DIAGNOSTIC IMAGING OF NON-MEDIASTINAL THORACIC INJURY

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The admission supine chest radiograph provides diagnostic findings related to immediately life-threatening conditions including tension pneumothorax, and mediastinal hematoma, as an indirect sign of possible aortic injury, or potentially life-threatening conditions including hemothorax and pneumothorax. Other conditions such as diaphragm rupture, flail chest, pulmonary contusion, pneumopericardium, and pneumomediastinum are also often diagnosed or suggested by initial plain radiography. In most centers the chest radiograph remains an integral part of the immediate imaging assessment of the hemodynamically stable trauma patient. The ability of CT to detect many types of pathology that are not usually diagnosed radiographically has increased use of this modality as an added or substitute screening study for patients sustaining chest injury. The utility of CT is most advantageous for direct diagnosis of vascular, airway, and diaphragm injury, as well as having greater sensitivity for the detection and accurate localization of the foci of active intrathoracic hemorrhage. In general, CT better defines the course of penetrating trauma than radiography, which is vital in determining the necessity of further studies of mediastinal injury. CT is more sensitive to diagnose subtle pneumothorax, pleural and pericardial effusions, lung contusions, and lacerations.

It is rare today for major trauma patients not to undergo CT of one or more body parts and inclusion of the thoracic CT, and often other body areas, without direct clinical findings is becoming increasingly common, given the frequent “clinical silence” of some possibly life-threatening intra-thoracic injuries. The degree of reliance on helical or MDCT in chest injury diagnoses must be considered in the total context of the emergency care environment of a given medical institution and its use may appropriately vary among different emergency departments.

Chest wall injury

Isolated fractures of the ribs, clavicle, or scapula seldom represent significant injuries, but reflect the magnitude and direction of chest wall impacts. The more compliant chest walls of children and younger adults may allow transmission of significant energy into the thorax without producing rib fractures, so even severe chest trauma can be present in the absence of rib or other thoracic skeletal injury. Rib fractures from a given impact are more likely to be present in older adults with less compliant chest walls. Fractures of the first three ribs, in particular, indicate significant energy transfer. Fractures involving the thoracic outlet, upper ribs, upper sternum, and clavicle may be accompanied by brachial plexus or vascular injury in 3.0% to 15.0% of patient.

Single rib fractures are usually of limited significance and identification or precise localization of these is of dubious clinical utility. Double fractures in four or more adjacent ribs or the combination of adjacent ribs and sternal or costochondral fractures can produce a focal area of chest-wall instability. Paradoxical movement of this "flail" segment during the respiratory cycle can impair respiratory mechanics and pulmonary drainage and promote the development of atelectasis and pneumonia. Although often recognized by physical inspection, a flail segment involving the upper ribs may be hidden by the chest-wall musculature. Fractured ribs accompanied by lacerations of intercostal arteries can cause major intra and extrapleural hemorrhage, often requiring angiographic localization and embolization. The irregular edges of fractured and displaced ribs can lacerate the pleura, peripheral lung, diaphragm, and adjacent abdominal organs.

Extrapleural hematomas (EPH) appear as focal lobulated areas of increased density on the chest radiograph. Due to their extrapleural nature, such hematomas indent the parietal pleura focally creating a convex margin toward the lung. Development of EPH over the apices may accompany fractures of the upper ribs or hemorrhage from the subclavian vessels from blunt trauma or iatrogenic causes. EPH will not change configuration with changes in patient position as will free pleural space fluid collections. On CT, the localization of a hematoma to either the pleural or extrapleural space is usually straightforward based on the factors noted above, but may be uncertain on occasion. Inaccurate localization may lead to incorrect chest tube placement. EPH produces medial displacement of a fat layer that is just external to the parietal pleura deep to the endothoracic fascia and inner intercostal muscles. This medial displacement of this fat layer aids in localization of hematoma to the extrapleural space.

Fractures of the sternum are infrequent, occurring in 1.5% to 4% of blunt chest trauma. The diagnosis may be made by clinical inspection and chest wall palpation, but typically is established by imaging. While a lateral chest radiograph will detect sternal fractures with reasonably high sensitivity this view is seldom obtained in the acute trauma assessment. The frontal view misses all sternal fractures unless associated with significant transverse displacement. CT should permit detection of most sternal fractures unless non-displaced or occurring in the horizontal (axial) plane. Sternal fractures often occur in a coronal orientation or have a component in that axis, which is easier to recognize by CT. Sternal fractures have been associated with major injuries to the heart and great vessels, although in actuality this association appears to be quite uncommon, particularly with isolated, non-displaced, and non-depressed sternal fracture patterns. Cardiac injury arising as a direct result of sternal fracture has been reported in 1.5% to 6% of patients. Laceration of the innominate artery secondary to a displaced fracture of the sternum has been reported, but appears to be quite rare. Crestanello et al noted that fractures of the manubrium rather than the sternal body require high force and are likely to be associated with more severe additional injuries. They described sternal fractures occurring as a result of direct impact, but also arising indirectly from flexion compression associated with thoracic spine wedge compression fractures. They also noted a 3-fold increase in the incidence of the injury with use of the shoulder-lap belt restraint system.

Most sternoclavicular dislocations are anterior and have no major clinical significance. However, posterior dislocations of the clavicle relative to the manubrium can damage adjacent vessels, superior mediastinal nerves, and the trachea or esophagus. Although sternoclavicular dislocations are demonstrable using angled chest radiographs (tube angled 35^{o} cranially), they are most easily diagnosed using axial CT. Posterior dislocation can result from a posterior and laterally directed force into the shoulder moving the lateral clavicle forward and pivoting the medial clavicle posteriorly. Thoracic angiography and esophagography are warranted to exclude injury in these structures.

Isolated fractures of the scapular are frequently overlooked in interpretation of both chest radiographs and thoracic CT. These injuries indicate the likelihood of significant chest wall impact and are important for that reason as well as to recognize as a cause for pain and limitation of shoulder girdle motion. Scapulothoracic dissociation (STD) is a rare and serious injury characterized by a lateral displacement of the entire forequarter with intact overlying skin, complete acromioclavicular separation, and usually multiple ipsilateral upper extremity fractures. Avulsion injuries to the brachial plexus and subclavian nerves always accompany the injury. Vascular injuries are also common and should be sought even in the presence of a normal distal pulse, which may be maintained by collateral flow. Usually there is a large supraclavicular hematoma on the involved side and the injury is apparent by inspection. The diagnosis may be suggested initially on chest radiography or CT. Both modalities typically demonstrate lateral scapular displacement and often an abnormal orientation of the involved scapula.

Fractures of the thoracic spine may be easily overlooked when interpreting the frontal chest radiograph in acute blunt trauma patients. These films are often underexposed and are frequently compromised by patient motion, overlying support lines and tubes, and poor positioning. More overt findings can easily distract a reader from a careful review of the radiograph for evidence of paraspinal hematoma and gross abnormalities of spinal alignment. A substantial percentage of thoracic injuries will be fracture-dislocations that will present with profound neurologic deficits, but many others will be amenable to reduction and stabilization before the onset or exacerbation of neurologic dysfunction. Similarly, review of thoracic CT images for bone detail, in addition to the traditional lung and soft tissue window surveys, can often detect unsuspected thoracic spine injuries. The presence of diffuse mediastinal hemorrhage associated with lower cervical, thoracic, or upper lumber spine fractures should not be assumed to arise strictly from the skeletal injury and concurrent major vascular injury should also be excluded. If a paraspinal hematoma surrounds a spine fracture more or less symmetrically and displaces the aorta, but the aorta and great vessels appear normal on high quality intravenous contrast enhanced thoracic CT, aortography is not required.

Pleural Space

Most chest radiographs in polytrauma patients or those with penetrating thoracic injury are obtained with the patient in the supine position. In this position pneumothorax tends to accumulate in the antero-inferior aspect of the pleural space potentially producing basal hyperlucency, a deepened lateral costo-phrenic sulcus, or a “double-diaphragm” appearance. It is important to scrutinize the lung bases and upper abdomen carefully to avoid missing this diagnosis. In uncertain cases or for follow-up after chest tube removal an erect expiratory radiograph offers the highest sensitivity for detection of small pneumothoraces. Several studies have documented much higher sensitivity of CT for pneumothorax as compared to supine chest radiographs, one of the many reasons for growing reliance on CT screening in thoracic trauma. Atypical locations of pleural space air include infrapulmonic, behind the pulmonary ligament, loculated by pleural adhesions, or confined to the medial pleural space. Skin folds, tape, gowns, vascular lines, and the medial scapular border create shadows that mimic pneumothorax. The complete absence of vascular shadows beyond the apparent visceral pleural line is a key-supporting finding. Occasionally, decubitus views with the side suspicious for pneumothorax non-dependent can help verify the diagnosis, but is often difficult to obtain with high-quality using portable equipment.

Tension pneumothorax

A tension pneumothorax produces high intrathoracic pressure reducing cardiac filling, compressing the ipsilateral lung, and displacement of the mediastinum contralaterally. In addition, high intrapleural pressure can depress the ipsilateral hemidiaphragm and widen the interspace between ipsilateral ribs. A hyperlucent hemithorax is usually observed with variable degrees of lung collapse. When a tension pneumothorax persists despite correct chest tube placement there should be concern for major airway injury. The increase in intrathoracic pressure is usually secondary to one-way movement of air from the lung, airway, or mediastinum into the pleural space. Though often apparent clinically, tension pneumothorax may often be diagnosed initially by radiography or CT and requires immediate notification of the clinical service urgent relief by tube thoracostomy.

Hemothorax

Hemothorax of some degree occurs in 50% of major trauma patients. On supine radiography liquid blood will layer posteriorly producing uniform increased density over the hemithorax and possibly a stripe of higher density along the lateral pleural space depending on quantity of fluid present. In the semi-erect or erect view the liquid blood will create a meniscus with increased density confined to the lower hemithorax. If a hemothorax is under pressure (arterial bleeding) the mediastinum can shift contralaterally and the ipsilateral lung is more readily compressed. On radiography, lung markings are generally visible and intact through a pleural-based density. Clotted blood may cause lobulated density along the pleural surface, but this is uncommon in acute trauma as blood is usually in a liquid state. One may see air-fluid level(s) in the semi-erect or erect position with a concurrent pneumothorax. Rarely blood/fluid collects in the sub-pulmonic space in the semi-erect patient, within fissures, or behind pleural adhesions. On CT, hemorrhage can be diagnosed by virtue of its density of 30 - 45 HU depending on the hematocrit, the degree of clot retraction, and .admixture of other types of fluid. Higher attenuation clot will be brighter than surrounding liquid blood (50 – 90 HU). Active extravasation of iodinated blood into the pleural space can be detected, particularly using MDCT, prompting urgent surgical or arteriographic intervention. The management of intrapleural hemorrhage depends on its initial quantity, rate of bleeding and overall patient condition.

In the setting of acute chest trauma other sources of pleural effusion can also occur. Simple serous effusions result from impaired pulmonary dynamics and decreased resorption of fluid by the pleura and are commonly associated with atelectasis or ipsilateral chest wall injury limiting respiratory excursions. Rarely, bilo-pleural fistulas can occur from simultaneous injury to the liver and right diaphragm. Chylous effusions result from traumatic disruption of the major thoracic lymphatic channels.

Lung Parenchyma

Pulmonary contusions and lacerations

Pulmonary contusions result from direct impact to the chest wall and often reflect the shape of the impacting object. As noted above, rib fractures associated with contusion as less common in children and young adults with more compliant ribs. Contusions appear radiodense and are usually peripheral, non-segmental, and non-lobar in distribution. Contusions are also commonly seen adjacent to the spine possibly related to direct impact of the lung into the rigid spine and may also result from the shearing effects of rapid deceleration. Increased lung density is due to alveolar and distal bronchial hemorrhage and edema. Since the small airways usually fill with blood, air-bronchograms are uncommon in areas of contusion. Pulmonary lacerations very frequently accompany pulmonary contusions and are much better seen by CT than radiographs. Often there are numerous small lacerations within areas of contused, consolidated lung producing a “Swiss cheese” appearance. In addition, variable-sized uniformly dense rounded areas of hematoma are present within these contused regions. Pulmonary lacerations typically become more apparent radiographically as edema and hemorrhage associated with contusions begins to resolve, usually within a few days of injury. On CT, pulmonary lacerations appear as ovoid or elliptical air spaces surrounded by a 2 - 3 m pseudomembrane. They may contain a central hematoma or air-hemorrhage level. In general, lung lacerations are benign, but complications can occur and are best shown by CT. Complications include infection and abscess formation, bronchopleural fistula formation when they are peripheral, progressive enlargement, most likely from a ball-valve mechanism compressing adjacent normal lung and hemorrhage. Lung hematomas slowly contract over time and can present later as a pulmonary “soft tissue nodule” if the recent history of chest trauma is not revealed. Failure of a pulmonary contusion to begin to resolve within a few days after injury or increasing lung density suggests superimposed pneumonia or ARDS.

Lung herniation

Rarely, a segment of lung may herniate through a defect in the chest wall created by a flail segment or direct penetration of the chest wall. Transthoracic lung herniation increases in likelihood with positive-pressure ventilatory support and with tearing of the internal thoracic fascia, parietal pleura, and pectoral and intercostal musculature. The diagnosis may be made by radiographs, but is easier to detect by CT. Although entrapment and strangulation of the herniated portion of lung can occur, in the author's experience significant sequelae generally do not develop if the herniated lung is small in size. Large herniated lung segments that restrict respiratory movement are typically surgically reduced and the overlying chest wall repaired.

Acute Diaphragm Tears

Injury to the diaphragm occurs in 0.8% to 5.8% of major blunt abdominal trauma cases undergoing laparotomy. Penetrating trauma is a far more common cause and is usually diagnosed directly at surgery. However, recent studies using MDCT with oral and intravenous contrast enhancement augmented by MPR have shown promise in documenting or excluding diaphragm injury from penetrating trauma. Diagnostic supine radiographic signs of blunt traumatic injury to the left hemidiaphragm occur in about 50% of patients (ranging from 27-60% in various series. Definitive radiographic diagnosis requires herniation of abdominal viscera, typically the stomach, above the hemidiaphragm. A nasogastric tube, perhaps with injection of some dilute oral contrast material, helps demonstrate the gastric fundus and its relationship to the hemidiaphragm. Focal constriction of the stomach or other herniating viscera at the level of the diaphragmatic tear may produce a "collar or hourglass sign", constriction that is pathognomonic of diaphragm rupture.

Injury to the left hemidiaphragm is more commonly diagnosed radiographically since herniation of abdominal contents is more likely to occur than on the right side where it is blocked by the liver. Other radiographic signs that are suggestive, but non-diagnostic of diaphragm rupture, are present in another 18% of patients and include a poorly defined or apparently elevated diaphragm, especially with contralateral mass effect on the heart and mediastinum, and air-fluid levels at the left lung base, It is important to obtain chest radiographs in blunt trauma patients after removed from positive pressure airway support since positive intrathoracic pressure will delay or prevent transdiaphragmatic herniation, whereas typical negative intrathoracic pressure will promote it. In such cases follow-up radiography may be of value since a delayed presentation of herniation is not uncommon. Ruptures of the right hemidiaphragm are strongly suggested after blunt trauma by both elevation of the apparent right hemidiaphragm or a mass-like hump contour of the apparent diaphragm. The torn diaphragm may appear completely normal radiographically or be associated only with ipsilateral atelectasis or pleural fluid. MDCT may show a band of relative decreased density within the liver parenchyma where it is indented by the torn diaphragm edges. On the AP supine radiograph, elevation of the apparent right hemidiaphragm 4 cm or more of the left should suggest the possibility of right diaphragm rupture. Direct signs of diaphragm injury by MDCT include visualization of the diaphragm tear, visualization of herniated abdominal content above the diaphragm and direct contact between the herniated abdominal viscera and the posterior chest wall, the “dependent viscera sign”. Diaphragm injuries are seldom isolated, so careful inspection of adjacent thoracic and abdominal structures is required. Rupture of the stronger right hemidiaphragm requires greater force than on the left and is usually associated with right-sided impacts and higher total patient injury severity scores.

Possible causes of falsely positive radiographic diagnoses of diaphragm tears include lacerations at the lung bases with air-fluid levels mimicking herniated bowel, phrenic nerve injury, Foramen of Bockdalek hernia, diaphragm paralysis, and eventration of the hemidiaphragm. Atelectasis, particularly of the left lower lobe, can elevate the apparent hemidiaphragm mimic diaphragm rupture with herniation. In such cases however, the mediastium and heart are pulled to the side of potential herniation as opposed to the expected contralateral mass effect.

False negative radiologic diagnoses are usually due to tears without associated herniation or mistaking acute injury for a remote or congenital abnormality. Again, acute injury is usually associated with mediastinal and cardiac displacement away from the herniated viscera and ipsilateral pleural effusion (hemothorax). Eventration of the diaphragm, a partially or completely fibrous membrane in place of a muscular contracting diaphragm, appears as a smoothly contoured, elevated apparent hemidiaphragm, more commonly seen on the left side. In this author’s experience, this abnormality is the most common mimic of true diaphragm rupture with herniation after atelectasis.

Usually penetrating injury to the diaphragm is discovered at surgical exploration performed due to assess penetrating injury of the peritoneal cavity. MDCT can be useful to clarify the course or trajectory of a penetrating thoraco-abdominal injury and determine its relationship to the diaphragms. Careful inspection of axial images in such cases may directly show the location and extent of diaphragm perforation. MDCT can often directly demonstrate the edges of the torn diaphragm and site of herniation if present. Thin axial section diaphragm CT, such as 50% overlapping 1mm overlapping slices provides for excellent MPR in the sagittal and coronal plane optimizing diagnostic accuracy. Typical lacerations created by penetrating injury are short (< 2cm) and unlikely to be associated with herniation, but delayed herniation is still possible. The author has found high-resolution MPR studies particularly useful for diagnosis or exclusion of right-sided diaphragm injury where herniation is less common.

If there is injury identified both above and below the diaphragm from a single stab wound, the diaphragm must have been violated, even if the tear is not directly seen. This concept cannot be used with multiple penetrations or ballistic injuries where a shock-wave may cause injury to the other side of the diaphragm without direct diaphragm penetration. The demonstration of blood around the diaphragm, a thickened diaphragm, or a wound tract in close proximity to the diaphragm should be considered evidence of direct injury and carefully followed if there is not evidence of herniation, particularly on the left side. In penetrating injury, on occasion, the author has observed oral or rectally administered contrast material leaking from perforated bowel through a torn diaphragm into the pleural space, an indirect, but conclusive sign of a full-thickness diaphragm disruption.

If the MDCT remains equivocal for diaphragm injury then MRI can be used as a third line diagnostic study. MRI will usually depict direct diaphragm discontinuity and visceral herniation and requires only T1-weighted sagittal and coronal images. MRI is very useful as well to confirm an intact diaphragm in blunt trauma patients with apparent diaphragm elevation on radiography.

Precise localization of penetrating diaphragm injuries is vital to determine if repair (depending on location as size of defect) is needed and to guide that repair, especially if a laparoscopic approach is utilized.

Selected References:

1. Gupta A, Jamshidi M, Rubin JR. Traumatic first rib fracture: is angiography necessary? A review of 730 cases. Cardiovasc Surg 5:48-53, 1997.
2. Ciraulo DL, Elliott D, Mitchell KA, Rodriguez A. Flail chest as a marker for significant injuries. J Am Coll Surg 178:466-70,1994.
3. Rashid MA, Wikstrom T, Ortenwall P. Nomenclature, classification, and signficance of traumatic extrapleural hematoma. J Trauma 49:286-90, 2000.
4. Aquino SL, Chiles C, Oaks T. Displaced extrapleural fat as revealed by CT scanning: evidence of extrapleural hematoma. AJR Am J Roentgenol 169: 687-9,1997.
5. Crestanello JA, Samuels LE, Kaufman MS, et al. Sternal fracture with mediastinal hematoma: delayed cardiopulmonary sequelae. J Trauma 47:161-4,1999.
6. Huggett JM, Roszler MH. CT findings of sternal fracture. Injury 29: 623-6, 1998.
7. Zinck SE, Primack SL. Radiographic and CT findings in blunt chest trauma. J Thorac Imaging 15: 87-96, 2000.
8. Gouldman JW, Miller RS. Sternal fracture:a benign entity? Am Surg 63:17-9,1997.
9. Collins J. Chest wall trauma. J Thorac Imaging15:112-9, 2000.
10. Sheafor DH, Mirvis SE. Scapulothoracic dissociation: report of fice cases and review of the literature. Emerg Radiol 2:279-85,1995.
11. Neff MA, Monk JS, Peters K, et al. Detection of occult pneumothoraces on abdominal computed tomographic scans in trauma patients. J Trauma 49:281-5, 2000.
12. Bridges KG, Welch G, Silver M, et al. CT detection of occult pneumothorax in multiple trauma patients. J Emerg Med 11:179-86,1993.
13. Trupka A, Waydhas C, Hallfeldt KK, et al. Value of thoracic computed tomography in the first assessment of severely injured patients with blunt chest trauma: results of a prospective study. J Trauma 43:405-11,1997.
14. Wagner RB, Crawford WO, Schimpf PP. Classification of parenchymal injuries of the lung. Radiology 167:77-82, 1988.
15. Shanmuganathan K, Killeen K, Mirvis SE, et al. Imaging of diaphragmatic injuries. J Thorac Imaging 15:104-11,2000.
16. Bergin D, Ennis R, Keogh C, et al. The "dependent viscera" sign in CT diagnosis of blunt traumatic diaphragmatic rupture. AJR Am J Roentgenol 177:1137-40, 2001.
17. Shanmuganathan K, Mirvis SE, White CS, et al. MR imaging evaluation of hemidiaphragms in acute blunt trauma: experience with 16 patients. AJR Am J Roentgenol 167:397-402, 1996.
18. Shanmuganathan K, Mirvis SE. Imaging diagnosis of nonaortic thoracic injury. Radiol Clin North Am. 1999 May;37(3):533-51, vi. Review.
19. Braatz T, Mirvis SE, Killeen K, Lightman NI. CT diagnosis of internal mammary artery injury caused by blunt trauma. Clin Radiol. 2001 Feb;56(2):120-3.
20. Leibecke T, Stoeckelhuber BM, Gellissen J, et al. Posttraumatic and postoperative cardiac luxation: computed tomography findings in nine patients. J Trauma. 2008 Mar;64(3):721-6.
21. Elmali M, Baydin A, Nural MS, Arslan B, Ceyhan M, Gürmen N. Lung parenchymal injury and its frequency in blunt thoracic trauma: the diagnostic value of chest radiography and thoracic CT. Diagn Interv Radiol. 2007 Dec;13(4):179-82.
22. Magnotti LJ, Weinberg JA, Schroeppel TJ, et al. Initial chest CT obviates the need for repeat chest radiograph after penetrating thoracic trauma. Am Surg. 2007 Jun;73(6):569-72; discussion 572-3.
23. Maturen KE, Adusumilli S, Blane CE, et al. Contrast-enhanced CT accurately detects hemorrhage in torso trauma: direct comparison with angiography. J Trauma. 2007 Mar;62(3):740-5.
24. Mirvis SE, Shanmuganagthan K. Imaging hemidiaphragmatic injury. Eur Radiol. 2007 Jun;17(6):1411-21. Epub 2007 Feb 17. Review.
25. Miller LA. Chest wall, lung, and pleural space trauma. Radiol Clin North Am. 2006 Mar;44(2):213-24,
26. Rees O, Mirvis SE, Shanmuganathan K. Multidetector-row CT of right hemidiaphragmatic rupture caused by blunt trauma: a review of 12 cases. Clin Radiol. 2005 Dec;60(12):1280-9.
27. Mirvis SE. Imaging of acute thoracic injury: the advent of MDCT screening. Semin Ultrasound CT MR. 2005 Oct;26(5):305-31. Review.
28. Gavelli G, Canini R, Bertaccini P, Battista G, Bnà C, Fattori R.Traumatic injuries: imaging of thoracic injuries. Eur Radiol. 2002 Jun;12(6):1273-94. Epub 2002 Apr 20. Review.