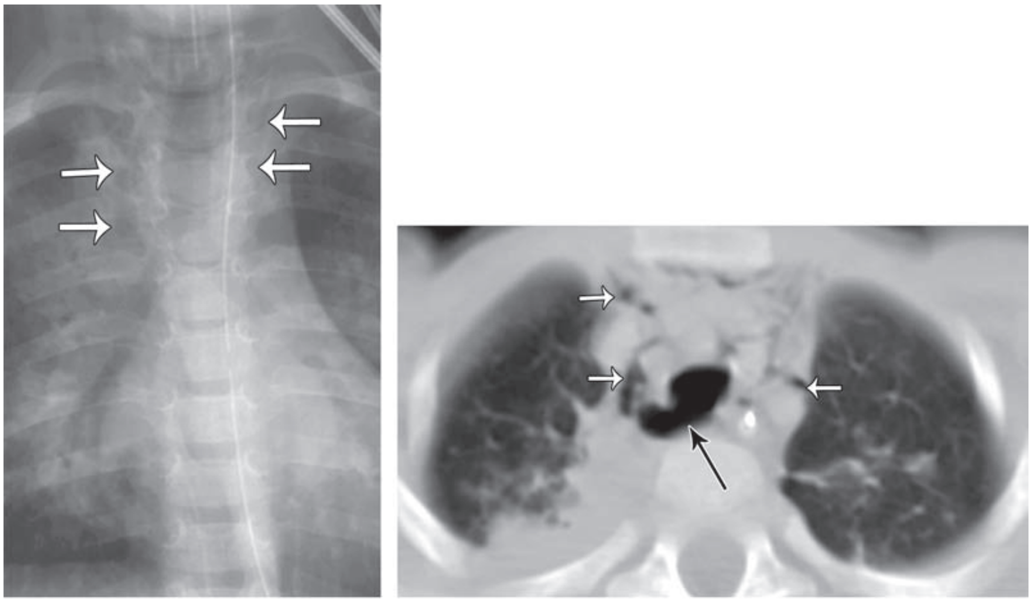
If CT findings suggest an injury to the tracheobronchial tree, definitive diagnosis with bronchoscopy should be attempted to confirm the diagnosis and to evaluate the site and extent of injury (14). Potential complications of tracheobronchial injuries include airway obstruction, pneumonia, bronchiectasis, abscess, and empyema.

Macklin Effect

Traumatic pneumomediastinum may have origins other than a tracheobronchial injury. The so-called Macklin effect involves alveolar ruptures, with air dissecting along bronchovascular sheaths and spreading into the mediastinum (18,19). The CT appearance of the Macklin effect is similar to that of pulmonary interstitial emphysema. Streaks of air along the bronchovascular bundles may be seen, as well as mediastinal air collections. The presence of the Macklin effect does not exclude the possibility of tracheobronchial injuries, which may coexist (19).

Injuries of the Esophagus

Blunt trauma to the esophagus is extremely rare, since this structure is well protected in the mediastinum. Most esophageal injuries occur from



a. b.

Figure 7. Tracheal laceration. **(a)** Collimated chest radiograph shows pneumomediastinum (arrows). **(b)** CT scan shows a tear (black arrow) at the right posterolateral portion of the trachea, along with pneumomediastinum (white arrows).

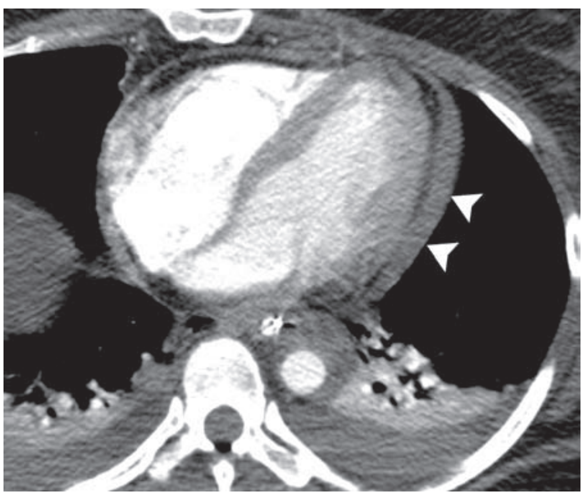


Figure 8. Blunt cardiac injury. CT scan shows a traumatic hemopericardium (arrowheads). The diagnosis of blunt cardiac injury was confirmed on the basis of abnormal electrocardiographic findings, elevated cardiac enzyme levels, and echocardiographic findings.

penetrating trauma. However, blunt esophageal injuries may result from a blow to the neck or a burst-type force (20). A blow to the neck typically results in cervical esophageal injuries, whereas a burst-type force may cause distal esophageal injuries (14,21). The latter mechanism is similar to that which causes a postemetic esophageal rupture. Distal esophageal tears usually occur along the left side of the esophageal wall, where less protection is afforded by the pleural lining and the heart. These tears are often associated with clinical symptoms, such as blood in the esophagus or odynophagia. CT findings may suggest the diagnosis of traumatic esophageal perforation (eg, the presence of pneumomediastinum, mediastinitis, hydropneumothorax, or leakage of orally administered contrast material into the mediastinum or pleural space). Water-soluble contrast esophagography, followed by flexible esophagoscopy, may be required to evaluate the site of injury.

Injuries of the Heart

Injuries of the heart usually result from motor vehicle collisions. Blunt cardiac injuries may range from contusion to frank rupture of the heart. Cardiac injury is among the most lethal injuries in thoracic trauma patients (1). However, patients with myocardial contusions, pericardial tears, injuries to the valves, or small tears in low-pressure cavities may survive their injuries to reach an emergency center. The diagnosis of blunt cardiac injury relies on a high degree of clinical suspicion. The patient may have abnormal electrocardiographic findings and elevated cardiac enzyme levels (22). Imaging manifestations of blunt cardiac injury include hemopericardium (Fig 8), contrast material extravasation into the pericardial sac or mediastinum, pneumopericardium (Fig 9), displacement of the heart due to cardiac herniation, and abnormal bowel gas in the chest due to diaphragmatic pericardial tear.

Teaching Point

Pericardial Injuries

Pericardial injuries are usually due to a direct blow to the chest or an indirect force from increased intraabdominal pressure. A tear may be as small as a few millimeters or may extend the entire length of the pericardium. A larger tear may be accompanied by cardiac herniation, which may result in cardiac dysfunction and death. The most common site of pericardial injury is the left side of the pericardium parallel to the phrenic nerve, followed by the diaphragmatic surface of the pericardium (23,24).

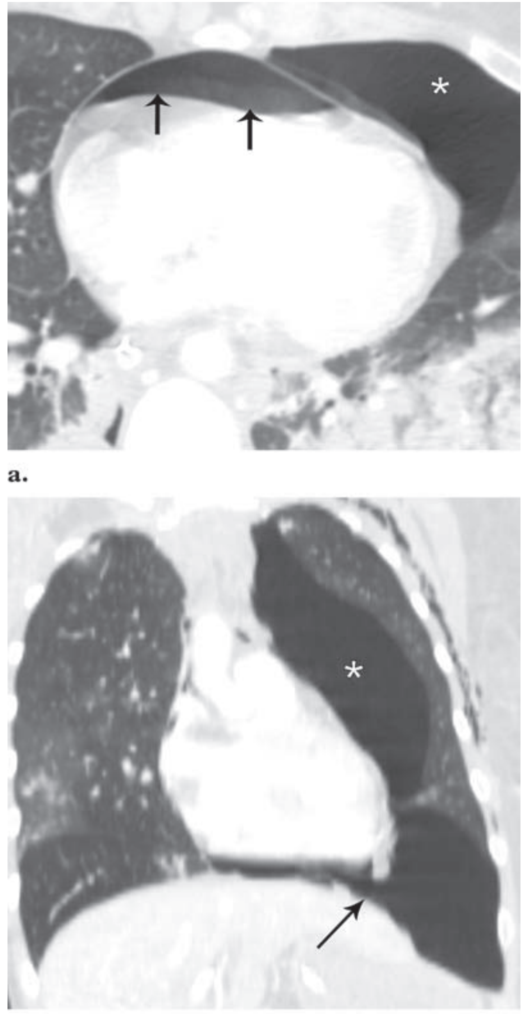
Injuries to the Heart Valves and Chambers

Injuries to the heart valves and chambers typically occur in patients with preexisting cardiac diseases who suffer traumatic events. These injuries account for approximately 9% of all blunt cardiac injuries. Injuries to the right-sided chambers are more common than left-sided injuries. The aortic, mitral, and tricuspid valves (in descending order of frequency) may be involved (24).

Injuries of the Aorta and Great Vessels

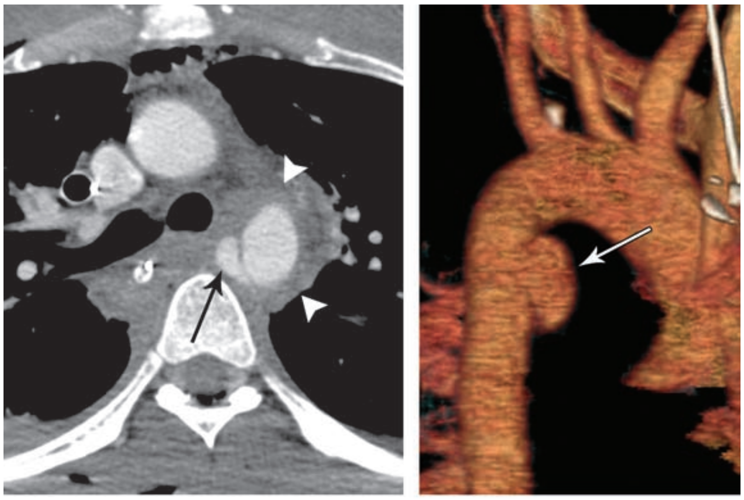
Thoracic Aortic Injury

Thoracic aortic injury is usually fatal. It accounts for 10%–15% of deaths following motor vehicle collisions in the United States (25). Between 85% and 90% of patients die before reaching the hospital, and approximately 50% of those who initially survive may die within 1 week without appropriate treatment (26). The most common cause of thoracic aortic injuries is a motor vehicle collision, with falls and pedestrian injuries being much less common causes (27). Rapid deceleration results in an intimal tear of the thoracic aorta, which can extend to become a full-thickness aortic wall injury. Thoracic aortic injuries typically occur at the sites of aortic attachments, including (in descending order of frequency) the proximal descending aorta (Fig 10), aortic arch, aortic root, and distal descending aorta at the aortic hiatus (Fig 11). A periaortic hematoma typically accompanies thoracic aortic injury and is believed to represent bleeding from small veins in the area or from the vasa vasorum of the aorta itself. A periaortic hematoma may be seen at chest radiography as a mediastinal abnormality such as mediastinal widening, blurring of the aortic contour, or thickening of the paratracheal stripe. The presence of a mediastinal abnormality at chest radiography has a diagnos-



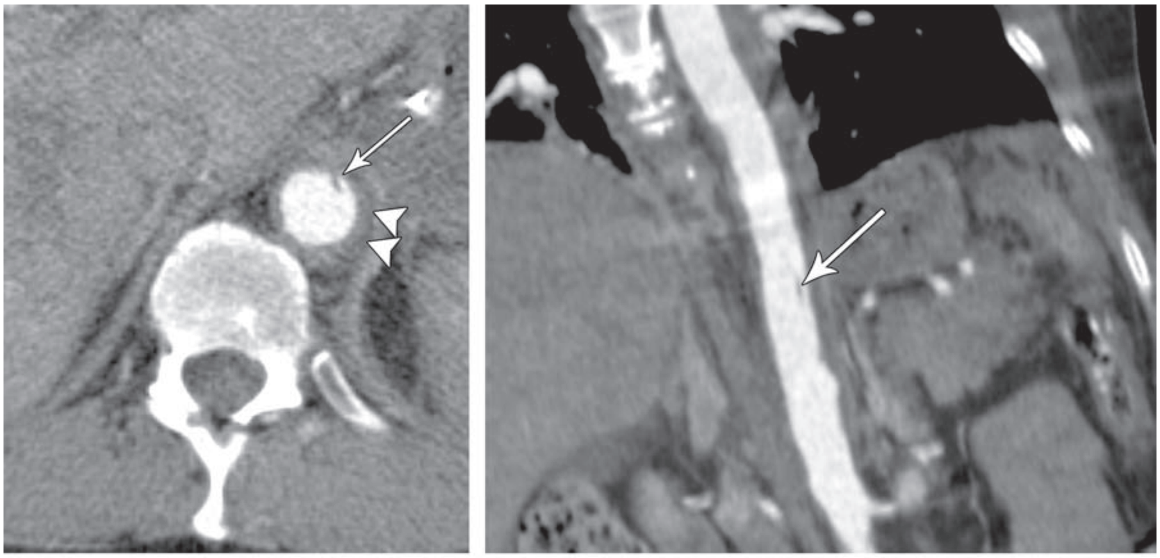
a. b.

Figure 9. Blunt cardiac injury. Axial **(a)** and coronal reformatted **(b)** CT images show a pericardial laceration (arrow in **b**) with pneumopericardium (arrows in **a**) resulting from extension of a left pneumothorax (*) into the pericardial space.



a. b.

Figure 10. Traumatic pseudoaneurysm of the proximal descending thoracic aorta. Axial **(a)** and 3D **(b)** CT images show an aortic pseudoaneurysm (arrow) distal to the origin of the left subclavian artery, with a periaortic hematoma (arrowheads in **a**).

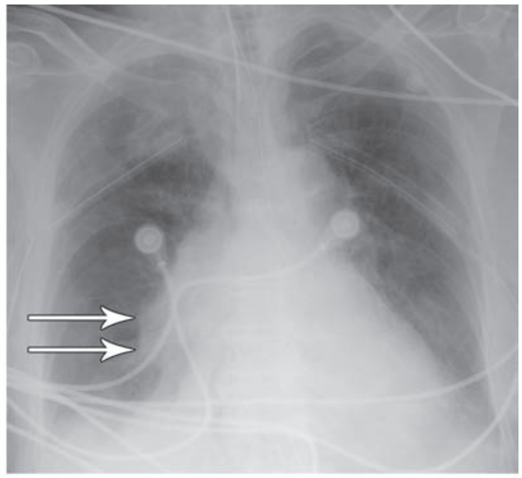


a. b.

Figure 11. Distal descending thoracic aortic injury. Axial **(a)** and coronal reformatted **(b)** CT images show an intimal flap (arrow) in the descending aorta at the level of the aortic hiatus, a finding that is consistent with thoracic aortic injury. Periaortic and retrocrural hematoma (arrowheads in **a**) is also observed.

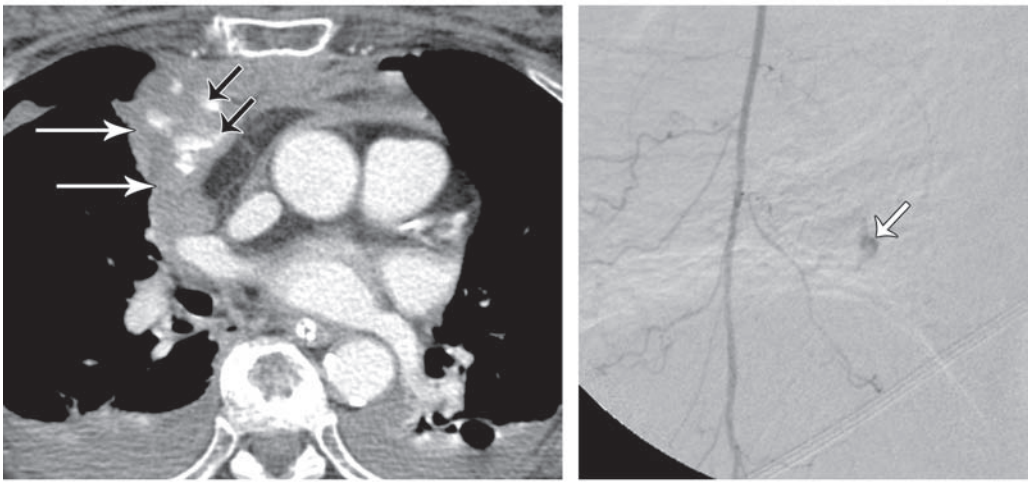
tic sensitivity of 90%–95% for a thoracic aortic injury, but a specificity of only 5%–10% (26). On rare occasions, aortic injuries are accompanied by only minimal (or no) periaortic hemorrhage. Therefore, conventional radiography may demonstrate no mediastinal abnormality, leading to false-negative radiographic findings for possible aortic injury. CT not only allows direct visualization of periaortic hematoma but also can show the actual aortic injuries, including aortic pseudoaneurysm, changes in aortic contour or diameter, intimal flap and thrombus, and contrast material extravasation. Multiplanar and volumetric reformation is useful in determining the distance of the injury from the aortic arch branches, the length of the injury, the diameter of the aorta above and below the injury, the type of vascular disease, and coexisting anatomic anomalies

Teaching Point

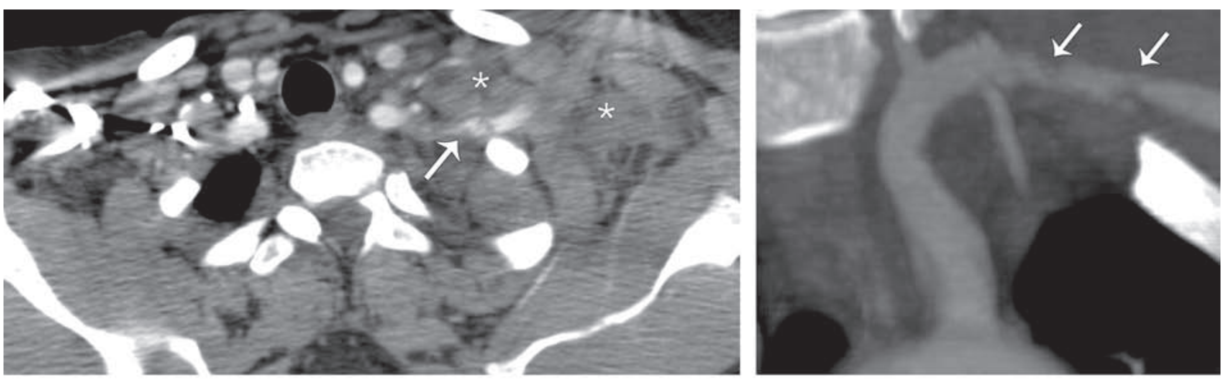


a.

Figure 12. Internal mammary artery injury. **(a)** Chest radiograph shows a prominent right cardiac border (arrows), an enlarged cardiac silhouette, and bilateral hemothoraces. **(b)** CT scan shows a hematoma in the anterior mediastinum (white arrows) with active extravasation (black arrows). **(c)** Catheter angiogram shows an active hemorrhage (arrow) from a branch of the right internal mammary artery.

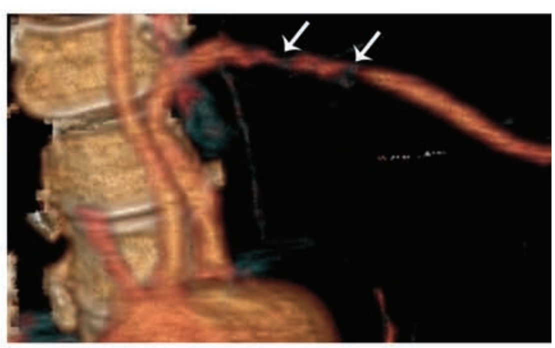


b. c.



a. b.

Figure 13. Subclavian artery injury. **(a)** CT scan shows intimal irregularity of the left subclavian artery (arrow) with a surrounding hematoma (*). **(b, c)** Maximum-intensity-projection **(b)** and 3D **(c)** CT images show the extent of arterial injury (arrows).



c.

(7,28). Many modern 16- and 64-section multidetector CT scanners are equipped with cardiac gating capability. This option permits more accurate evaluation of ascending aortic injury, especially in patients with tachycardia and marked aortic pulsatile motion. The current problem with routine cardiac gating in cases of chest trauma is the "band artifact" in patients with a pulse rate over 80, which distorts findings on multiplanar and volumetric reformatted images. Consequently, most centers perform routine chest trauma CT without cardiac gating. However, in patients with ascending aortic pulsatile motion, a second cardiac-gated study can be performed with the intravenous administration of 60 mL of contrast material. The axial scans are excellent for ruling out ascending aortic injury. The multiplanar and volumetric reformatted images are prepared from an initial nongated examination. The precise characterization of injury is crucial for determining optimal treatment for thoracic aortic injury, since options involving blood pressure control and stent placement are becoming widely accepted (28).

Injury to the Internal Mammary Artery

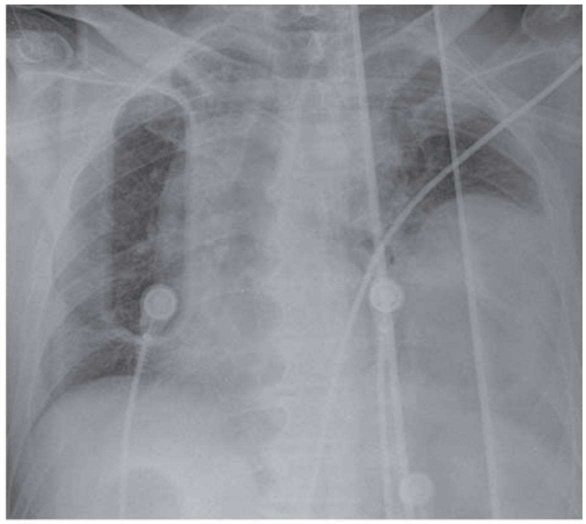
Another potential (albeit uncommon) cause of active mediastinal hemorrhage is injury to the internal mammary artery. Mediastinal hematoma may be obscured at conventional radiography but can be detected at CT. The injury may be life threatening due to ongoing blood loss and can compress the right ventricle, resulting in impaired ventricular filling. Evidence of active bleeding is suggested by contrast material extravasation, which typically has an attenuation value close to that of an adjacent artery (Fig 12) (29).

Injuries to the Aortic Arch Branches

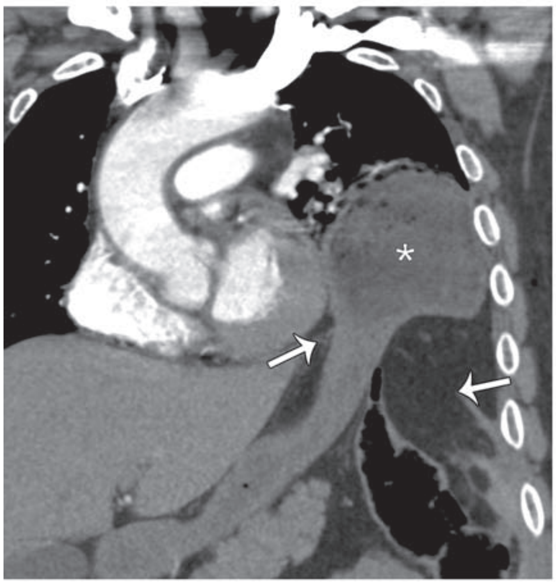
Injuries to the aortic arch branches include traumatic occlusion, dissection, pseudoaneurysm, and contrast material extravasation. They usually result from sudden neck extension or shoulder traction, leading to stretching of the aortic branches. Injuries to the common carotid artery may cause neurologic deficit, including stroke. In patients with thoracic aortic injury, identification of injuries to other branches is important, since it may alter the surgical approach. For surgical repair of an isolated thoracic aortic injury, surgeons typically use posterolateral thoracotomy; in combined injuries, median sternotomy may be preferred (30). The presence of periarterial hematoma in the superior mediastinum or lower cervical region is an important indirect sign of possible brachiocephalic or subclavian artery injury (Fig 13).

Injuries of the Diaphragm

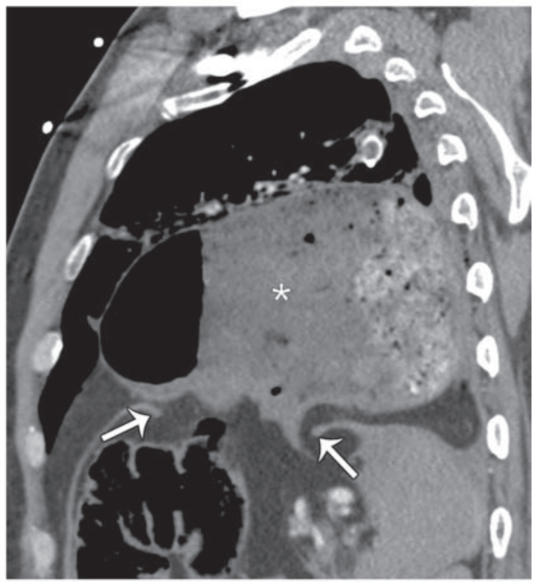
Blunt injuries to the diaphragm are uncommon, with a prevalence of 0.16%–5% in blunt trauma patients (31,32). Injuries are caused by a sudden increase in intraabdominal or intrathoracic pressure against a fixed diaphragm. The tears are typically large and involve the posterolateral surface of the hemidiaphragm at the site of previous embryonic diaphragmatic fusion. Injuries may occur at the central portion of the diaphragm or at the site of diaphragmatic attachments. The right hemidiaphragm is less frequently injured than the left, which may be explained by the greater strength of the right hemidiaphragm and the protective effect of the liver (31–33). Injuries to the diaphragm pose a risk of visceral organ herniation through the defect, which can occur acutely at the time of injury or be delayed. Visceral organ herniation may result in organ incarceration, strangulation, or perforation. The type of herniated contents depends on the size and location of the injury. The liver, small bowel, or large bowel may herniate through a right-sided diaphragmatic defect; the stomach, small bowel, large bowel, or spleen may herniate through a left-sided defect. Rare locations of traumatic diaphragmatic herniation include the pericardium and the esophageal hiatus. Imaging manifestations of diaphragmatic injury depend on the side of injury (left or right hemidiaphragm), the presence of herniated abdominal viscera, and concomitant pleural or pulmonary injuries. Conventional radiographic findings may suggest the diagnosis of blunt diaphragmatic injuries with a high specificity when there is herniation of a hollow viscus into the thorax. Other findings include upward extension of a nasogastric tube tip above the left hemidiaphragm, elevation of the involved hemidiaphragm, and loss of diaphragmatic contour. Multidetector CT with coronal and sagittal reformation



a.



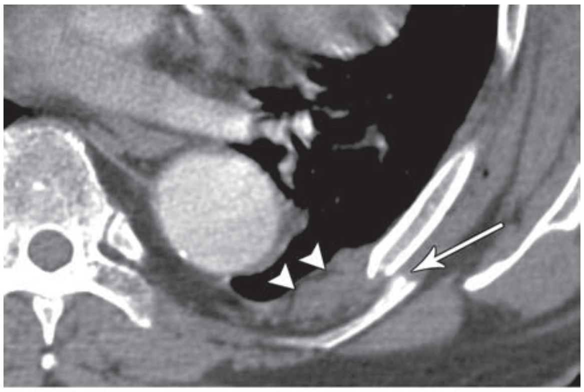
b.



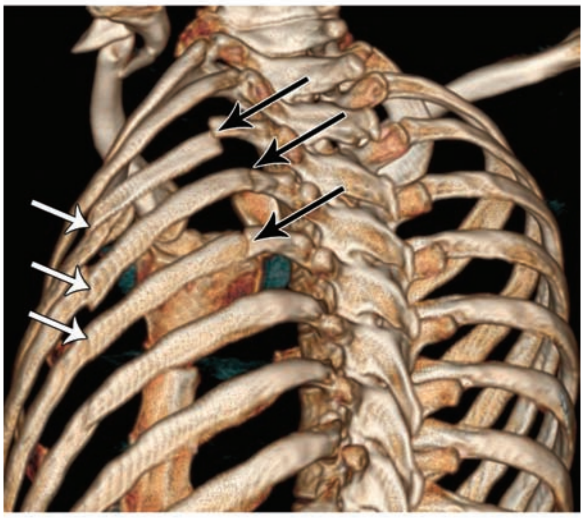
c.

Figure 14. Diaphragmatic injury. **(a)** Chest radiograph shows marked elevation of the left hemidiaphragm. **(b, c)** Coronal **(b)** and sagittal **(c)** reformatted CT images reveal a large left diaphragmatic defect (arrows) with herniation of the stomach (*) into the thorax.

can show even a small diaphragmatic discontinuity and help identify any herniated viscera (Fig 14). Other CT signs of diaphragmatic injury include the "collar" sign, the "dependent viscera" sign, diaphragmatic thickening, and peridiaphragmatic contrast material extravasation. The collar sign is produced by a waistlike constriction of herniated viscera at the site of herniation. The dependent viscera sign (34) results from the abdominal viscera falling dependently against the posterior chest wall through the diaphragmatic tear. Injuries to the diaphragm are commonly accompanied by hemothorax and hemoperitoneum. Blood on both sides of the diaphragm without obvious intraabdominal injury should raise suspicion for possible diaphragmatic injury. CT has an overall sensitivity in the diagnosis of blunt diaphragmatic rupture of 70%–100%, with a greater sensitivity for left-sided injuries, and a specificity of 75%–100% (31,32,35). Limitations of single-section helical CT can be overcome with multidetector CT performed with thin-section collimation and section overlap to produce high-resolution coronal and sagittal reformatted images. This allows better vi-



a.



b.

Figure 15. Rib fractures and flail chest. **(a)** CT scan shows a displaced left posterior rib fracture (arrow) with a subpleural hematoma (arrowheads). **(b)** Three-dimensional CT image (left posterior oblique projection) obtained in a different patient shows multiple displaced fractures of three contiguous ribs. Each rib has both a posterolateral fracture (white arrows) and a posterior fracture (black arrows), which together produce a flail segment.

sualization of the diaphragm and differentiation of the diaphragm from adjacent soft tissues.

Injuries of the Chest Wall

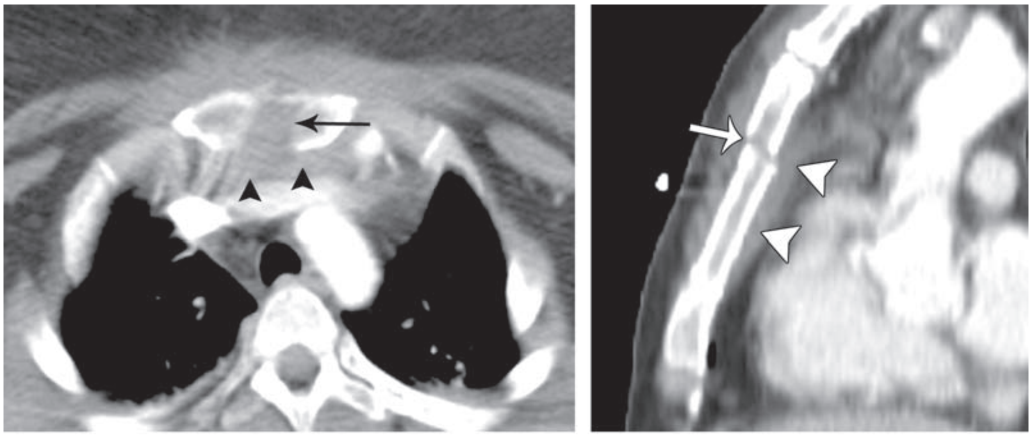
Blunt injuries of the chest wall are very common in clinical practice, resulting from motor vehicle collisions, falls, and blows from blunt objects. The spectrum of injuries includes chest wall contusion, hematoma in the chest wall or extrapleural space, and fractures.

Rib Fracture

The most common skeletal injury in blunt chest trauma is rib fracture, which occurs in approximately 50% of patients. Simple rib fractures are usually not significant in isolation and are rarely life threatening. However, multiple or bilateral rib fractures may indicate more severe thoracic injury, which may result in increased morbidity and mortality (6,36). Rib fractures may serve as an external manifestation of possible coexisting thoracic or abdominal injuries (36). Fractures of the first through third ribs are considered to be high-energy trauma because these ribs are well protected by the scapulae, clavicles, and musculature. These fractures may be associated with brachial plexus injury or subclavian vascular injuries. Fractures of the lower three ribs may be associated with liver, spleen, and kidney injuries and, less frequently, with lung injuries. In elderly persons, rib fractures can be a significant source of pain and splinting. Limited respiratory movement may lead to an increased prevalence of atelectasis and subsequent pneumonia, which may increase morbidity and mortality (37). Chest radiography is routinely used to assist in the diagnosis of rib fractures, even though it has limited sensitivity. Rib radiography can provide superior visualization of the ribs and rib fractures. CT is the most sensitive technique for imaging rib fractures, since it can help determine the site and number of fractures and, more important, provide information regarding any associated injuries.

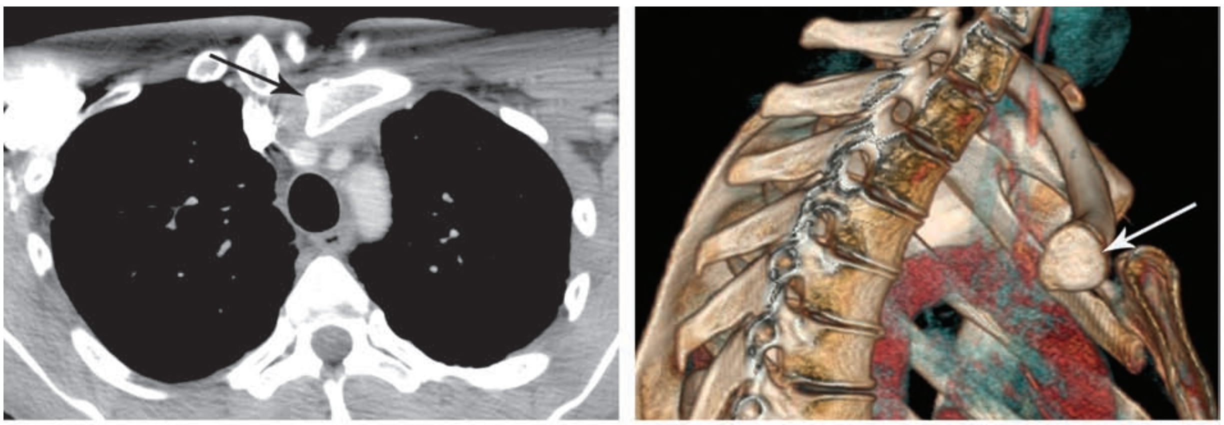
Flail Chest

Flail chest is a traumatic condition in which there are three or more contiguous ribs with fractures in two or more places. Fractures usually occur in the anterior and anterolateral portions of the middle to lower ribs. These fractures create a flail segment (Fig 15) that can move paradoxically relative to the remainder of the chest during respiration in a spontaneously ventilating patient. Although imaging can show fractures, it is the clinical examination that will demonstrate paradoxic motion. Flail chest serves as a marker for significant intrathoracic injury, since more than one-half of affected patients may have associated injuries requiring surgical treatment (38). These patients often require mechanical ventilation for prolonged periods (39).

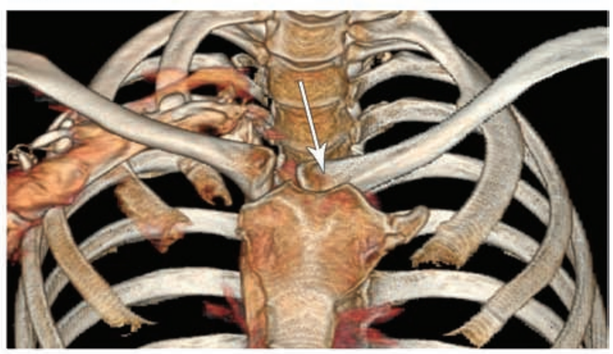


a. b.

Figure 16. Sternal fractures. **(a)** Axial CT scan (soft-tissue window) shows a sagittally oriented fracture of the manubrium (arrow) with a retrosternal hematoma (arrowheads). **(b)** Sagittal reformatted CT image (soft-tissue window) obtained in a different patient reveals a transverse fracture of the body of the sternum (arrow) with a retrosternal hematoma (arrowheads). The latter finding is more difficult to appreciate on axial scans.



a. b.



c.

Figure 17. Posterior sternoclavicular dislocation. Axial **(a)** and 3D **(b, c)** CT images demonstrate a posterior dislocation of the left clavicular head (arrow) relative to the manubrium.

Fractures of the Scapula

Fractures of the scapula are uncommon, accounting for 3%–5% of all shoulder girdle fractures (40) and occurring in 3.7% of patients with multiple injuries (41). Significant force may be required to fracture a scapula, whether a direct blow to the scapula or an indirect axial force transmitted through the humerus. Scapular fractures commonly occur in motor vehicle collisions and in falls from great heights. They are associated with other injuries—including pneumothorax, hemothorax, pulmonary injuries, and spinal injuries—in 35%–98% of cases (40,42). Most fractures involve the body and neck of the scapula, although they may also involve the glenoid, coracoid, or acromion process. The majority of scapular fractures are treated conservatively, with nonunion occurring only rarely. Exceptions include displaced glenoid intraarticular fractures and displaced juxtaarticular fractures, which typically require surgical management (40,43). Scapular fractures may be overlooked at initial clinical evaluation due to more severe coexisting injuries. Also, the scapula may not be easily visualized at routine chest trauma radiography. Multiple radiographic views of the scapula can provide information regarding fracture sites, involvement, and displacement. CT with multiplanar and volumetric reformation can provide additional information regarding intraarticular extension of the fractures.

Sternal Fractures

Sternal fractures may result from deceleration injuries or direct blows to the anterior chest wall. Fractures commonly involve the sternal body and the manubrium. Although sternal fractures have been viewed as a marker for high-energy trauma (6,44), a simple sternal fracture may occur as an isolated injury (45). However, displaced sternal fractures and those with associated manubriosternal joint disruption frequently occur with thoracic, cardiac (46), and spinal (47) injuries. Sternal fractures are best demonstrated at CT on multiplanar reformatted images, especially sagittal images. On occasion, a fracture line may be difficult to detect at axial CT, and the clue to the diagnosis may be the presence of anterior mediastinal hemorrhage (Fig 16).

Sternoclavicular Dislocations

Sternoclavicular dislocations may be either anterior or posterior. Posterior dislocations are more serious, since they may cause injuries to the mediastinal blood vessels, trachea, and esophagus (48,49). They typically result from a posterior blow to the shoulder or a blow to the medial clavicle, resulting in a posteriorly displaced clavicular head relative to the manubrium (Fig 17). Posterior sternoclavicular dislocations may be subtle or not visualized at conventional radiography. Therefore, when there is a clinical suspicion for this entity, CT with intravenous contrast material administration can be used to confirm the diagnosis and evaluate for possible associated vascular injury. Anterior sternoclavicular dislocations usually result from an anterior blow to the shoulder. They are typically evident on palpation because the head of the clavicle is dislocated and protrudes anteriorly. Anterior dislocations are more common than posterior dislocations. In addition, they typically have a more benign course, and conservative treatments are usually justified. However, they may result in chronic pain, ankylosis, and deformity (50).

Conclusions

Multidetector CT can quickly and accurately help diagnose a variety of thoracic injuries in trauma patients. These injuries can be clearly displayed with multiplanar and volumetric reformation.

References

1. The American College of Surgeons Committee on Trauma Leadership. In: Clark DE, Fantus RJ, eds. National Trauma Data Bank (NTDB) Annual Report 2007. Chicago, Ill: American College of Surgeons, 2007; 1–64.
2. Gaillard M, Hervé C, Mandin L, Raynaud P. Mortality prognostic factors in chest injury. J Trauma 1990;30:93–96.
3. Report on injuries in America: all unintentional injuries, 2005. Available at: http://www.nsc.org/library/report_table_1.htm. Accessed December 9, 2007.
4. Exadaktylos AK, Sclabas G, Schmid SW, Schaller B, Zimmermann H. Do we really need routine computed tomographic scanning in the primary evaluation of blunt chest trauma in patients with “normal” chest radiograph? J Trauma 2001;51:1173–1176.
5. Omert L, Yeaney WW, Protetch J. Efficacy of thoracic computerized tomography in blunt chest trauma. Am Surg 2001;67:660–664.
6. Livingston DH, Haurer CJ. Trauma to the chest wall and lung. In: Moore EE, Feliciano DV, Mattox KL, eds. Trauma. 5th ed. Philadelphia, Pa: McGraw-Hill, 2004; 507–537.
7. Downing SW, Sperling J, Mirvis SE, et al. Experience with spiral CT scanning as the sole diagnostic method for traumatic aortic rupture. Ann Thorac Surg 2001;72:495–501.
8. Mayberry JC. Imaging in thoracic trauma: the trauma surgeon’s perspective. J Thorac Imaging 2000;15:76–86.
9. Miller LA. Chest wall, lung, and pleural space trauma. Radiol Clin North Am 2006;44:213–224.
10. De Moya MA, Seaver C, Spaniolas K, et al. Occult pneumothorax in trauma patients: development of an objective scoring system. J Trauma 2007;63:13–17.
11. Wagner RB, Crawford WO Jr, Schimpf PP. Classification of parenchymal injuries of the lung. Radiology 1988;167:77–82.
12. Cohn SM. Pulmonary contusion: review of the clinical entity. J Trauma 1997;42:973–979.
13. Wanek S, Mayberry JC. Blunt thoracic trauma: flail chest, pulmonary contusion, and blast injury. Crit Care Clin 2004;20:71–81.
14. Riley RD, Miller PR, Meredith JW. Injury to the esophagus, trachea and bronchus. In: Moore EE, Feliciano DV, Mattox KL, eds. Trauma. 5th ed. Philadelphia, Pa: McGraw-Hill, 2004; 539–552.
15. Euathrongchit J, Thoongsuwan N, Stern EJ. Nonvascular mediastinal trauma. Radiol Clin North Am 2006;44:251–258.
16. Chen JD, Shanmuganathan K, Mirvis SE, Killeen KL, Dutton RP. Using CT to diagnose tracheal rupture. AJR Am J Roentgenol 2001;176:1273–1280.

17. Scaglione M, Romano S, Pinto A, Sparano A, Scialpi M, Rotondo A. Acute tracheobronchial injuries: impact of imaging on diagnosis and management implications. Eur J Radiol 2006;59:336–343.
18. Macklin CC. Transport of air along sheaths of pulmonic blood vessels from alveoli to mediastinum: clinical implications. Arch Intern Med 1939;64:913–926.
19. Wintermark M, Schnyder P. The Macklin effect: a frequent etiology for pneumomediastinum in severe blunt chest trauma. Chest 2001;120:543–547.
20. Strauss DC, Tandon R, Mason RC. Distal thoracic oesophageal perforation secondary to blunt trauma: case report. World J Emerg Surg 2007;2:8.
21. Martel G, Al-Sabti H, Mulder DS, Sirois C, Evans DC. Acute tracheoesophageal burst injury after blunt chest trauma: case report and review of the literature. J Trauma 2007;62:236–242.
22. Pasquale M, Timothy F. Practice management guidelines for trauma from the Eastern Association for the Surgery of Trauma. J Trauma 1998;44:941–956.
23. Fulda G, Brathwaite CE, Rodriguez A, Turney SZ, Dunham CM, Cowley RA. Blunt traumatic rupture of the heart and pericardium: a ten-year experience (1979–1989). J Trauma 1991;31:167–173.
24. Parmley LF, Manion WC, Mattingly TW. Nonpenetrating traumatic injury of the heart. Circulation 1958;18:371–396.
25. Parmley LF, Mattingly TW, Manion WC, Jahnke EJ Jr. Nonpenetrating traumatic injury of the aorta. Circulation 1958;17:1086–1101.
26. Pretre R, Chilcott M. Blunt trauma to the heart and great vessels. N Engl J Med 1997;336:626–632.
27. Burkhart HM, Gomez GA, Jacobson LE, Pless JE, Broadie TA. Fatal blunt aortic injuries: a review of 242 autopsy cases. J Trauma 2001;50:113–115.
28. Mirvis SE, Shanmuganathan K. Diagnosis of blunt traumatic aortic injury 2007: still a nemesis. Eur J Radiol 2007;64:27–40.
29. Braatz T, Mirvis SE, Killeen K, Lightman NI. CT diagnosis of internal mammary artery injury caused by blunt trauma. Clin Radiol 2001;56:120–123.
30. Mottox KL, Wall MJ Jr, LeMaire SA. Injury to the thoracic great vessels. In: Moore EE, Feliciano DV, Mattox KL, eds. Trauma. 5th ed. Philadelphia, Pa: McGraw-Hill, 2004; 571–591.
31. Sliker CW. Imaging of diaphragmatic injuries. Radiol Clin North Am 2006;44:199–211.
32. Mirvis SE, Shanmuganathan K. Imaging hemidiaphragmatic injury. Eur Radiol 2007;17:1411–1421.
33. Asensio JA, Petrone P, Demetriades D. Injury to the diaphragm. In: Moore EE, Feliciano DV, Mattox KL, eds. Trauma. 5th ed. Philadelphia, Pa: McGraw-Hill, 2004; 613–635.
34. Bergin D, Ennis R, Keogh C, Fenlon HM, Murray JG. The "dependent viscera" sign in CT diagnosis of blunt traumatic diaphragmatic rupture. AJR Am J Roentgenol 2001;177:1137–1140.
35. Larici AR, Gotway MB, Litt HI, et al. Helical CT with sagittal and coronal reconstructions: accuracy for detection of diaphragmatic injury. AJR Am J Roentgenol 2002;179:451–457.
36. Ziegler DW, Agarwal NN. The morbidity and mortality of rib fractures. J Trauma 1994;37:975–976.
37. Barnea Y, Kashtan H, Skornick Y, Werbin N. Isolated rib fractures in elderly patients: mortality and morbidity. Can J Surg 2002;45:43–46.
38. Athanassiadi K, Gerazounis M, Theakos N. Management of 150 flail chest injuries: analysis of risk factors affecting outcome. Eur J Cardiothorac Surg 2004;26:373–376.
39. Ciraulo DL, Elliott D, Mitchell KA, Rodriguez A. Flail chest as a marker for significant injuries. J Am Coll Surg 1994;178:466–470.
40. Butters KP. Fractures of the scapula. In: Bucholz RW, Heckman JD, Court-Brown C, eds. Rockwood and Green's fractures in adults. 6th ed. Philadelphia, Pa: Lippincott Williams & Wilkins, 2006; 1257–1284.
41. Weening B, Walton C, Cole PA, Alanezi K, Hanson BP, Bhandari M. Lower mortality in patients with scapular fractures. J Trauma 2005;59:1477–1481.
42. Lunsjo K, Tadros A, Czechowski J, Abu-Zidan FM. Scapular fractures and associated injuries in blunt trauma: a prospective study [abstr]. J Bone J Surg Br 2006;88(suppl):141-b.
43. Zlowodzki M, Bhandari M, Zelle B, Kregor PJ, Cole PA. Treatment of scapular fractures: systematic review of 520 fractures in 22 case series. J Orthop Trauma 2006;20:230–233.
44. Wedde TB, Quinlan JF, Khan A, Khan HJ, Cunningham FO, McGrath JP. Fractures of the sternum: the influence of non-invasive cardiac monitoring on management. Arch Orthop Trauma Surg 2007;127:121–123.
45. Knobloch K, Wagner S, Haasper C, et al. Sternal fractures are frequent among polytraumatised patients following high deceleration velocities in a severe vehicle crash. Injury 2008;39:36–43.
46. De Waele JJ, Calle PA, Blondeel L, Vermassen FE. Blunt cardiac injury in patients with isolated sternal fractures: the importance of fracture grading. Eur J Trauma 2002;28:178–182.
47. von Garrel T, Ince A, Junge A, Schnabel M, Bahrs C. The sternal fracture: radiographic analysis of 200 fractures with special reference to concomitant injuries. J Trauma 2004;57:837–844.
48. Cope R. Dislocations of the sternoclavicular joint. Skeletal Radiol 1993;22:233–238.
49. Buckley BJ, Hayden SR. Posterior sternoclavicular dislocation. J Emerg Med 2008;34:331–332.
50. Kälicke T, Andereya S, Westhoff J, Gekle C, Müller EJ, Muhr G. Anterior sternoclavicular dislocation caused by indirect compression trauma. Eur J Trauma 2003;29:327–330.

This article meets the criteria for 1.0 credit hour in category 1 of the AMA Physician's Recognition Award. To obtain credit, see accompanying test at http://www.rsna.org/education/rg_cme.html.

Multidetector CT of Blunt Thoracic Trauma

Rathachai Kaewlai, MD, et al

RadioGraphics 2008; 28:1555–1570 • **Published online** 10.1148/rg.286085510 • **Content Codes:** CH CT ER

Page 1558
CT readily characterizes pleural fluid in the setting of trauma with determination of the attenuation value. Blood in the pleural space typically has an attenuation of 35--70 HU. Measurement of pleural fluid attenuation should be routine in the interpretation of chest trauma CT to distinguish simple fluid from acute blood.

Page 1558
The timing of the development of pulmonary contusion is often helpful in determining the cause of areas of pulmonary opacity in trauma patients. Focal areas of pulmonary opacity appearing 24 hours or more after injury suggest diagnoses other than contusion, including aspiration, pneumonia, and fat embolism.

Page 1560
Common imaging manifestations of bronchial injuries are pneumomediastinum and pneumothorax. The latter occurs if an injury extends to the pleural space. The presence of a persistent pneumothorax, even with chest tube placement and suction, should raise concern for possible bronchial injury.

Page 1561
The diagnosis of blunt cardiac injury relies on a high degree of clinical suspicion. The patient may have abnormal electrocardiographic findings and elevated cardiac enzyme levels. Imaging manifestations of blunt cardiac injury include hemopericardium, contrast material extravasation into the pericardial sac or mediastinum, pneumopericardium, displacement of the heart due to cardiac herniation, and abnormal bowel gas in the chest due to diaphragmatic pericardial tear.

Page 1563
CT not only allows direct visualization of periaortic hematoma but also can show the actual aortic injuries, including aortic pseudoaneurysm, changes in aortic contour or diameter, intimal flap and thrombus, and contrast material extravasation. Multiplanar and volumetric reformation is useful in determining the distance of the injury from the aortic arch branches, the length of the injury, the diameter of the aorta above and below the injury, the type of vascular disease, and coexisting anatomic anomalies.