CT of Blunt Diaphragmatic Rupture[1]

Amandine Desir, MD • Benoît Ghaye, MD

CME FEATURE

See www.rsna.org/education/rg_cme.html

LEARNING OBJECTIVES FOR TEST 3

After completing this journal-based CME activity, participants will be able to:

- Describe the characteristic anatomic locations and patterns of injury seen in BDR.
- Recognize CT signs that are suggestive of BDR.
- Discuss the pitfalls of using CT to assess the diaphragm in trauma patients.

TEACHING POINTS

See last page

The diagnosis of blunt diaphragmatic rupture (BDR) is difficult and often missed, leaving many patients with this traumatic injury at risk for life-threatening complications. The potential diagnostic pitfalls are numerous and include anatomic variants and congenital and acquired abnormalities. Chest radiography, despite its known limitations, may still be helpful in the early assessment of severe thoracoabdominal trauma and for detecting initially overlooked BDR or late complications of BDR. However, since the development of helical and multidetector scanners, computed tomography (CT) has become the reference standard; thus, knowledge of the CT signs suggestive of BDR is important for recognition of this injury pattern. A large number of CT signs of BDR have been described elsewhere, many of them individually, but the use of various appellations for the same sign can make previously published reports confusing. The systematic description and classification of CT signs provided in this article may help clarify matters and provide clues for diagnosing BDR. The authors describe 19 distinct CT signs grouped in three categories: direct signs of rupture, indirect signs that are consequences of rupture, and signs that are of uncertain origin. Since no single CT sign can be considered a marker leading to a correct diagnosis in every case of BDR, accurate diagnosis depends on the analysis of all signs present.

Abbreviation: BDR = blunt diaphragmatic rupture

RadioGraphics 2012; 32:477–498 • **Published online** 10.1148/rg.322115082 • **Content Codes:** CH CT ER GI

[1]From the Department of Radiology, Cliniques Universitaires Saint-Luc, Université Catholique de Louvain, Avenue Hippocrate 10, 1200 Brussels, Belgium. Presented as an education exhibit at the 2010 RSNA Annual Meeting. Received April 12, 2011; revision requested May 12 and received July 18; accepted November 7. For this journal-based CME activity, the authors, editor, and reviewers have no relevant relationships to disclose. **Address correspondence to** B.G. (e-mail: *benoit.ghaye@uclouvain.be*).

Introduction

Diaphragmatic injuries are estimated to occur in 0.8%–8% of patients with blunt abdominal trauma (1–12). When a conservative approach to trauma management is taken, blunt diaphragmatic rupture (BDR) remains undiagnosed at initial presentation in 7%–66% of cases; in most such cases, the right hemidiaphragm is affected. BDR may be missed for many reasons. The condition is often clinically silent or may be overshadowed by associated injuries. The diagnosis is easier when BDR manifests with complications, but complications may occur long after the initial trauma. Furthermore, radiologic image interpretation is difficult: The chest radiographic features of BDR are subtle and nonspecific, and a large number of signs observed at computed tomography (CT) have been described with varying appellations in the literature. Finally, there is a general lack of awareness on the part of both clinicians and radiologists about this condition (1,4,9,11,13–30). Unfortunately, diaphragmatic rupture does not resolve spontaneously, and the resultant complications may be disastrous (1). The keys to diagnosing BDR are a constant high degree of suspicion in every case of severe thoracoabdominal trauma and knowledge of the various CT signs of diaphragmatic rupture.

The article describes 19 CT signs of BDR that have been reported in the literature. The anatomic, embryologic, and pathophysiologic information necessary to recognize each sign and differentiate it from others is provided. Most of these signs are categorized as either direct or indirect, according to whether BDR is directly depicted on images or is indirectly evidenced by findings of herniation, loss of the border between the thorax and abdomen, or other abnormal but nonspecific features. A few signs that might fit into either of these two categories but that are considered to have an uncertain origin or to be controversial are discussed separately. Because chest radiography often plays a role in the delayed detection of BDR and its complications, radiographic findings also are summarized, and those that are highly suggestive or indicative of the diagnosis are described in detail.

Anatomic and Embryologic Considerations

The diaphragm is a musculotendinous sheet that separates the thoracic and abdominal cavities; its convex upper aspect faces the thorax, and its concave inferior part faces the abdomen. It consists of peripheral muscle fibers that originate from the entire circumference of the lower thoracic inlet and converge into a central tendon (Fig 1). This muscular part comprises three groups of fibers described as sternal, costal, or lumbar, according to the anatomic structure on which they insert peripherally. The central tendon is a thin but strong aponeurosis with a cloverleaf shape. The left and right hemidiaphragmatic domes rise lateral to the heart; in most people, the right dome is approximately one intercostal space higher than the left (1).

Three major orifices traverse the diaphragm: the aortic hiatus, the inferior vena cava foramen, and the esophageal hiatus. There may be variable diaphragmatic regions in which muscle fibers are deficient and have been replaced by areolar tissue and where the thorax is thus separated from the abdomen only by the pleura, peritoneum, and fascia. These points of weakness are located in regions of embryologic development where groups of muscle fibers from different origins meet: the right and left sternocostal triangles (where the sternal and costal fibers meet) and the lumbocostal triangles (where the costal and lumbar fibers meet) (31–34). The presence of weak areas explains the frequent occurrence of chronic nontraumatic conditions such as the Bochdalek hernia, which must be borne in mind when assessing the diaphragm in trauma patients (see the section on "Diagnostic Pitfalls at CT").

A detailed review of the embryology of the diaphragm is not possible here; however, some characteristics of the diaphragm that are directly related to embryologic development may influence the pattern of diaphragmatic rupture. Indeed, it is thought that the weak posterolateral areas of the diaphragm correspond to the zones in which the pleuroperitoneal membranes join with the septum transversum and the dorsal mesentery of the esophagus to close the pleuroperitoneal ducts in the 8th week of gestation (18,31,32).

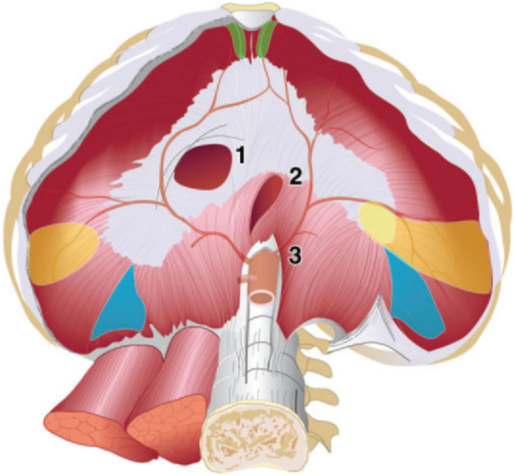


Figure 1. Drawing of the diaphragm from the abdominal perspective shows the peripheral muscle fibers (reddish-brown) and central tendon (gray) surrounding three main orifices: the inferior vena cava foramen *(1)*, esophageal hiatus *(2)*, and aortic hiatus *(3)*. The right and left sternocostal (green) and lumbocostal (blue) triangles are frequent sites of nontraumatic herniation. The areas of pleuroperitoneal membrane fusion, at the posterolateral aspects of the diaphragm (yellow), are frequent sites of BDR, perhaps because of structural weakness.

Ruptures of the Diaphragm

Diaphragmatic rupture causes a loss of continuity in muscular and tendinous fibers of the membrane, with resultant communication between the thoracic and abdominal cavities (1). BDR occurs with approximately the same frequency and injury pattern in adults and children alike (20,35).

The most common causes of diaphragmatic injuries are penetrating trauma from knife or gunshot wounds and severe blunt trauma from motor vehicle accidents, with the ratio of one to the other depending mainly on the geographic location and socioeconomic status of trauma patients (25,28,36). Patients with penetrating trauma nearly always undergo exploratory surgery, which facilitates prompt diagnosis and treatment of injuries. Patients with blunt trauma are more often managed conservatively, a fact that makes the diagnosis of BDR more difficult. Once diagnosed, BDR is best treated surgically to avoid complications (9).

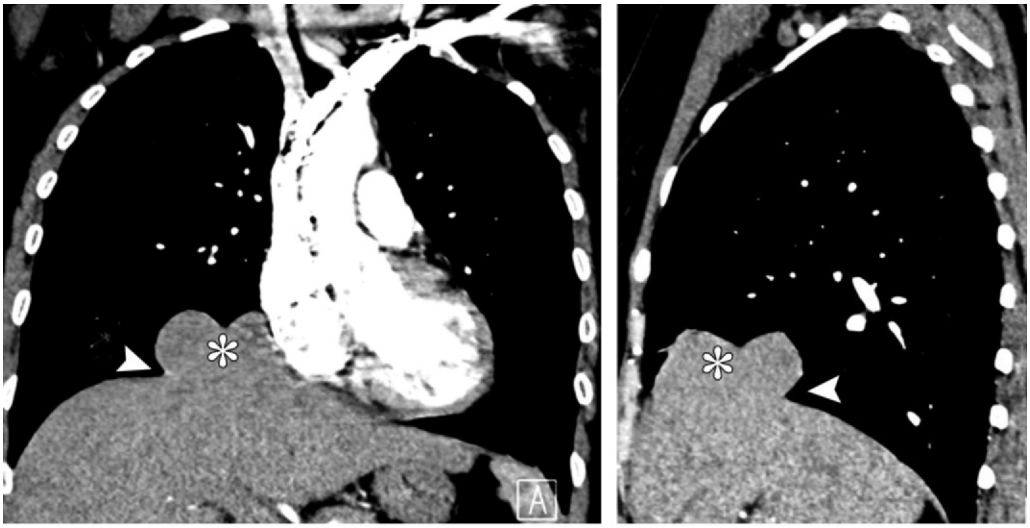
Mechanism of Injury

Blunt diaphragmatic injuries result from considerable force and most often occur in vehicular impact (90% of cases), a fall from a height, or a crushing blow (1,2,4,6,7,11). The exact mechanism of BDR is not completely understood, but it is hypothesized that the pattern of blunt diaphragmatic injuries depends partly on the direction of impact (1,2,4,37). A lateral thoracoabdominal impact results in distortion and anteroposterior elongation of the chest wall, which may cause shearing of the diaphragm or avulsion of its attachments. In a frontal impact (eg, against the steering wheel of a car), an abrupt rise in intraabdominal pressure is transmitted to the diaphragm by the abdominal viscera (37,38). The timing of impact in the respiratory cycle as well as the position of the glottis may further contribute to the pleuroperitoneal pressure gradient (1,37). Other reported mechanisms include the sudden traumatic contraction of the diaphragm against a closed glottis (reflex contraction) and penetration of the diaphragm by a fractured or fragmented rib; the latter event may result in an atypical location of BDR (ie, at the crus or the esophageal hiatus) (1,2,27,37).

Patterns of Injury

Left Side, Right Side, or Both Sides?—BDR occurs more often on the left side than on the right, with a mean left-to-right ratio of approximately 3:1 (range, 1.5:1 to 7:1) (2,3,6–9,11,13,15,23,25,26,36–46). The greater frequency of occurrence of left-sided BDR is thought to result from multiple factors: the protective effect of the liver on the right side, an area of congenital embryologic weakness in

Teaching Point



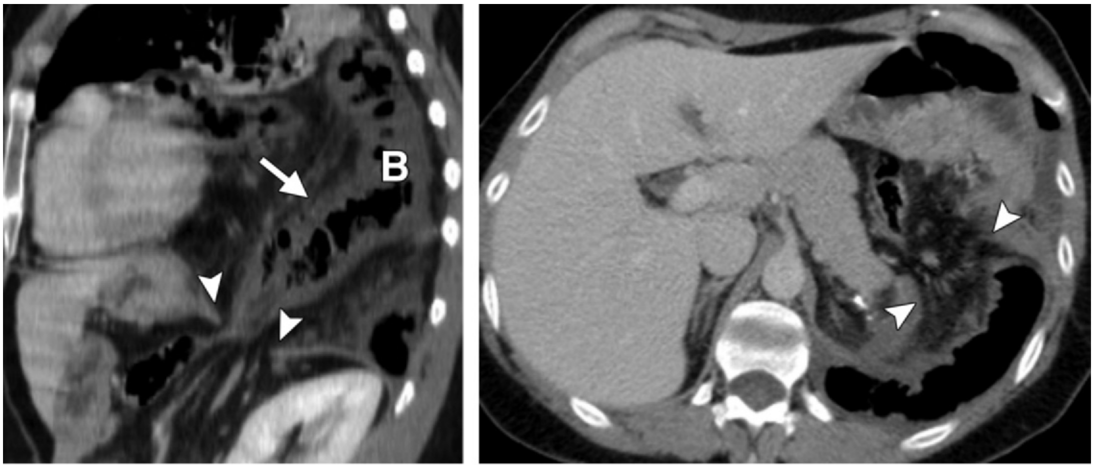
a. b.

Figure 2. Right-sided BDR discovered incidentally in a 43-year-old woman 10 years after severe thoracoabdominal trauma due to a motor vehicle accident. Coronal **(a)** and sagittal **(b)** contrast-enhanced reformatted CT images show herniation of part of the liver dome (*) into the thorax through a small anterior defect, which is evident from the focal constriction of herniated liver (collar sign) (arrowhead). A posttraumatic pseudoaneurysm with a diameter of 35 mm also was seen at the level of the aortic isthmus (not shown).

the posterolateral aspect of the left hemidiaphragm, and the greater inherent resistance of the right hemidiaphragm relative to the left (11,14,18,37,47). BDR most frequently results from a laterally directed impact and usually occurs on the side receiving the impact; for example, in automobile accidents, BDR most often occurs on the side nearest the door (4,48). The predominance of left-sided BDR may also be related to the fact that in most countries contributing to the medical literature about trauma the steering wheel is on the left side of the automobile (8,48). When the impact is frontal, BDR more often occurs on the left side, whereas when the impact comes from behind, BDR occurs with approximately equal frequency on the left and right sides (4,48). Last, the predominance of left-sided BDR may be partly due to underdiagnosis of right-sided BDR (11). Indeed, radiologic signs are more subtle on the right side: The defect in right-sided BDR may be sealed by the liver, and herniation may therefore be delayed or absent. In addition, severe injuries to organs, which occur more frequently when BDR is right sided, might mask BDR and result in death even before diagnostic imaging can be performed (2,11). Cases of intrapericardial and bilateral BDR are rare (less than 1%–6%) (2,3,8,11,26,32,49,50).

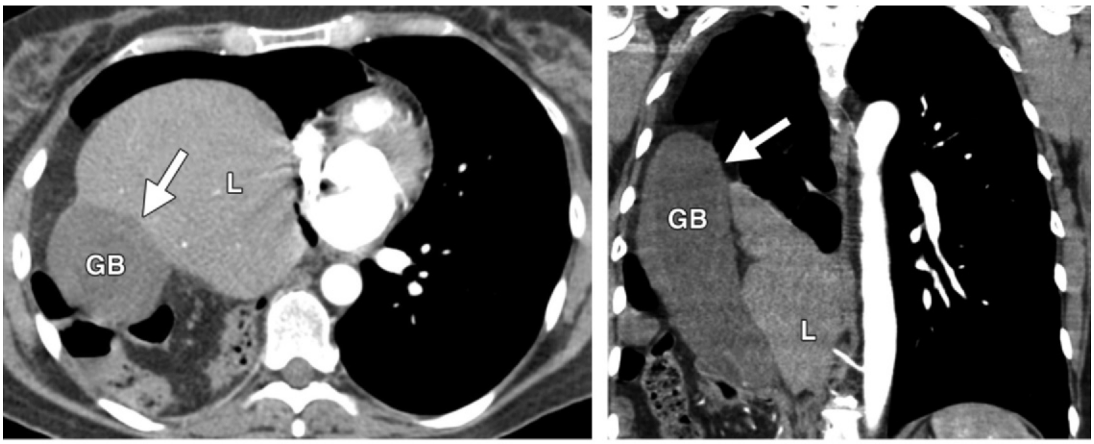
Site and Size.—The location and extent of the diaphragmatic tears in BDR varies and has no fixed pattern; furthermore, most articles in the literature about BDR do not precisely describe the location and extent of the lesions (3,11). However, ruptures in the posterolateral area and extending centrally in a radial fashion, frequently toward the angle between the pericardium and the esophageal hiatus, are most often reported (2,3,5,37,38,47,51). Descriptions of transverse or central lesions and peripheral detachment also can be found (3,32,47,52,53). Involvement of the esophageal hiatus is uncommon; the distal esophagus generally remains intact even in cases of traumatic transdiaphragmatic gastric hernia. This fact accounts for the U-shaped nasogastric tube sign seen at chest radiography in some patients with BDR (see the section on "Findings at Chest Radiography") (38,51).

Most tears in BDR are longer than 10 cm, whereas penetrating injuries to the diaphragm tend to be short (1–2 cm) (2,3,6,14,17,37). However, short tears also have been found in BDR; these are most often discovered incidentally during surgery or, lately, at imaging because of delayed complications (Figs 2–5) (7,37,54).

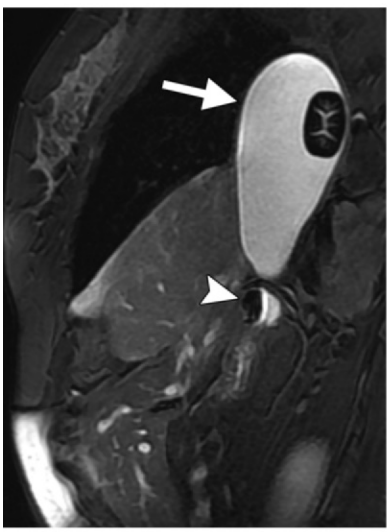


a. b.

Figure 3. Bowel strangulation in a 19-year-old woman with severe abdominal pain and sepsis 7 years after severe blunt trauma. **(a)** Sagittal contrast-enhanced reformatted CT image shows left-sided BDR, depicted as a 3-cm-long segmental diaphragmatic defect (arrowheads) through which a bowel loop *(B)* bulges into the thorax. The hernia is evident from the waistlike constriction of the bowel at the level of the diaphragm (collar sign). Thickening and hypoenhancement of the herniated bowel wall (arrow) are suggestive of strangulation. The herniated abdominal contents are positioned against the posterior wall of the thorax (dependent viscera sign). **(b)** The collar at the base of the herniated bowel (arrowheads) is more difficult to detect on the axial CT image than on reformatted images in other planes. Bowel edema without ischemia was found at surgery. (Case courtesy of Mostafa El Hajjam, MD, Club Thorax, Paris, France.)



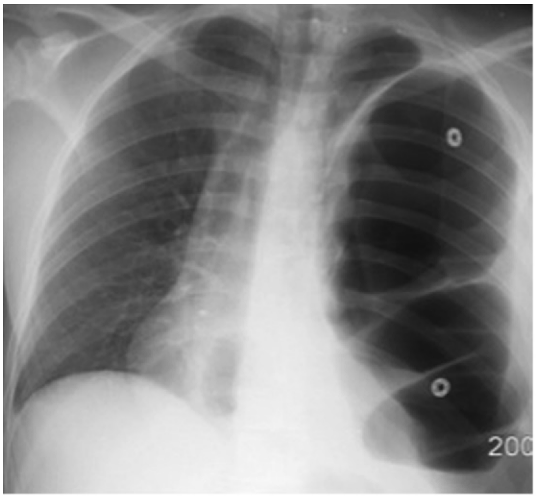
a. b.



c.

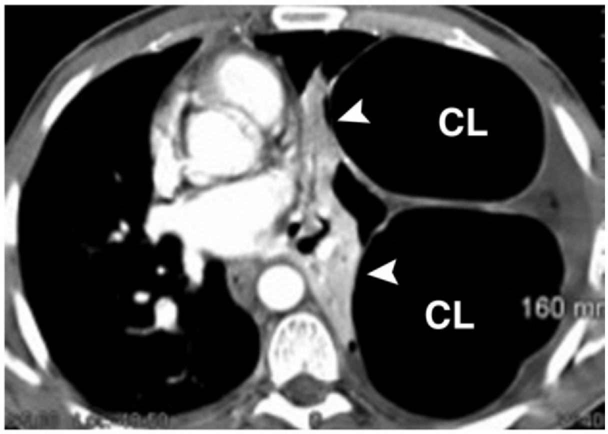
Figure 4. Cholecystitis in a 39-year-old woman with right pleural pain 15 years after trauma leading to right-sided BDR that went undiagnosed. **(a)** Axial contrast-enhanced CT image shows herniation of the liver *(L)*, gallbladder *(GB)*, abdominal fat, and bowel loops through the diaphragmatic defect. The bowel contacts the posterior thoracic wall (dependent viscera sign). Note the severe thickening of the gallbladder wall (arrow). **(b)** Coronal contrast-enhanced CT image helps confirm herniation of the gallbladder and part of the liver into the thorax (herniation through a defect sign). Thickening of the gallbladder wall (arrow) is better depicted on this coronal image than in **a**. The patient underwent medical treatment for cholecystitis and was scheduled for surgery. **(c)** Preoperative sagittal T2-weighted MR image provides clear depiction of the herniated gallbladder with a normal appearance of the wall (arrow). Two biliary stones are visible, one in the gallbladder and the other embedded in the cystic duct (arrowhead). (Case courtesy of Mostafa El Hajjam, MD, Club Thorax, Paris, France.)

Figure 5. Left-sided BDR complicated by bowel obstruction in a 30-year-old man 1 year after a traffic accident. **(a)** Chest radiograph shows a distended and air-filled bowel loop in the left hemithorax, more than 15 cm above the level of the right hemidiaphragm (elevated abdominal organs sign), with resultant mediastinal displacement toward the right side. **(b)** Abdominal radiograph shows air-fluid levels in the right upper quadrant and absence of air in the distal gastrointestinal tract, a finding suggestive of colonic occlusion. **(c)** Axial contrast-enhanced CT image at the level of the lower thorax shows distended and herniated colonic loops *(CL)* in direct contact with the collapsed left lung parenchyma (abdominal viscera abutting thoracic fluid or a thoracic organ sign) (arrowheads). As in **a**, the heart is displaced toward the right. (Case courtesy of Jacques Giron, MD, Club Thorax, Paris, France.)



a.

b.



c.

Associated Injuries

Teaching Point

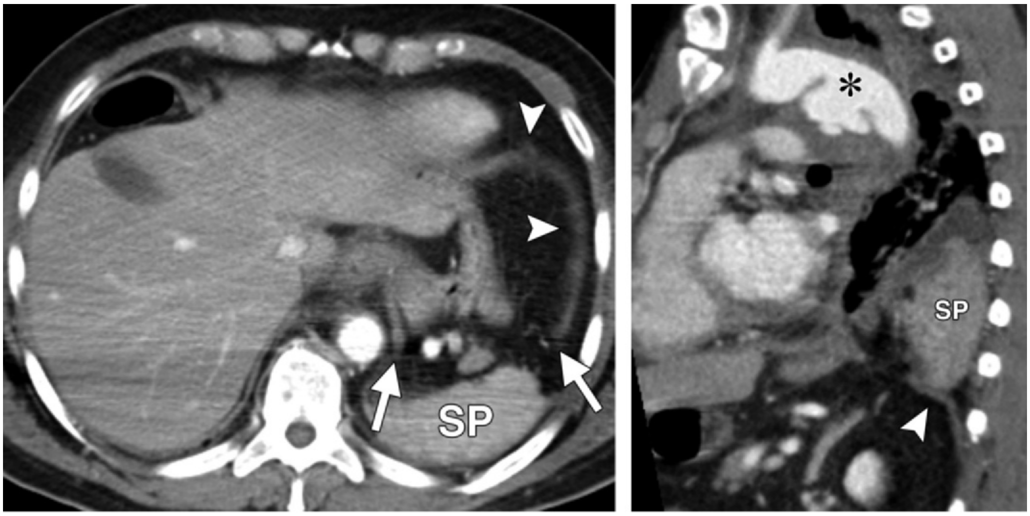
BDR is associated with other life-threatening injuries in 44%–100% of cases and almost never occurs as an isolated injury (1,2,7,8,11,38). The most common injuries associated with left-sided BDR are splenic injuries; with right-sided BDR, liver lesions are most common, but renal, aortic, cardiac, and osseous (spine, pelvis, rib) lesions also are frequently encountered (Fig 6) (1,8,11,12). Thoracic injuries such as rib fracture, pneumothorax, and pleural effusion are present in 90% of cases of BDR (2).

Complications

Teaching Point

Spontaneous healing of diaphragmatic ruptures has never been reported. The normally negative pleuroperitoneal pressure gradient (7–22 cm H_20), along with continuous diaphragmatic motion, contributes to the persistence of the lesion (1,2,11,28). Because of negative intrapleural pressure, abdominal structures generally herniate into the thorax. Such herniation may be delayed for days or years (from 1 day to 48 years), which may make the diagnosis at chest radiography and CT more difficult; however, herniation occurs within 3 years in 80% of cases (1,5,28,55). The use of positive pressure ventilatory support at the patient's admission overcomes the negative pleuroperitoneal pressure gradient, may thereby prevent or delay herniation, and thus may account for false-negative findings at initial imaging examinations (6,45). However, in some patients, herniation may be promoted by an increased pleuroperitoneal pressure gradient secondary to a transient elevation in peritoneal pressure, which may occur in Valsalva maneuver, pregnancy, or additional abdominal trauma, or by a decrease in pleural pressure during deep inspiration (38,55).

Figure 6. Left-sided BDR in a 60-year-old man after a motorcycle accident. **(a)** Axial contrast-enhanced CT image clearly shows both edges of the ruptured diaphragm (segmental diaphragmatic defect sign) (arrows). The anterolateral part of the diaphragm is thickened (thickening of the diaphragm sign) (arrowheads), and the spleen *(SP)* has herniated into the thorax (herniation through a defect sign). **(b)** Sagittal reformatted CT image shows that the spleen *(SP)* and abdominal fat are located above the diaphragm (arrowhead) and positioned dependently against the posterior thoracic wall (dependent viscera sign). Note the associated aortic rupture at the level of the isthmus (*).



a. b.

The most commonly herniated organs in cases of left-sided BDR are the stomach, colon, spleen, and omentum; in cases of right-sided BDR, the liver most often herniates (1,7,37,51). Herniation of the kidney, small intestine, and pancreatic tail is less frequent. Multiple organs are often involved in herniation. Life-threatening complications of herniation include the incarceration and subsequent occlusion of a hollow viscus (Fig 5) and necrotic ischemia of herniated organs, which may occur more frequently in small defects (1). Other reported complications of BDR include respiratory insufficiency, pneumonia, pleural effusion and empyema, cardiac tamponade (in cases of pleuropericardial rupture), central venous obstruction related to herniation or to a marked mediastinal shift, and intrathoracic splenosis associated with splenic rupture (56,57).

Mortality

Short-term mortality due specifically to BDR is presumably low (11,36). However, among patients who have BDR, overall mortality resulting from other life-threatening injuries associated with BDR varies from 12% to 42% (1,3,4,6–8,11,25,26,29,36,44,45,50). Therefore, BDR must be considered a marker of severe injury. If unrecognized, it may lead to delayed complications, for which the reported global mortality is 30% (66% in the presence of strangulation of a hollow viscus) (9,28,36).

Imaging Evaluation and Findings

Because blunt abdominal trauma is usually conservatively managed and exploratory laparotomy is seldom performed, an accurate and noninvasive diagnostic technique is needed. Thus, CT has become the cornerstone of the diagnostic work-up for patients with blunt trauma, most of whom undergo a whole-body CT examination.

The results of numerous studies have shown poor accuracy in the diagnosis of BDR at conventional CT performed with nonhelical scanners (sensitivity, 0%–66%; specificity, 76%–99%) (2,9,18,23,36,41,45). However, diagnostic performance improves with the use of helical CT (sensitivity, 56%–87%; specificity, 75%–100%) and multidetector CT (sensitivity, 71%–90%; specificity, 98%–100%) because of the higher quality of axial images and multiplanar reformatted images (13,15–17,43,54,58–60). Although the utility of multiplanar reformatted images in routine clinical practice was once debated, the increasing availability of scanners and workstations that can complete the necessary processing with rapidity and ease seems to have silenced the controversy. Additional

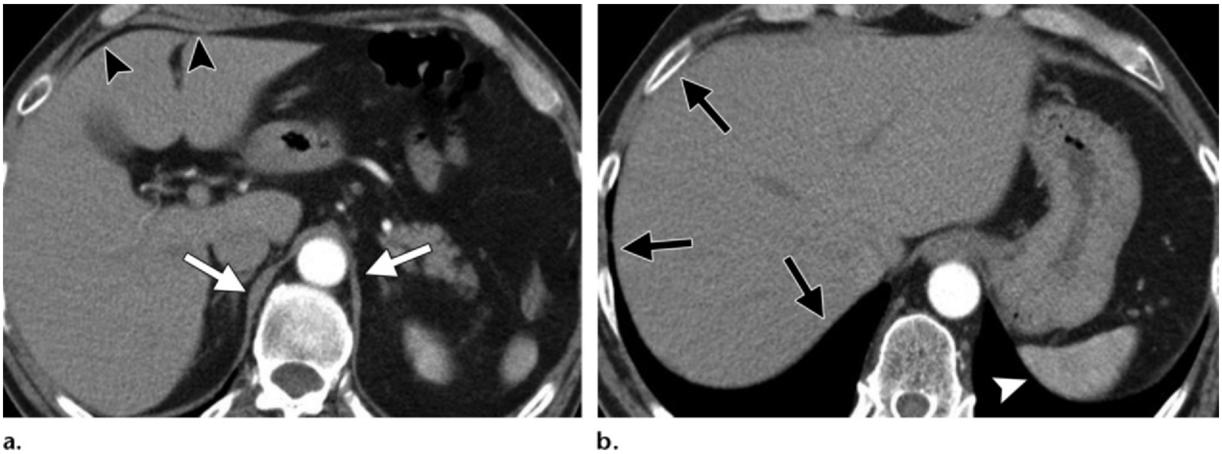


Figure 7. Normal anatomy. **(a)** Axial CT image provides good delineation of the diaphragm against the fatty layer along the liver (arrowheads) and crura (arrows). **(b)** Axial CT image obtained at a higher level in the same patient shows poor delineation of the diaphragm in the absence of an interposed fat layer between it and both the liver (arrows) and spleen (arrowhead). In the normal anatomy, both hemidiaphragms are dome shaped, and the abdominal structures are separated from the posterior chest wall by the costophrenic sulcus, which contains both lower lung lobes.

review of multiplanar reformatted images may aid in the recognition of some BDR signs, allow differentiation between diaphragmatic lesions and peridiaphragmatic ones, and strengthen confidence in a diagnosis of BDR (particularly right-sided BDR), especially for less experienced readers (14,15,18,40,53,54,58,61).

Most CT signs of diaphragmatic injuries are applicable also to magnetic resonance (MR) imaging. Although MR imaging has admitted limitations for use in the acute trauma setting, it can play a valuable role in the evaluation of delayed manifestations or in patients whose CT examinations are suboptimal (Fig 4) (62).

Several characteristics of the diaphragm may lead to confusion in the imaging work-up of trauma patients. First, the diaphragm may be difficult to visualize when it is in contact with soft-tissue organs, pulmonary lesions, or fluid. The most striking instances of this problem occur when the right hemidiaphragm directly contacts the liver (Fig 7). Lack of depiction of the diaphragm also may be due to its orientation parallel to the axial plane, a factor that adds to the usefulness of coronal and sagittal reformatted images (1). Second, the normal diaphragm may appear irregular or nodular, an appearance that may lead to diagnostic confusion. Various patterns of costal insertion and muscle fiber organization may produce diaphragmatic slips (periodic nodular scalloping of the diaphragm) (Fig 8), which may cause indentations in adjacent organs such as the liver or spleen (31,63).

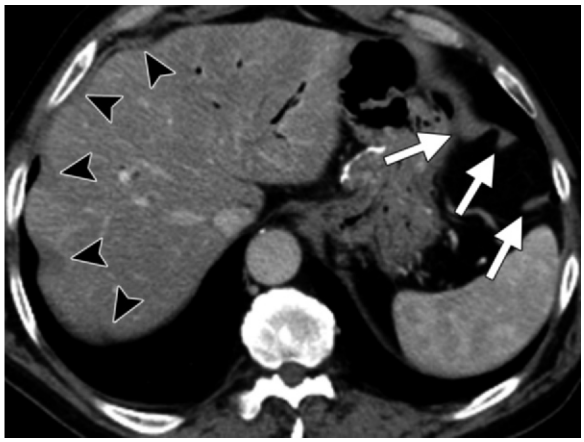


Figure 8. Normal anatomic variant in a nontrauma patient. Axial contrast-enhanced CT scan shows a normal appearance of indentations in the liver surface (arrowheads), features produced by periodic diaphragmatic slips. The left hemidiaphragm is irregular, periodically thickened and nodular in some places (arrows) and much thinner in others, but there is no sign of herniation.

Nineteen CT signs suggestive of BDR have been described in the English-language literature, many of them individually. This literature can be confusing, as there is no consensus about the appellation or classification of these signs,

Classification, Description, and Appellations of 19 CT Signs of Diaphragmatic Rupture

Sign No.	Sign Description	Other Appellations
	Direct Signs	
1	Segmental diaphragmatic defect	Abrupt discontinuity, direct visualization of injury
2	Dangling diaphragm	...
3	Absent diaphragm	Complete absence of visualization of the diaphragm, segmental nonrecognition of the diaphragm, indistinct hemidiaphragm
	Indirect Signs Related to Herniation	
4	Herniation through a defect	...
5	Collar	Hourglass constriction sign, mushroom sign (in hepatic hernia)
6	Hump	...
7	Band	...
8	Dependent viscera	...
9	Sinus cutoff	...
10	Abdominal content peripheral to the diaphragm or lung	...
11	Elevated abdominal organs	Apparent elevation of hemidiaphragm
	Indirect Signs Related to Loss of Border between Thorax and Abdomen	
12	Abdominal fluid abutting a thoracic structure	...
13	Abdominal viscera abutting thoracic fluid or a thoracic organ	...
14	Pneumothorax and pneumoperitoneum	...
15	Hemothorax and hemoperitoneum	...
	Signs of Uncertain or Controversial Origin	
16	Thickening of the diaphragm	Curled diaphragm sign
17	Diaphragmatic or peridiaphragmatic contrast medium extravasation	...
18	Hypoenhanced diaphragm	Hypoattenuated diaphragm
19	Fractured rib	Presumed laceration of diaphragm by rib, trajectory sign

Sources.—References 1, 9, 13, 14, 16, 17, 19, 20–24, 27, 30, 31, 47, 59, and 64.

and none of the signs described could serve as a diagnostic marker. To allow a more systematic consideration of the CT features of BDR, we propose the following general system of classification: *(a)* direct signs of diaphragmatic injury (eg, a visible "hole" in the diaphragm); *(b)* indirect signs that are related to the consequences of diaphragmatic rupture; and *(c)* signs with an origin that is uncertain or controversial. Because several signs in category *b* represent the same phenomenon, we propose the further subdivision of the group of indirect signs into those produced by the herniation of abdominal structures into the chest cavity and those related to the loss of delimitation between the thorax and abdomen (Table).

These 19 signs are described separately in the following sections. Each description includes a definition of the sign, explanation of the underlying anatomic or pathophysiologic abnormalities, and discussion of any available sensitivity and specificity data for use of the sign in diagnosis of BDR. Potential diagnostic pitfalls associated with each sign also are described.

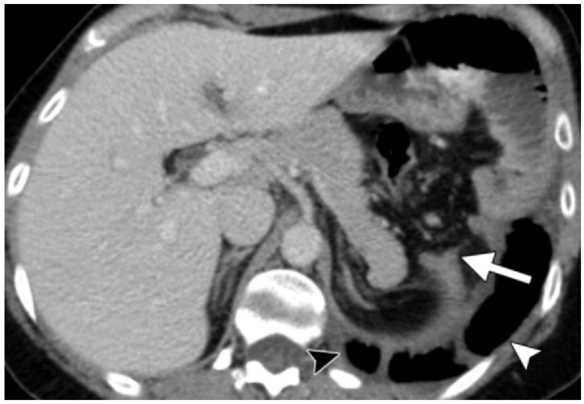


Figure 9. Left-sided BDR in a 42-year-old man after a motor vehicle accident. Axial contrast-enhanced CT scan shows a curvilinear flap extending away from the chest wall toward the center of the abdomen (dangling diaphragm sign) (arrow), a finding that represents the torn free edge of the left hemidiaphragm, the distal part of which appears thickened (thickening of the diaphragm sign). An air-filled bowel loop is seen peripheral to the diaphragm, within the pleural cavity (abdominal content peripheral to the diaphragm or lung sign) (arrowheads).

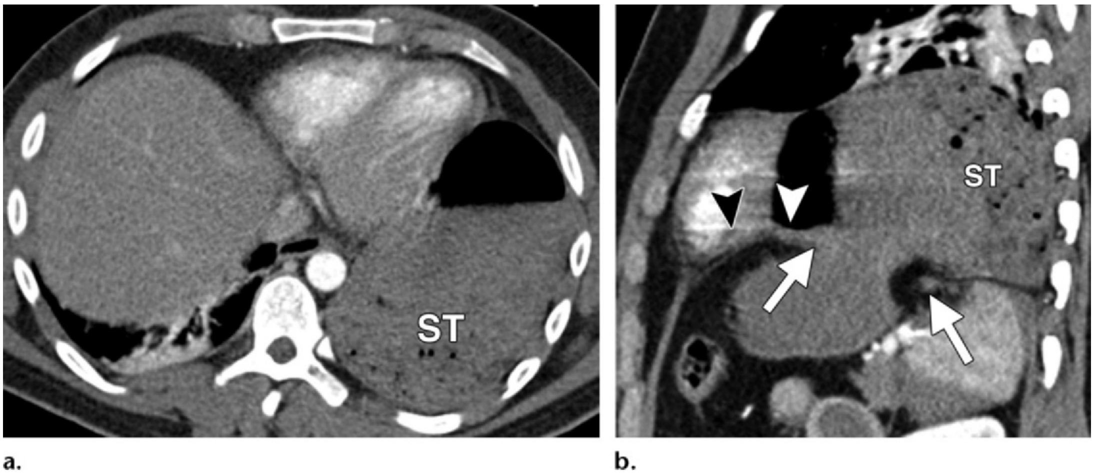


Figure 10. Left-sided BDR in a 25-year-old man after a motor vehicle accident. **(a)** Axial contrast-enhanced CT scan shows the complete absence of the left hemidiaphragm (absent diaphragm sign). The stomach *(ST)* is in a dependent position and contacts the posterior thoracic wall (dependent viscera sign). **(b)** Sagittal reformatted CT image better depicts herniation of the stomach (herniation through a defect sign) and dependent viscera. A segment of the diaphragm not visible in **a** is seen here in its normal horizontal orientation (arrowheads), and the segmental diaphragmatic defect sign (arrows) is clearly visible. Note the direct contact between the stomach and lung (abdominal viscera abutting thoracic fluid or a thoracic organ sign).

Direct CT Signs

Segmental Diaphragmatic Defect (Sign 1).— The segmental diaphragmatic defect sign represents a focal and abrupt loss of continuity in the diaphragm (Figs 3, 6) (22,27). The free edge of the disrupted diaphragm demarcates the defect and may appear thickened because of muscle retraction or hemorrhage (see the section "Thickening of the Diaphragm [Sign 16]"). A segmental diaphragmatic defect is more clearly depicted when it is small (Fig 3) or seen against a background of abdominal fat or aerated lung (27,36). The reported sensitivity of this sign for the overall diagnosis of BDR is 17%–80% (16.5%–66% for right-sided BDR, 22%–87.5% for left-sided BDR), and the reported specificity ranges from 90% to 100% (2,9,13–16,19,40,43,59). Lesions or consolida-

Figure 11. Right-sided BDR in a 33-year-old man. Sagittal contrast-enhanced reformatted CT image shows herniation of the liver *(L)* into the thorax through a diaphragmatic defect (arrows) (herniation through a defect sign, segmental diaphragmatic defect sign). The diaphragmatic segments that remain in place are thickened (arrowheads) (thickening of the diaphragm sign). The dome of the liver is located in a dependent position, against the posterior ribs (dependent viscera sign).

tion at the lung bases and pleural or peritoneal effusion may mask a segmental diaphragmatic defect (9,15).

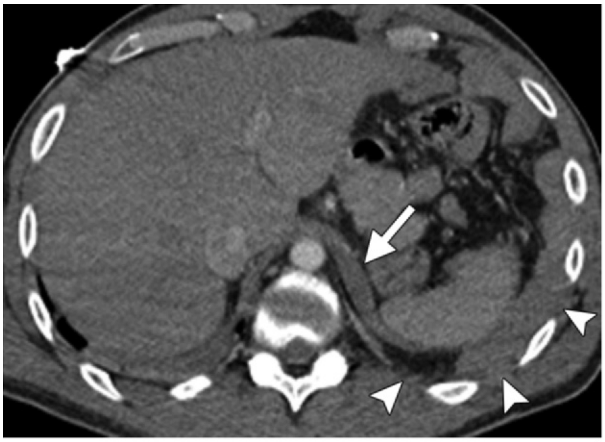
Because of the high prevalence of nontraumatic diaphragmatic defects in the general population, the diagnosis of BDR should not be based on the presence of this sign alone (see the section on "Diagnostic Pitfalls at CT") (9,33,63). The patient's characteristics and the corresponding demographic data must be borne in mind during image interpretation; with regard to patient age, for example, BDR occurs more often in young males, whereas chronic nontraumatic diaphragmatic defects are seen more often in the elderly (4,6–8,25,26,38,63).

Dangling Diaphragm (Sign 2).—The dangling diaphragm sign is produced by the free edge of the torn diaphragm, which curls inward from its normal course, toward the center of the body, forming a comma-shaped or curvilinear structure with soft-tissue attenuation at a near right angle with the chest wall (Fig 9) (16). The dangling diaphragm sign is linked to the segmental diaphragmatic defect sign and may be associated with a local thickening of the diaphragm. The term *dangling diaphragm* was used to describe this sign in only one previously published study, in which the sign was found to have an associated sensitivity of 54% and a specificity of 98% for the diagnosis of BDR (16).

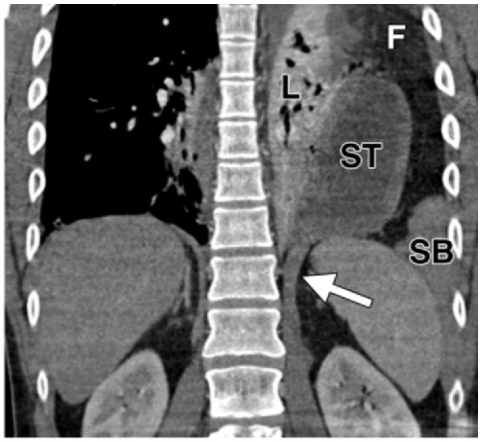
Absent Diaphragm (Sign 3).—The absent diaphragm sign is represented by the absence of part or all of the hemidiaphragm, without demonstration of a tear, in areas where the diaphragm is expected to be well demonstrated (ie, outlined by fat or air) (Fig 10) (13,22). The absent diaphragm sign is not generally seen in isolation but is usually associated with a large hernia. The reported sensitivity of this sign for the diagnosis of BDR is 18%–43%, and its diagnostic specificity is 91% (13,43). Direct contact of the diaphragm with soft tissue or fluids may create a false appearance of an absent diaphragm (65).

Indirect CT Signs Related to Herniation

Herniation through a Defect (Sign 4).—The herniation through a defect sign is produced by the passage of abdominal organs or peritoneal fat into the pleural space or, more rarely, the pericardial space (Figs 2–6, 11, 12) (22,64). The reported overall sensitivity of this finding for the diagnosis of BDR is 50%–95% (8%–50% for right-sided BDR, 42%–91% for left-sided BDR). The reported specificity is 98%–100% (2,9,13–16,40,43,59). The most common diagnostic mimics are congenital and acquired hernias.



a.



b.

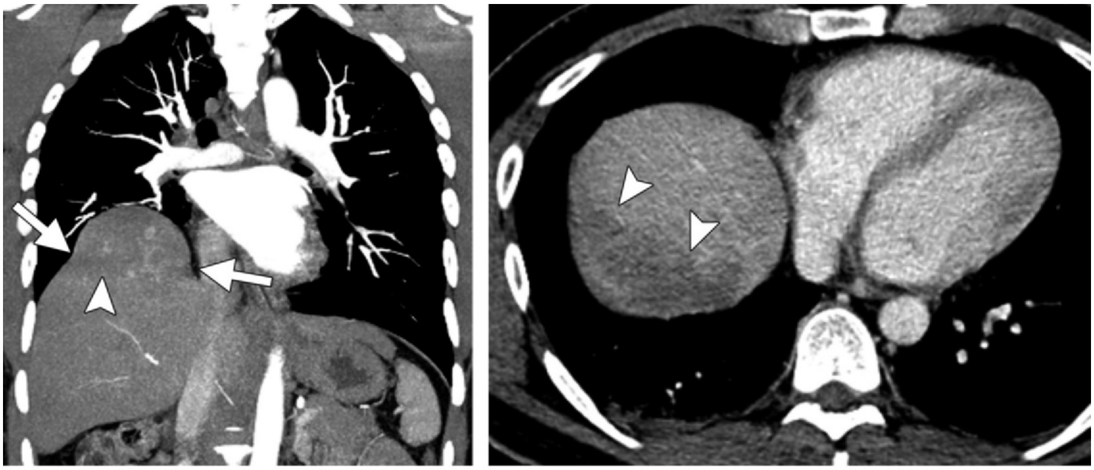
Figure 12. Left-sided BDR in a 36-year-old man after a motor vehicle accident. **(a)** Axial contrast-enhanced CT image shows thickening of the left diaphragmatic crus (arrow) in comparison with the right crus (thickening of the diaphragm sign). Abdominal fat and small bowel (arrowheads) are seen posterior and lateral to the spleen and the remaining part of the diaphragm (dependent viscera sign, abdominal content peripheral to the diaphragm or lung sign). **(b)** Coronal contrast-enhanced reformatted CT image at the level of the spleen shows thickening of the left crus (arrow). Parts of the stomach *(ST)*, small bowel *(SB)*, and omental fat *(F)* have herniated into the thorax and directly contact the collapsed lung *(L)* (herniation through a defect sign, abdominal viscera abutting thoracic fluid or a thoracic organ sign).

Figure 13. Motion artifacts in a patient with an intact diaphragm. Coronal contrast-enhanced reformatted CT image shows apparent collar (arrows) and band (arrowheads) signs of BDR, misleading appearances that actually resulted from respiratory motion.

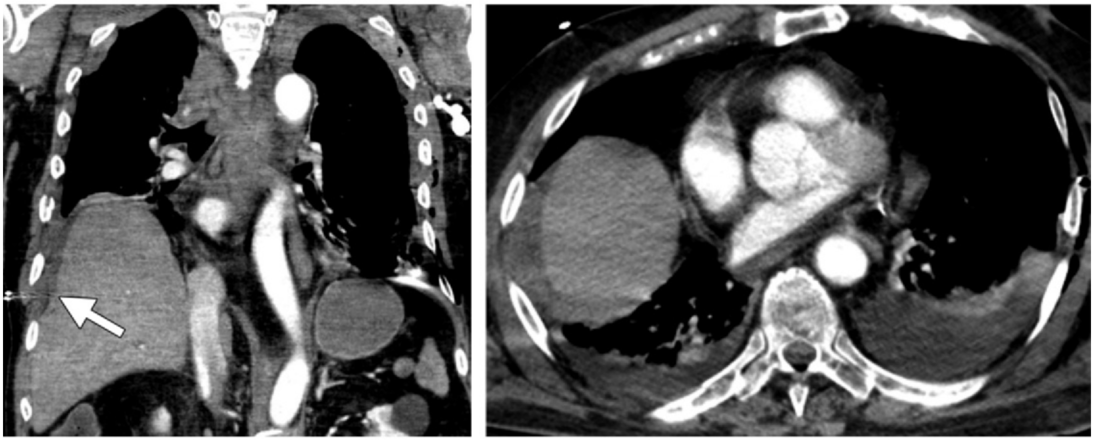
Collar (Sign 5).—The collar sign corresponds to a waistlike constriction of the herniated structure at the site of the diaphragmatic rupture (Figs 2, 3) (9,30). It may appear as a focal and sometimes subtle indentation of the herniated organ, especially on the right side in case of liver herniation. Although commonly better demonstrated on multiplanar reformatted images, it may occasionally be the only finding on axial images that leads to recognition of the hernia (1). The overall sensitivity of this sign for a diagnosis of BDR ranges from 16% to 63% (0%–50% for right-sided BDR, 37%–73% for left-sided BDR), with higher values when multiplanar reformatted images are included in the image review. Specificity is 98%–100% (2,9,13,15,16,40,43,59).

Indentations in abdominal structures can be seen in other conditions also: The liver may appear indented because of a traumatic fracture or diaphragmatic slips (Fig 8) or because of respiratory motion–related artifacts (Fig 13). The collar sign also may be seen in congenital and acquired nontraumatic hernias of the diaphragm.

Hump and Band (Signs 6 and 7).—The hump and band signs both result from herniation of the liver through a right-sided diaphragmatic rupture (14). The hump sign is a variation of the collar sign on the right side, the term *hump* referring to the shape of the herniated liver located above the level of the diaphragm (Figs 14, 15). The band sign corresponds to a linear area of hypoattenuation that transects the herniated liver between the torn edges of the diaphragm (Fig 14). The origin of this bandlike feature is uncertain, but it is hypothesized to result from compression by the ruptured diaphragm and resultant hypoperfusion of the liver parenchyma



14a. 14b.



15a. 15b.

Figures 14, 15. **(14)** Right-sided BDR in a 35-year-old man after a motor vehicle accident. **(a)** Coronal maximum intensity projection image from contrast-enhanced CT shows herniation of the liver dome through a diaphragmatic rupture (hump sign), with a smooth collar sign (arrows) and a linear area of subtle hypoattenuation (band sign) (arrowhead) extending across the base of the defect. **(b)** Axial contrast-enhanced CT image shows an area of hypoattenuation (arrowheads) in the dome of the liver, a finding that might correspond to the band visible in **a**. **(15)** Right-sided BDR in an 80-year-old man after a motor vehicle accident. **(a)** Coronal contrast-enhanced reformatted CT image shows the dome of the liver extending more than 4 cm above the level of the left hemidiaphragm, producing a hump (elevated abdominal organs sign, hump sign). The arrow indicates the laterally displaced segment of the ruptured diaphragm. **(b)** Hepatic displacement and deformation are difficult to appreciate on the axial contrast-enhanced CT image, and the dependent viscera sign is absent.

at the base of the hernia (14). The hump and band signs are well demonstrated on coronal and sagittal reformatted images but generally are only faintly seen on axial images because of the in-plane orientation of the band. Reported sensitivities are 50%–83% for the hump sign and 33%–42% for the band sign. Specificities are not reported in the literature (14,40).

A particularly high apex of the right hemidiaphragm could easily be mistaken for a hump sign. To avoid this error, an attentive search should be made for an associated collar sign. In addition, the contours of the liver should be carefully examined; they are not as smoothly rounded in the presence of BDR as they are in the presence of an intact diaphragm. A pseudo band or pseudo collar sign also may result from a hepatic laceration, hepatic fracture, respiratory motion–related artifact, or diaphragmatic slips (Figs 8, 13).

Dependent Viscera (Sign 8).—The dependent viscera sign represents direct contact between the herniated abdominal organs and the posterior chest wall, without interposition of the lung (59). Axial CT images at the level of the diaphragm normally show the liver on the right side and the stomach, bowel, and spleen on the left side, suspended in a medial position by the diaphragm and separated from the posterior chest wall by the lung within the costophrenic sulcus (Fig 7). The loss of diaphragmatic support after a rupture may cause the abdominal organs to fall into a dependent position against the posterior thoracic wall when the patient is supine (Figs 3, 4, 6, 10, 11, 16). Thus, on the right side, the upper third of the liver or bowel will abut the posterior right ribs, and on the left side, the bowel or stomach will be in contact with the posterior left ribs (59). The reported overall sensitivity of this sign for the diagnosis of BDR is 54%–90% (33%–83% for right-sided BDR, 64%–100% for left-sided BDR). The reported specificity is 98%–100% (13,14,16,40,59). Some authors have emphasized that this sign has low sensitivity for the detection of small diaphragmatic ruptures, ruptures in an atypical location (eg, an anterior location), and ruptures associated with a large pleural effusion (17). A congenital hernia or hiatal hernia also may produce a dependent viscera sign.

Sinus Cutoff (Sign 9).—The sinus cutoff sign (sign 9) is a variant of the dependent viscera sign that occurs in the presence of BDR with a pleural effusion. It is produced by the effect of herniated abdominal contents on the distribution of fluid in the posterior costophrenic sulcus. The herniated structures may fall onto the posterior pleura (see the section "Dependent Viscera [Sign 8]") and thus prevent the expected layering of fluid along the pleural cavity; the posterior costophrenic sulcus containing the effusion then appears to be interrupted or abruptly blunted medially or laterally by the herniated structures (Fig 16). This sign has been reported in only one article, and sensitivity and specificity statistics are not available (21). Congenital and hiatal hernias also may produce an appearance that resembles the sinus cutoff sign.

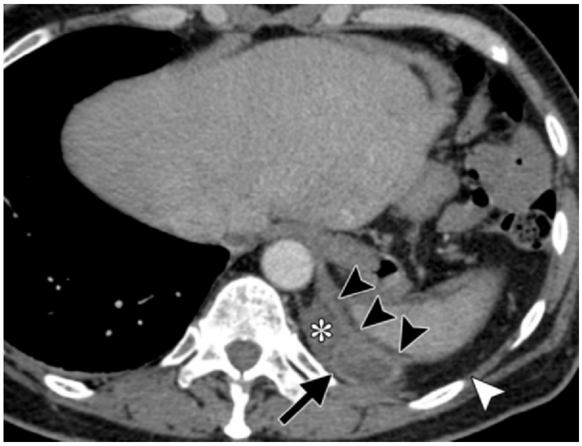


Figure 16. Left-sided BDR in a 61-year-old woman after a motor vehicle accident. Axial contrast-enhanced CT image shows a small bowel loop (arrow) in the left pleural space peripheral to the diaphragm (black arrowheads) (abdominal content peripheral to the diaphragm or lung sign). Peritoneal fat and bowel are in a dependent position along the posterior left ribs (white arrowhead) (dependent viscera sign). Herniated bowel and abdominal fat prevent normal layering of fluid (*) in the pleural cavity (sinus cutoff sign).

Abdominal Content Peripheral to the Diaphragm or Lung (Sign 10).—On axial images depicting the normal diaphragm, any structure external to the domelike upper contour is intrathoracic, whereas structures beneath or internal to the diaphragm are intraabdominal (22). Abdominal organs or fatty tissue seen peripheral to the diaphragm or posterior to the crura represent herniation into the thoracic cavity (Figs 9, 12, 16). No sensitivity or specificity statistics have been reported for this sign. Rarely, large pleural effusions may cause inversion of the diaphragm; in this condition, fluid and structures located peripherally to the diaphragm are intraabdominal and not herniated.

Elevated Abdominal Organs (Sign 11).—The elevated abdominal organs sign is produced by the displacement of abdominal structures cephalad, above the level of the hemidiaphragm contralateral to the side of the lesion on supine images (coronal reformatted images, topographic CT images) (Figs 5, 15) (13,14,23). There is no consensus in the literature about a threshold measurement

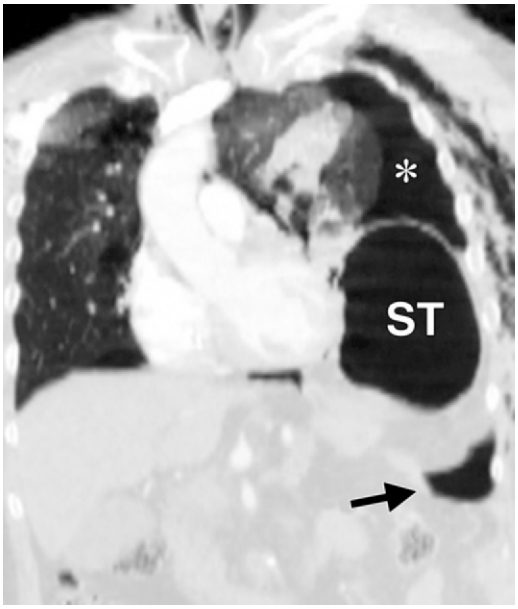


Figure 17. Left-sided BDR in a 60-year-old man after a motor vehicle accident. Coronal contrast-enhanced CT image shows the presence of air in the pleural space (*) and peritoneal cavity (arrow) (pneumothorax and pneumoperitoneum sign). Thoracic parietal emphysema is also seen. The stomach *(ST)* has herniated into the thorax and contacts the collapsed lung and pericardial sac (abdominal viscera abutting thoracic fluid or a thoracic organ sign).

defining this sign or the procedure for measuring elevation: Nchimi et al (13,23) proposed that a right hemidiaphragmatic elevation of more than 5 cm above the level of the left hemidiaphragm be used as a threshold for right-sided BDR, and that a left hemidiaphragmatic elevation of more than 4 cm above the level of the right hemidiaphragm be used as a threshold for left-sided BDR. Rees et al (14) found a significant correlation between right hemidiaphragmatic elevation of 4 cm above the level of the left hemidiaphragm and right-sided BDR. The reported sensitivity of the elevated abdominal organs sign for the diagnosis of BDR overall is 50%–83% (40%–58% for right-sided BDR, 63.5%–71% for left-sided BDR), and its reported specificity is 89%–99% (2,13,14,16,40).

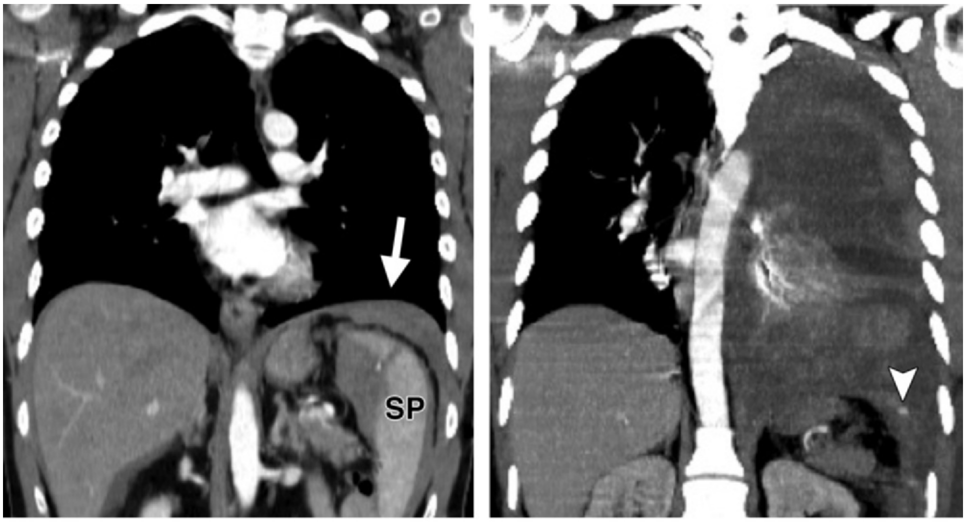
In isolation, this sign cannot be considered diagnostic of BDR. The potential diagnostic pitfalls are numerous: They include anatomic variants, eventration, phrenic nerve injury, gaseous distention of the gastrointestinal tract, partial lung collapse, and subpulmonic effusion (24).

Indirect CT Signs Related to Loss of the Border between the Thorax and Abdomen

Indirect CT signs of BDR that are related to loss of the thoracoabdominal border are abdominal fluid abutting a thoracic structure (sign 12), abdominal viscera abutting thoracic fluid or a thoracic organ (sign 13), pneumothorax and pneumoperitoneum (sign 14), and hemothorax and hemoperitoneum (sign 15).

Loss of the border between the thorax and abdomen allows fluid and air to pass from the thorax to the abdomen and from the abdomen to the thorax (9,24). Thus, the presence of blood and/or air in both the pleural cavity and the abdominal cavity after trauma is suggestive of BDR (Fig 17). Communication between the thorax and abdomen allows a herniated abdominal organ to bathe in a pleural effusion or drift into direct contact with a thoracic organ, most frequently the lung (Figs 5, 10, 12). It also allows the passage of an abdominal effusion into the pleural space, although this event is difficult to prove because it is rarely possible to differentiate an effusion with a pleural origin from one with a peritoneal origin. The presence of fluid on both sides of the injured diaphragm may mask a direct sign of rupture, such as a segmental diaphragmatic defect (9,16,17,59). The simultaneous presence of signs 13 and 15 (abdominal viscera abutting thoracic fluid or a thoracic organ, hemothorax and hemoperitoneum) is associated with a sensitivity of 20%–60% for a diagnosis of right-sided BDR and 36%–45% for a diagnosis of left-sided BDR, with a specificity of 95%–100% (13).

Fluid in both pleural and peritoneal spaces can be found in patients with chronic conditions such as hepatic hydrothorax or Demons-Meigs syndrome and in those undergoing peritoneal dialysis, as well as in those with BDR.



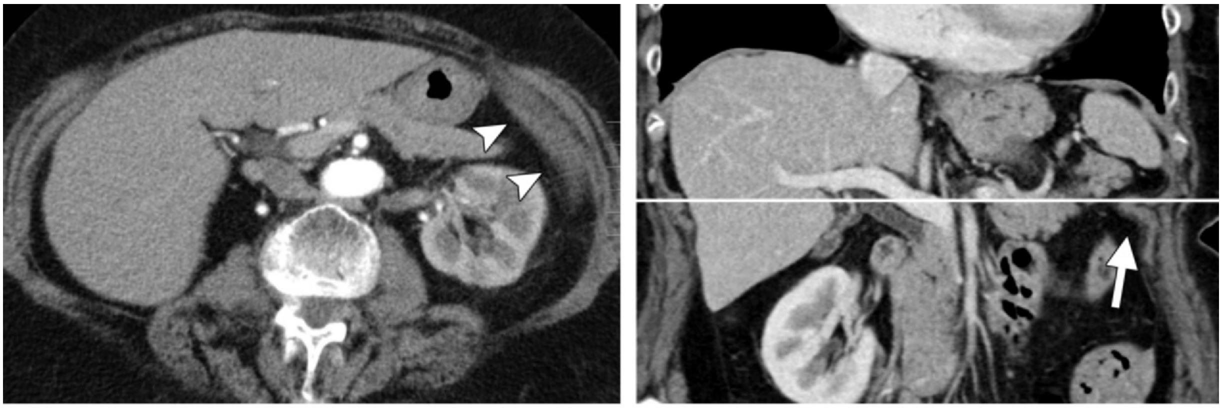
a. b.

Figure 18. **(a)** Coronal contrast-enhanced reformatted CT image obtained in a 42-year-old man with blunt thoracoabdominal trauma from a motor vehicle accident shows diffuse thickening (arrow) of the left hemidiaphragm and laceration of the spleen *(SP)*. **(b)** Coronal contrast-enhanced reformatted CT image obtained a few hours later, as a massive left hemothorax developed, shows a pool of extravasated contrast medium in contact with the diaphragm (arrowhead), a finding suggestive of BDR. At surgery, a lesion was found in a small branch of the superior diaphragmatic artery, with no evidence of BDR. The apparent diaphragmatic thickening in **a** was due to diffusion of a retroperitoneal hemorrhage. (Case courtesy of Mostafa El Hajjam, MD, Club Thorax, Paris, France.)

CT Signs of Uncertain or Controversial Origin

Thickening of the Diaphragm (Sign 16).—Abnormal thickening of the diaphragm is sometimes seen in the presence of BDR; the thickening may be smooth or nodular and focal or diffuse. This CT sign is thought to be caused by retraction of the leaves of the ruptured diaphragm (Figs 6, 9, 11, 12) (19,20). When the thickened diaphragm is irregular or scalloped, the sign also might be described as the "curled diaphragm" sign (20). There is no consensus in the literature about the optimal site for measuring the thickness of the diaphragm, but the hemidiaphragmatic thickness is generally assessed visually in comparison with the contralateral hemidiaphragm at the same level. The reported overall sensitivity of thickening of the diaphragm for the diagnosis of BDR is 56%–75% (50%–100% for right-sided BDR, 36%–68% for left-sided BDR). The reported specificity is 95% (13,19,40). Thickening of the diaphragm may be seen also in the presence of a partial rupture with associated edema or hematoma, or it may be simulated by diffusion of fluid or blood from the retroperitoneal space into the area around the diaphragm; thus, this sign is not always indicative of BDR (Fig 18) (13,19,33,66). Furthermore, there is substantial normal variation in the thickness of the crura or leaflets and the smoothness of the diaphragm in the general population, depending on individual characteristics such as age and body habitus; for example, the diaphragm may appear nodular at peripheral insertions on ribs, and diaphragmatic slips or areas of muscle redundancy may be seen (Figs 8, 19) (63). However, in trauma patients, thickening of the diaphragm in the absence of a retroperitoneal contusion or infiltration is considered highly suggestive of BDR, particularly when it is associated with other CT signs of BDR (13).

Diaphragmatic or Peridiaphragmatic Contrast Medium Extravasation (Sign 17).—Arterial extravasation of contrast medium in or near the diaphragm may be suggestive of a diaphragmatic injury. The CT finding of diaphragmatic or peridiaphragmatic extravasation of the contrast



a. b.

Figure 19. Diaphragmatic slip in a nontrauma patient. **(a)** Axial CT image shows apparent thickening of the left hemidiaphragm (arrowheads), a finding suggestive of an in-plane diaphragmatic slip or redundancy of diaphragmatic muscle. **(b)** Coronal reformatted CT image clearly depicts a fold in the intact diaphragm (arrow) at the level at which **a** was obtained (horizontal white line).

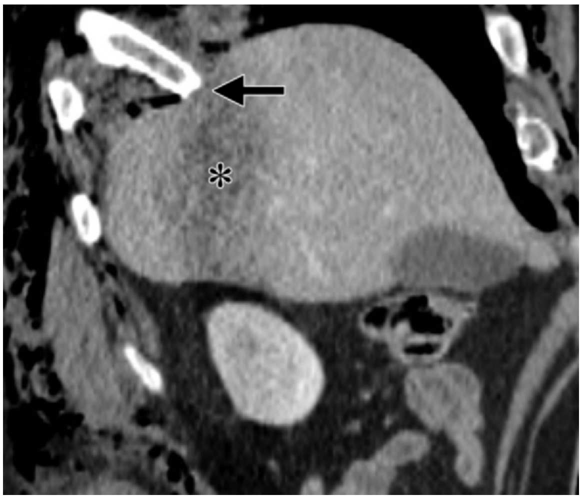


Figure 20. Right-sided BDR in a 56-year-old man after a motor vehicle accident. Sagittal oblique contrast-enhanced reformatted CT image shows a costal fragment (fractured rib sign) (arrow) abutting and pointing toward the deformed hepatic dome, with an associated liver contusion (*). The presence of BDR was confirmed at surgery.

medium is encountered predominantly in penetrating injuries and is rarely reported in blunt trauma injuries (16,17). Furthermore, because it is not easy to distinguish between intrinsic diaphragmatic bleeding and bleeding from an adjacent organ, this sign must be considered nonspecific for BDR; nevertheless, its appearance may help focus attention on the diaphragm (Fig 18). Although the overall sensitivity of this sign is only 0%–12%, its reported specificity is surprisingly high (93%–98%), probably because of the limited number of patients in whom it has been observed (13,16,43).

Hypoenhanced Diaphragm (Sign 18).—Descriptions of the hypoenhanced diaphragm sign on contrast-enhanced CT images are based on only one reported case of BDR (13). The hypoenhanced area in this patient was located at the level of the crus of the ruptured right hemidiaphragm and was associated with nonrecognition of part of the diaphragm, thickening of another part, and hypoperfusion of the spleen and right kidney. The hypoenhancement of the diaphragm in this patient was believed to be indicative of devascularization.

Fractured Rib (Sign 19).—The fractured rib sign is present when a juxtadiaphragmatic costal bone fragment points toward the diaphragm and is suspected to have directly perforated it (Fig 20) (2,13,18,27). The fractured rib sign was first described by Holland et al (27) and later referred to as "presumed laceration of the diaphragm by a fractured rib" in a study by Nchimi et al (13). A similar sign seen in cases of penetrating trauma, the trajectory sign, has been described as "the depiction of a missile or puncturing instrument trajectory" adjacent to or passing through the diaphragm (17). The reported sensitivity of the fractured rib sign is low; no specificity statistics have been reported (13). In patients with severe trauma, this sign should direct attention to the diaphragm; however, when seen alone, it cannot be considered diagnostic.

Diagnostic Pitfalls at CT

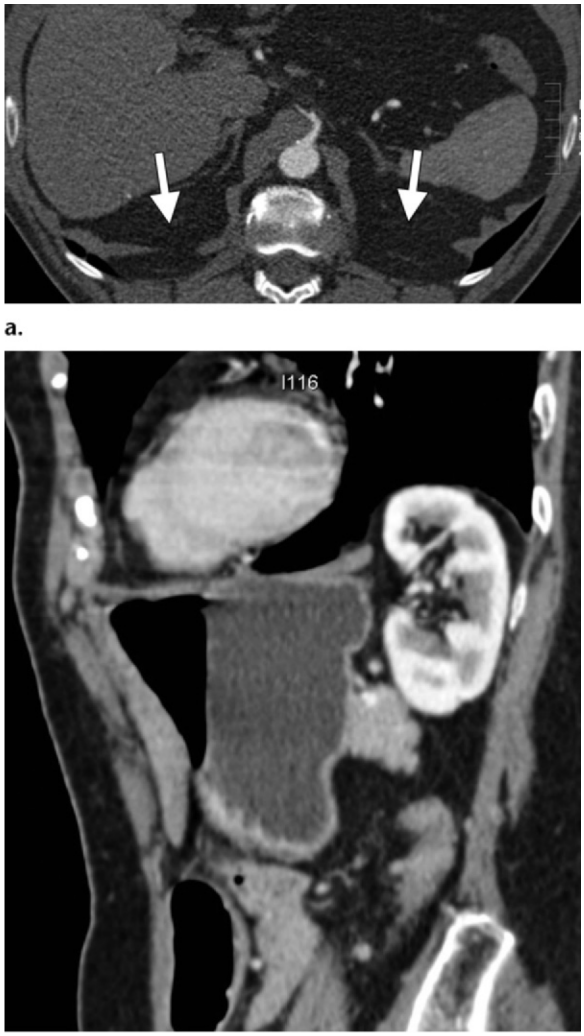
Congenital Hernias.—The most common type of congenital diaphragmatic hernia seen at CT is the posterior diaphragmatic hernia or Bochdalek hernia, which occurs either in the lumbocostal triangles or in the areas where the pleuroperitoneal membranes fuse, posterolateral to the diaphragm. This type of hernia is seen in approximately 6% of asymptomatic adults, most often on the left side. Most Bochdalek hernias that are discovered incidentally in adults are small and contain only abdominal fat; however, the hernias vary in size, and larger ones may contain an abdominal viscus (Fig 21) (31,67).

Another common type of congenital diaphragmatic hernia is the anterior diaphragmatic hernia or Morgagni hernia, which results from a congenital defect of the anteromedial part of the diaphragm (sternocostal triangle) (31). Congenital hernias involving the central tendon (central diaphragmatic hernias) are rare (32).

Acquired Defects.—Acquired chronic defects known as diaphragmatic fenestrations or discontinuities may be found in any region of the diaphragm but are most often located in its posterior aspect or at the crura (33,63,68). The prevalence of these defects increases with increasing patient age, and their size ranges from less than 1 mm to 1 cm or more in rare cases. These defects are responsible for the migration of fluid, air, and inflammatory and tumoral cells through the diaphragm.

A hiatal hernia is generally easily differentiated from this type of diaphragmatic rupture because of its characteristic anatomic features. However, the appearance of a very large hiatal hernia may cause confusion and lead to false-positive findings of BDR (Fig 22).

Diaphragmatic Eventration.—Diaphragmatic eventration is an abnormal area of diaphragmatic relaxation and elevation, a condition that most often affects the left hemidiaphragm. The affected region may be thinned but remains intact. Paresis or paralysis of the left or right hemidiaphragm because of injury to the phrenic nerve is one of many possible causes of eventration.



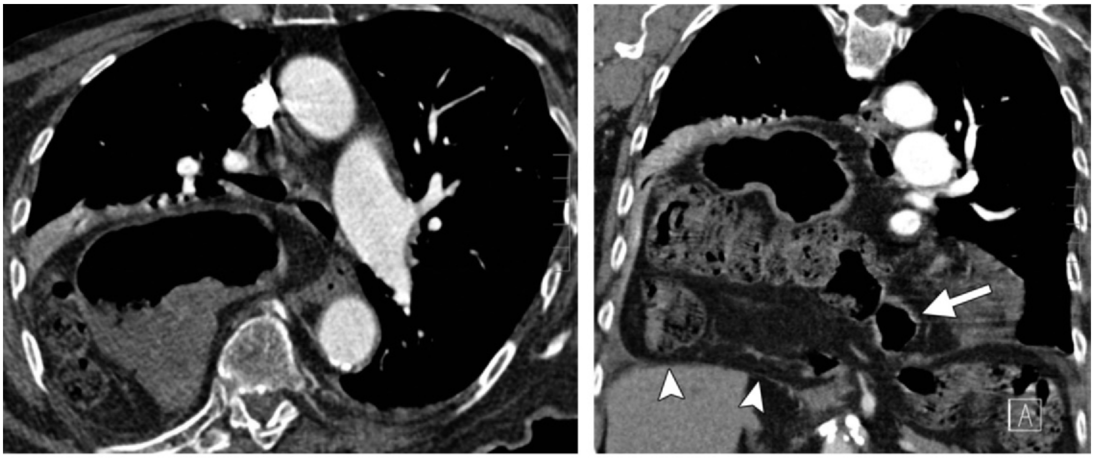
a.

b.

Figure 21. Bochdalek hernias. **(a)** Axial contrast-enhanced CT image shows bilateral abdominal fat herniation into the thorax (arrows). **(b)** In another patient, sagittal reformatted contrast-enhanced CT image shows asymptomatic partial herniation of the left kidney through the Bochdalek foramen.

Findings at Chest Radiography

Chest radiography is usually the initial imaging test performed in trauma patients. Although most patients with severe thoracoabdominal trauma subsequently undergo body CT, chest radiography remains an important diagnostic test when CT cannot be performed for some



a. b.

Figure 22. Large hiatal hernia in an 86-year-old man. **(a)** Axial contrast-enhanced CT image shows a large hiatal hernia that contains part of the stomach, colonic loops, and abdominal fat. The herniated abdominal contents contact the posterior thoracic wall and compress the posterior aspect of the carina. **(b)** Coronal reformatted CT image more clearly depicts herniation through the esophageal hiatus (arrow), with a thin but intact right hemidiaphragm (arrowheads). The CT features in this case mimic the dependent viscera and elevated abdominal organs signs of BDR.

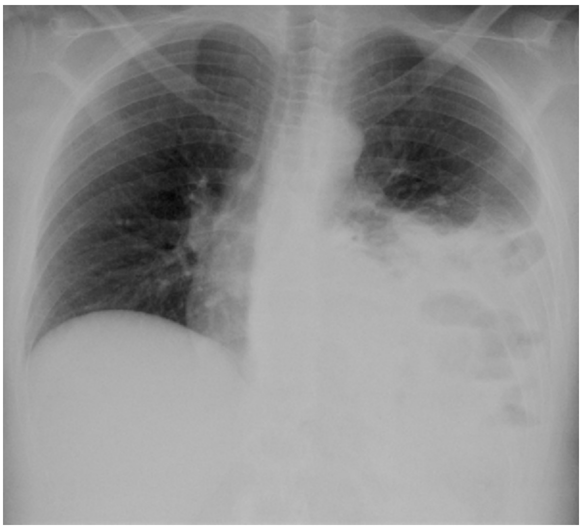


Figure 23. Left-sided BDR in a 19-year-old woman (same patient as in Fig 3). Chest radiograph shows obliteration of the left hemidiaphragmatic contour with elevation of gas-containing structures from the gastrointestinal tract above the expected level of the left hemidiaphragm and a resultant slight mediastinal shift toward the right side.

reason or when clinical manifestations of diaphragmatic rupture are absent or delayed. It is therefore important that radiologists be familiar with suggestive or highly suggestive radiographic signs of BDR (23).

The diaphragmatic contours may appear abnormal at radiography in as many as 77% of patients with BDR, but abnormal contours often are deemed a nonspecific finding. BDR is missed in more than one-half of cases, particularly when it affects the right hemidiaphragm (3,6,9,11,23,26,29,45,50,51).

Teaching Point

Radiographic findings that are highly suggestive or indicative of BDR include the presence of intrathoracic gastrointestinal tract air (Fig 23) with or without an associated collar sign or air-fluid level above the expected level of the diaphragm, and an abnormal U-shaped course of the nasogastric tube with its tip projecting above the level of the diaphragm (6,51). An upper hemidiaphragmatic contour that rises more than 4–6 cm above the level of the contralateral hemidiaphragm also is considered highly suggestive of BDR (Fig 5a).

Radiographic findings that are suggestive of BDR but are less diagnostically specific include obliteration or distortion of the diaphragmatic contours; mild (<4 cm) elevation of the presumed diaphragmatic shadow; a mediastinal shift toward the nonaffected side; and the presence of traumatic thoracic injuries such as pneumothorax, pulmonary contusion, and multiple fractures of the ribs, spine, or both (2,3,5,6,23,51,69). Although these signs are nonspecific to BDR and may result from other traumatic or nontraumatic abnormalities at the lung bases, their observation at radiography should lead the radiologist to perform CT or review previously acquired CT scans for evidence of BDR (Fig 24). Repeat chest radiography may aid in the detection of BDR because signs of rupture may not appear until associated lower parenchymal and pleural injuries have resolved or positive pressure assisted ventilation of the patient is terminated (2,18,29).

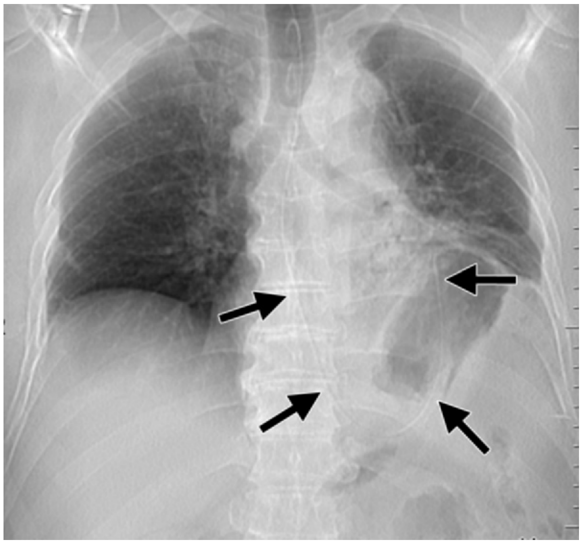


Figure 24. Chest radiograph shows features highly suggestive of left-sided BDR in a 55-year-old man: a markedly elevated left hemidiaphragm; basal consolidation of the left lung; and a nasogastric tube deformed into a U shape, with its distal extremity located above the expected level of the left hemidiaphragm (arrows). Left-sided BDR was found at subsequent CT and confirmed at surgery.

Conclusions

Teaching Point

Knowledge of the various CT signs suggestive of BDR is important to improve the detection of this underdiagnosed pattern of traumatic thoracoabdominal injury. The observation of two or more CT signs is associated with a substantially higher probability of the presence of BDR. Even signs with a low predictive value may alert the radiologist to the need to examine the diaphragm more closely for other features supportive of the diagnosis of BDR or the exclusion of that diagnosis. The accuracy of a diagnosis of BDR is increased by the observation of multiple associated CT signs of rupture. Confidence in the diagnosis of BDR, especially for less experienced readers, may be increased by a review of multiplanar reformatted images.

Acknowledgment.—The authors thank Patrick Omoumi, MD, Cliniques Universitaires Saint-Luc, Brussels, Belgium, for his help in manuscript preparation.

References

1. Nchimi A, Szapiro D, Dondelinger RF. Injuries of the diaphragm. In: Dondelinger RF, ed. Imaging and intervention in abdominal trauma. Berlin, Germany: Springer-Verlag, 2004; 205–236.
2. Shanmuganathan K, Killeen K, Mirvis SE, White CS. Imaging of diaphragmatic injuries. J Thorac Imaging 2000;15(2):104–111.
3. Mueller CF, Pendarvis RW. Traumatic injury of the diaphragm: report of seven cases and extensive literature review. Emerg Radiol 1994;1(3):118–132.
4. Kearney PA, Rouhana SW, Burney RE. Blunt rupture of the diaphragm: mechanism, diagnosis, and treatment. Ann Emerg Med 1989;18(12):1326–1330.
5. Shackleton KL, Stewart ET, Taylor AJ. Traumatic diaphragmatic injuries: spectrum of radiographic findings. RadioGraphics 1998;18(1):49–59.
6. Rodriguez-Morales G, Rodriguez A, Shatney CH. Acute rupture of the diaphragm in blunt trauma: analysis of 60 patients. J Trauma 1986;26(5):438–444.
7. Sarna S, Kivioja A. Blunt rupture of the diaphragm: a retrospective analysis of 41 patients. Ann Chir Gynaecol 1995;84(3):261–265.
8. Chughtai T, Ali S, Sharkey P, Lins M, Rizoli S. Update on managing diaphragmatic rupture in blunt trauma: a review of 208 consecutive cases. Can J Surg 2009;52(3):177–181.
9. Murray JG, Caoili E, Gruden JF, Evans SJ, Halvorsen RA Jr, Mackersie RC. Acute rupture of the diaphragm due to blunt trauma: diagnostic sensitivity and specificity of CT. AJR Am J Roentgenol 1996;166(5):1035–1039.
10. Kuhlman JE, Pozniak MA, Collins J, Knisely BL. Radiographic and CT findings of blunt chest trauma: aortic injuries and looking beyond them. RadioGraphics 1998;18(5):1085–1106; discussion 1107–1108.

11. Boulanger BR, Milzman DP, Rosati C, Rodriguez A. A comparison of right and left blunt traumatic diaphragmatic rupture. J Trauma 1993;35(2):255–260.
12. Reiff DA, McGwin G Jr, Metzger J, Windham ST, Doss M, Rue LW 3rd. Identifying injuries and motor vehicle collision characteristics that together are suggestive of diaphragmatic rupture. J Trauma 2002;53(6):1139–1145.
13. Nchimi A, Szapiro D, Ghaye B, et al. Helical CT of blunt diaphragmatic rupture. AJR Am J Roentgenol 2005;184(1):24–30.
14. 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;60(12):1280–1289.
15. Killeen KL, Mirvis SE, Shanmuganathan K. Helical CT of diaphragmatic rupture caused by blunt trauma. AJR Am J Roentgenol 1999;173(6):1611–1616.
16. Desser TS, Edwards B, Hunt S, Rosenberg J, Purtill MA, Jeffrey RB. The dangling diaphragm sign: sensitivity and comparison with existing CT signs of blunt traumatic diaphragmatic rupture. Emerg Radiol 2010;17(1):37–44.
17. 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(2):451–457.
18. Mirvis SE, Shanmuganagthan K. Imaging hemidiaphragmatic injury. Eur Radiol 2007;17(6):1411–1421.
19. Leung JC, Nance ML, Schwab CW, Miller WT Jr. Thickening of the diaphragm: a new computed tomography sign of diaphragm injury. J Thorac Imaging 1999;14(2):126–129.
20. Koplewitz BZ, Ramos C, Manson DE, Babyn PS, Ein SH. Traumatic diaphragmatic injuries in infants and children: imaging findings. Pediatr Radiol 2000;30(7):471–479.
21. Kaya SO, Karabulut N, Yuncu G, Sevinc S, Kiroğlu Y. Sinus cut-off sign: a helpful sign in the CT diagnosis of diaphragmatic rupture associated with pleural effusion. Eur J Radiol 2006;59(2):253–256.
22. Heiberg E, Wolverson MK, Hurd RN, Jagannadharao B, Sundaram M. CT recognition of traumatic rupture of the diaphragm. AJR Am J Roentgenol 1980;135(2):369–372.
23. Gelman R, Mirvis SE, Gens D. Diaphragmatic rupture due to blunt trauma: sensitivity of plain chest radiographs. AJR Am J Roentgenol 1991;156(1):51–57.
24. Dee PM. The radiology of chest trauma. Radiol Clin North Am 1992;30(2):291–306.
25. Gwely NN. Outcome of blunt diaphragmatic rupture: analysis of 44 cases. Asian Cardiovasc Thorac Ann 2010;18(3):240–243.
26. Shah R, Sabanathan S, Mearns AJ, Choudhury AK. Traumatic rupture of diaphragm. Ann Thorac Surg 1995;60(5):1444–1449.
27. Holland DG, Quint LE. Traumatic rupture of the diaphragm without visceral herniation: CT diagnosis. AJR Am J Roentgenol 1991;157(1):17–18.
28. Reber PU, Schmied B, Seiler CA, Baer HU, Patel AG, Büchler MW. Missed diaphragmatic injuries and their long-term sequelae. J Trauma 1998;44(1):183–188.
29. Bergeron E, Clas D, Ratte S, et al. Impact of deferred treatment of blunt diaphragmatic rupture: a 15-year experience in six trauma centers in Quebec. J Trauma 2002;52(4):633–640.
30. Demos TC, Solomon C, Posniak HV, Flisak MJ. Computed tomography in traumatic defects of the diaphragm. Clin Imaging 1989;13(1):62–67.
31. Panicek DM, Benson CB, Gottlieb RH, Heitzman ER. The diaphragm: anatomic, pathologic, and radiologic considerations. RadioGraphics 1988;8(3):385–425.
32. Schumpelick V, Steinau G, Schlüper I, Prescher A. Surgical embryology and anatomy of the diaphragm with surgical applications. Surg Clin North Am 2000;80(1):213–239, xi.
33. Restrepo CS, Eraso A, Ocazionez D, Lemos J, Martinez S, Lemos DF. The diaphragmatic crura and retrocrural space: normal imaging appearance, variants, and pathologic conditions. RadioGraphics 2008;28(5):1289–1305.
34. Warwick R, Williams PL. Fasciae and muscles of the trunk. In: Warwick R, Williams PL, eds. Gray's anatomy. 35th ed. London, England: Elsevier, 1973;516–519.
35. Barsness KA, Bensard DD, Ciesla D, Partrick DA, Hendrickson R, Karrer FM. Blunt diaphragmatic rupture in children. J Trauma 2004;56(1):80–82.
36. Chen JC, Wilson SE. Diaphragmatic injuries: recognition and management in sixty-two patients. Am Surg 1991;57(12):810–815.
37. Estrera AS, Platt MR, Mills LJ. Traumatic injuries of the diaphragm. Chest 1979;75(3):306–313.
38. Andrus CH, Morton JH. Rupture of the diaphragm after blunt trauma. Am J Surg 1970;119(6):686–693.
39. Meyers BF, McCabe CJ. Traumatic diaphragmatic hernia: occult marker of serious injury. Ann Surg 1993;218(6):783–790.
40. Chen HW, Wong YC, Wang LJ, Fu CJ, Fang JF, Lin BC. Computed tomography in left-sided and right-sided blunt diaphragmatic rupture: experience with 43 patients. Clin Radiol 2010;65(3):206–212.
41. Voeller GR, Reisser JR, Fabian TC, Kudsk K, Mangiante EC. Blunt diaphragm injuries: a five-year experience. Am Surg 1990;56(1):28–31.
42. Guth AA, Pachter HL, Kim U. Pitfalls in the diagnosis of blunt diaphragmatic injury. Am J Surg 1995;170(1):5–9.
43. Worthy SA, Kang EY, Hartman TE, Kwong JS, Mayo JR, Müller NL. Diaphragmatic rupture: CT findings in 11 patients. Radiology 1995;194(3):885–888.

44. Athanassiadi K, Kalavrouziotis G, Athanassiou M, et al. Blunt diaphragmatic rupture. Eur J Cardiothorac Surg 1999;15(4):469–474.
45. Shapiro MJ, Heiberg E, Durham RM, Luchtefeld W, Mazuski JE. The unreliability of CT scans and initial chest radiographs in evaluating blunt trauma induced diaphragmatic rupture. Clin Radiol 1996;51(1):27–30.
46. Mihos P, Potaris K, Gakidis J, et al. Traumatic rupture of the diaphragm: experience with 65 patients. Injury 2003;34(3):169–172.
47. Peck WA Jr. Right-sided diaphragmatic liver hernia following trauma. Am J Roentgenol Radium Ther Nucl Med 1957;78(1):99–108.
48. Thakore S, Henry J, Todd AW. Diaphragmatic rupture and the association with occupant position in right-hand drive vehicles. Injury 2001;32(6):441–444.
49. Sharma OP. Traumatic diaphragmatic rupture: not an uncommon entity—personal experience with collective review of the 1980's. J Trauma 1989;29(5):678–682.
50. Wiencek RG Jr, Wilson RF, Steiger Z. Acute injuries of the diaphragm: an analysis of 165 cases. J Thorac Cardiovasc Surg 1986;92(6):989–993.
51. Perlman SJ, Rogers LF, Mintzer RA, Mueller CF. Abnormal course of nasogastric tube in traumatic rupture of left hemidiaphragm. AJR Am J Roentgenol 1984;142(1):85–88.
52. Shehata SM, Shabaan BS. Diaphragmatic injuries in children after blunt abdominal trauma. J Pediatr Surg 2006;41(10):1727–1731.
53. Trésallet C, Menegaux F, Izzillo R, Nguyen-Thanh Q, Cardot V, Chigot JP. Usefulness of CT reconstructed pictures for diaphragmatic rupture after blunt trauma. J Am Coll Surg 2004;198(4):666–667.
54. Israel RS, Mayberry JC, Primack SL. Diaphragmatic rupture: use of helical CT scanning with multiplanar reformations. AJR Am J Roentgenol 1996;167(5):1201–1203.
55. McHugh K, Ogilvie BC, Brunton FJ. Delayed presentation of traumatic diaphragmatic hernia. Clin Radiol 1991;43(4):246–250.
56. Fidvi SA, Kroop SA, Klein SA. Posttraumatic thoracic splenosis and chronic aortic pseudoaneurysm. J Thorac Imaging 1999;14(4):300–302.
57. Backhus LM, Bremner RM. Images in clinical medicine: intrathoracic splenosis after remote trauma. N Engl J Med 2006;355(17):1811.
58. Israel RS, McDaniel PA, Primack SL, Salmon CJ, Fountain RL, Koslin DB. Diagnosis of diaphragmatic trauma with helical CT in a swine model. AJR Am J Roentgenol 1996;167(3):637–641.
59. 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(5):1137–1140.
60. Allen TL, Cummins BF, Bonk RT, Harker CP, Handrahan DL, Stevens MH. Computed tomography without oral contrast solution for blunt diaphragmatic injuries in abdominal trauma. Am J Emerg Med 2005;23(3):253–258.
61. Brink JA, Heiken JP, Semenkovich J, Teefey SA, McClennan BL, Sagel SS. Abnormalities of the diaphragm and adjacent structures: findings on multiplanar spiral CT scans. AJR Am J Roentgenol 1994;163(2):307–310.
62. Shanmuganathan K, Mirvis SE, White CS, Pomerantz SM. MR imaging evaluation of hemidiaphragms in acute blunt trauma: experience with 16 patients. AJR Am J Roentgenol 1996;167(2):397–402.
63. Caskey CI, Zerhouni EA, Fishman EK, Rahmouni AD. Aging of the diaphragm: a CT study. Radiology 1989;171(2):385–389.
64. Smith L, Lippert KM. Peritoneopericardial diaphragmatic hernia. Ann Surg 1958;148(5):798–804.
65. Sliker CW. Imaging of diaphragm injuries. Radiol Clin North Am 2006;44(2):199–211.
66. Burks DW, Mirvis SE, Shanmuganathan K. Acute adrenal injury after blunt abdominal trauma: CT findings. AJR Am J Roentgenol 1992;158(3):503–507.
67. Gale ME. Bochdalek hernia: prevalence and CT characteristics. Radiology 1985;156(2):449–452.
68. Iochum S, Ludig T, Walter F, Sebbag H, Grosdidier G, Blum AG. Imaging of diaphragmatic injury: a diagnostic challenge? RadioGraphics 2002;22(Spec Issue):S103–S116; discussion S116–S118.
69. Pikoulis E, Delis S, Scandalakis P, et al. Reliability of initial chest radiographs in the diagnosis of blunt diaphragmatic rupture. Ann Chir Gynaecol 2000;89(1):10–13.

CT of Blunt Diaphragmatic Rupture

Amandine Desir, MD • Benoît Ghaye, MD

RadioGraphics 2012; 32:477–498 • **Published online** 10.1148/rg.322115082 • **Content Codes:** CH CT ER GI

Page 479
BDR occurs more often on the left side than on the right, with a mean left-to-right ratio of approximately 3:1 (range, 1.5:1 to 7:1) (2,3,6–9,11,13,15,23,25,26,36–46).

Page 482 (Figure on page 483)
BDR is associated with other life-threatening injuries in 44%–100% of cases and almost never occurs as an isolated injury (1,2,7,8,11,38). The most common injuries associated with left-sided BDR are splenic injuries; with right-sided BDR, liver lesions are most common, but renal, aortic, cardiac, and osseous (spine, pelvis, rib) lesions also are frequently encountered (Fig 6) (1,8,11,12).

Page 482
Spontaneous healing of diaphragmatic ruptures has never been reported. The normally negative pleuroperitoneal pressure gradient (7–22 cm H_20), along with continuous diaphragmatic motion, contributes to the persistence of the lesion (1,2,11,28). Because of negative intrapleural pressure, abdominal structures generally herniate into the thorax. Such herniation may be delayed for days or years (from 1 day to 48 years), which may make the diagnosis at chest radiography and CT more difficult; however, herniation occurs within 3 years in 80% of cases (1,5,28,55). The use of positive pressure ventilatory support at the patient's admission overcomes the negative pleuroperitoneal pressure gradient, may thereby prevent or delay herniation, and thus may account for false-negative findings at initial imaging examinations (6,45).

Page 495 (Figure 5 on page 482. Figure 23 on page 495)
Radiographic findings that are highly suggestive or indicative of BDR include the presence of intrathoracic gastrointestinal tract air (Fig 23) with or without an associated collar sign or air-fluid level above the expected level of the diaphragm, and an abnormal U-shaped course of the nasogastric tube with its tip projecting above the level of the diaphragm (6,51). An upper hemidiaphragmatic contour that rises more than 4–6 cm above the level of the contralateral hemidiaphragm also is considered highly suggestive of BDR (Fig 5a).

Page 496
Knowledge of the various CT signs suggestive of BDR is important to improve the detection of this underdiagnosed pattern of traumatic thoracoabdominal injury. The observation of two or more CT signs is associated with a substantially higher probability of the presence of BDR. Even signs with a low predictive value may alert the radiologist to the need to examine the diaphragm more closely for other features supportive of the diagnosis of BDR or the exclusion of that diagnosis. The accuracy of a diagnosis of BDR is increased by the observation of multiple associated CT signs of rupture.