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Traumatic injuries of the diaphragm: overview of imaging findings and diagnosis

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Abstract

Injuries to the diaphragm muscle occur in penetrating and severe blunt trauma and can lead to delayed hernia formation. Computed tomography is the mainstay in the diagnosis of these injuries, which may be subtle at presentation. Imaging findings differ between blunt and penetrating trauma. Key features in blunt trauma include diaphragm fragment distraction and organ herniation because of increased intra-abdominal pressure. In penetrating trauma, herniation is uncommon, and the trajectory of the object is critical in making the diagnosis of diaphragm injury in these patients. Radiologists must keep a high index of suspicion for injury to the diaphragm in cases of trauma to the chest or abdomen.

Key words: Diaphragm injury—Blunt trauma—Penetrating trauma—Diaphragm rupture—Diaphragm hernia

The diaphragm is a dome-shaped sheet of skeletal muscle and tendon that plays a critical role in respiratory function and also serves to separate the thoracic and abdominal cavities. As it represents the boundary between the chest and abdomen, the diaphragm may be injured by trauma to either half of the torso. Injuries to the diaphragm are uncommon, occurring in approximately 3% of patients with thoracoabdominal trauma [1]. They often do not represent a cause of acute morbidity to trauma patients and are frequently missed clinically [2]. However, they are important to recognize because of the potential for late adverse outcomes related to hernia formation.

If not recognized early, a tear within the diaphragm muscle can enlarge over time and allow abdominal organs to herniate into the chest [3, 4]. If not repaired, diaphragm injuries may present months or even many years later with organ herniation. This can lead to respiratory compromise by compression of the lungs or, worse, bowel obstruction or organ ischemia (Fig. 1). It is equally important to recognize this delayed presentation, as it may easily be misinterpreted as an elevated diaphragm or eventration [3].

In both penetrating and blunt trauma, diaphragm injuries are often associated with injuries to other organs [5, 6]. In the acute setting, approximately one third of patients will undergo emergent laparotomy for management of these other injuries [7]. The most common associated injuries include the liver (approximately half of patients), lung, spleen, and kidney [5]. At the time of laparotomy, the surgeon will inspect the diaphragm for injuries and typically repair it then. If the patient has no other indications for laparotomy but is found to have a diaphragm injury at imaging, surgical management depends on the side of the injury. Some small right-sided injuries may not need repair because the liver will prevent herniation of other organs through a small defect [8]. Delayed diaphragm injuries may be repaired with a thoracic, rather than abdominal, approach [8].

Diaphragm injuries may occur from both blunt and penetrating trauma, with many but not all series showing that injuries are slightly more frequent in penetrating trauma [4, 9, 10]. It is important to recognize that, due to different mechanisms, the imaging characteristics of diaphragm injuries differ in blunt and penetrating trauma. Blunt diaphragm injury occurs from intense, abrupt pressure to the abdominal cavity that results in excessive tension on the diaphragm muscle itself and consequent rupture [11]. This pressure tends to create a large tear in the muscle and may force abdominal organs directly into the chest. Blunt diaphragm injuries are more common on the left side; it may be that there is congenital weakness in the diaphragm at this location, or the liver may be protective on the right side [7].

Penetrating diaphragm injuries, however, result from a sharp object directly lacerating the muscle. These injuries tend to be smaller than the large tears that are seen

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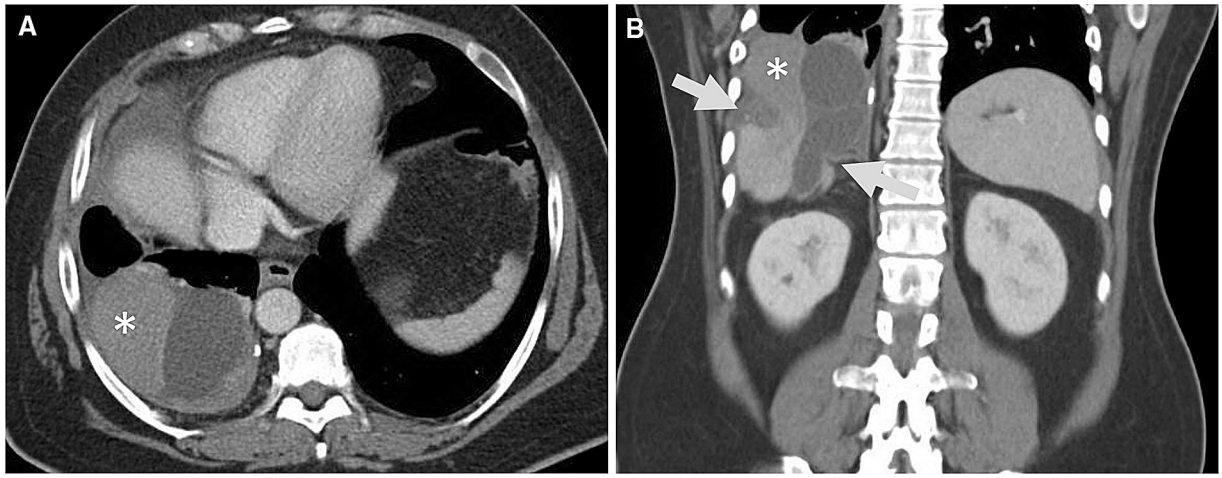

Fig. 1. 52-year-old woman with a chronic right hemidiaphragmatic hernia, believed to be iatrogenic. **A** Transverse and **B** coronal CT images show that a portion of the right hepatic lobe has herniated through the defect, along with the gallbladder. This portion of the liver is hypoenhancing (*asterisk*), indicative of ischemia. The edges of the diaphragm muscle are shown with *arrows*.

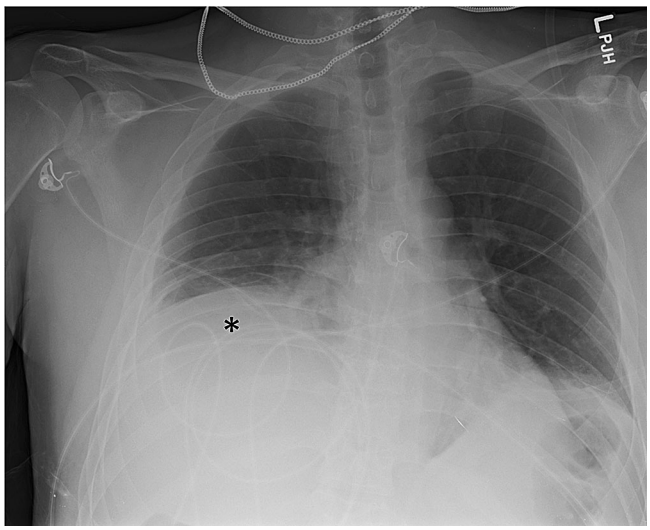

Fig. 2. 40-year-old man found to have elevated *right* hemidiaphragm (*asterisk*) after all-terrain vehicle accident, proven to represent a diaphragmatic injury.

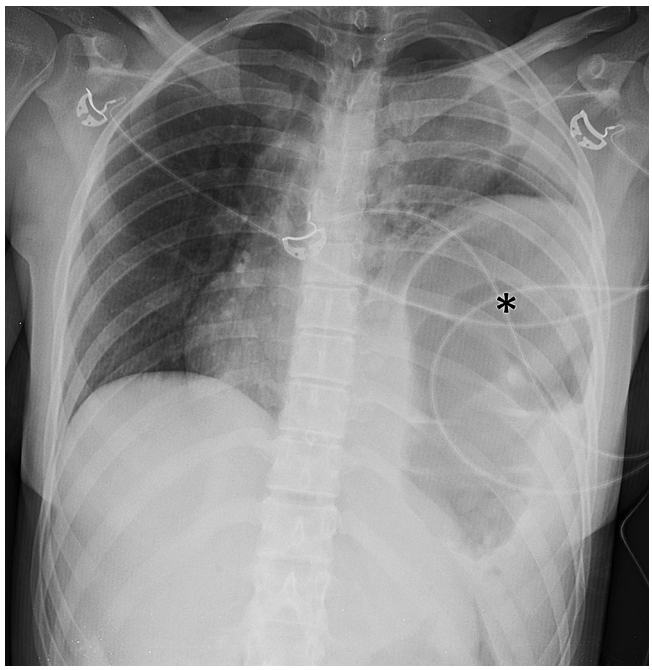

Fig. 3. 23-year-old man status post motor vehicle collision with elevated *left* hemidiaphragm (*asterisk*) containing several bowel loops, consistent with a left diaphragmatic injury.

in blunt injuries, and there is no pressure gradient forcing abdominal contents into the chest (acutely). For these reasons, penetrating injuries are more likely to be missed at initial evaluation [6, 12]. Penetrating injuries from stabbing are also reportedly more common on the left, perhaps because of the preponderance of right-handed attackers.

Initial evaluation

Chest radiograph

The chest radiograph is an important tool for the initial evaluation of trauma patients, as it allows for identification of immediately life-threatening injuries such as tension pneumothorax. Diaphragm injuries can be identified on chest radiograph by marked elevation of one hemidiaphragm (Fig. 2) or, particularly on the left, by herniation of bowel into the thorax (Fig. 3). The sensitivity of the chest radiograph is relatively low, particularly in penetrating trauma, and may be normal in up to 40% of patients [13].

Computed tomography (CT)

Owing to its high sensitivity for intra-abdominal injuries, CT is now standard of care in the evaluation of most

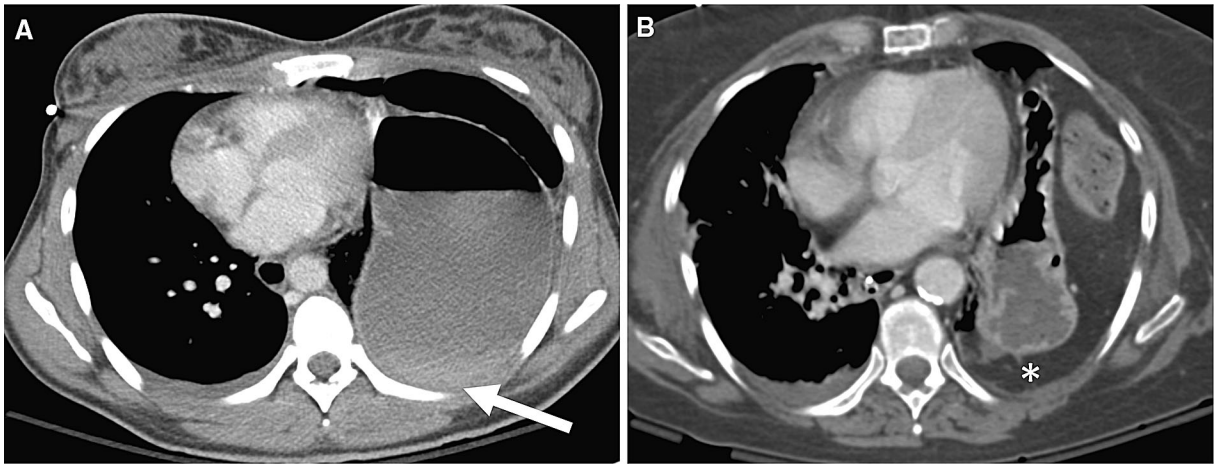

Fig. 4. **A** 23-year-old woman presented after motor vehicle collision. Note that the gastric fundus touches the posterior pleural surface (*arrow*), as the stomach has herniated into the chest in this patient with left hemidiaphragm injury. This finding is known as the *dependent viscera sign*. **B** 74-year-old man presented after motor vehicle collision. In this patient, the gastric fundus and abdominal fat (*asterisk*) touch the posterior pleural surface, representing another example of the dependent viscera sign, indicating injury to the left hemidiaphragm.

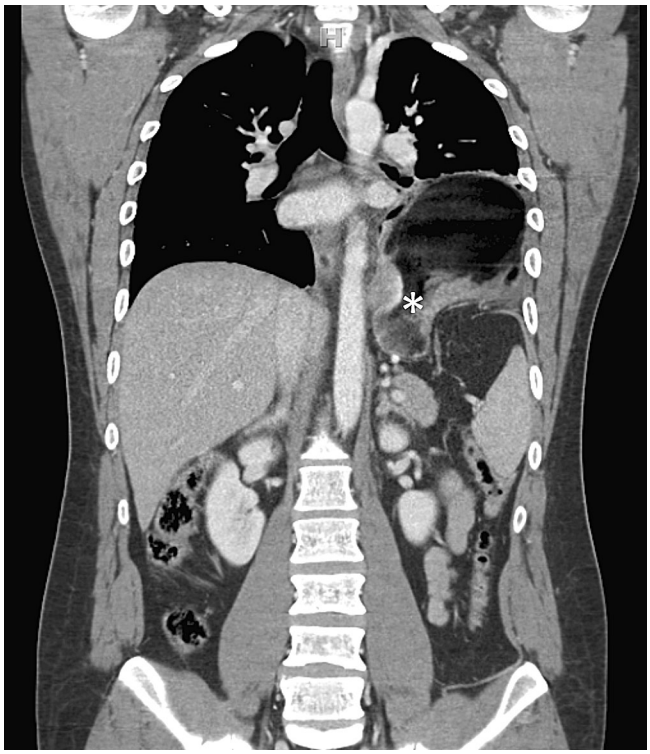

Fig. 5. 30-year-old man with left hemidiaphragm injury after motor vehicle collision. Note that the stomach has herniated through the diaphragmatic defect; constriction of the portion passing through the tear represents the *collar sign* (*asterisk*).

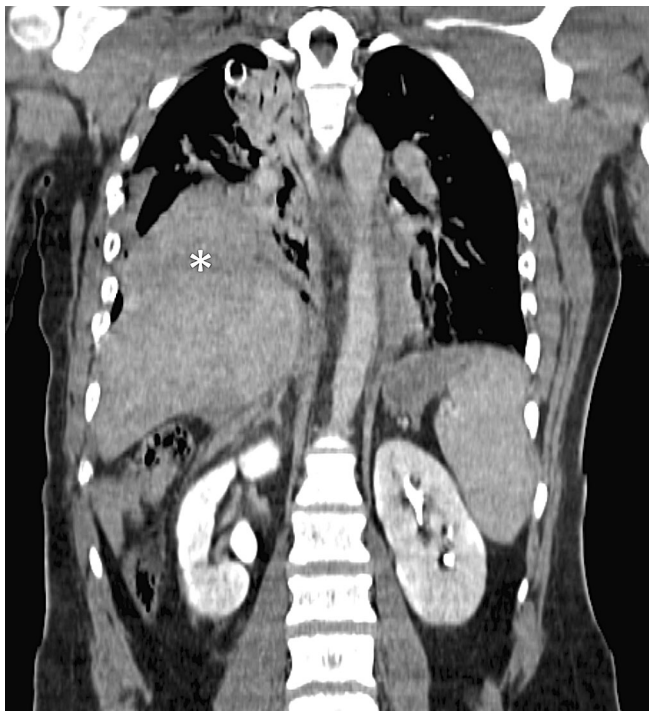

Fig. 6. 31-year-old man with right hemidiaphragm injury after motor vehicle collision. Note the constriction of the portion of the liver herniating through the defect (*asterisk*), which represents a right-sided collar sign, also known as the *cottage loaf sign*. Also note the decreased enhancement of the herniated portion of the liver, which represents the *band sign*, presumably resulting from decreased perfusion.

trauma patients [14, 15], with CT findings frequently helping determine the need for surgical intervention. In some cases, particularly in penetrating trauma, the diaphragm may be the sole site of intra-abdominal injury [6], and thus correct diagnosis by CT is critical to determine proper patient management. Several studies have been performed to evaluate the sensitivity of CT for

blunt and penetrating diaphragm injury [16–20], with sensitivity around 80%–90% depending on the study and mechanism. As noted above, penetrating and blunt diaphragm injuries have disparate imaging characteristics, and we will discuss these in detail below.

Magnetic resonance imaging (MRI)

MRI is useful in evaluating the function of the diaphragm, as it can provide real-time imaging in multiple planes [21]. Due to limited availability and the length of the examination, MRI is generally not appropriate in the acute setting, particularly for trauma patients who may be hemodynamically unstable or unable to cooperate with breathing instructions. MRI may be considered for problem solving in select cases in the subacute setting if CT findings are equivocal or functional information is desired [22].

Blunt trauma

Blunt diaphragm injuries occur as excessive force upon the abdomen is transmitted through the diaphragm muscle, causing a tear and often forcing abdominal contents into the thoracic cavity. These are typically associated with severe trauma and multi-organ injuries [1, 10], and as noted above, left hemidiaphragm rupture is more common. Findings at CT reflect the fact that the tears are typically large, the torn fragments are often distracted, and intra-abdominal contents may be displaced through the hole, all a consequence of the pressure-related injury [18, 19, 23–26].

Displaced organs

Several signs reflect abdominal organs herniating through the diaphragmatic defect, representing directs signs of diaphragm injury. These differ with respect to the side of the diaphragm that is injured. Injuries on the left side may show displacement of the spleen or bowel (particularly stomach) into the chest. One may identify the *dependent viscera* sign, which refers to the fact that the herniated organs touch the posterior pleural surface instead of being held anteriorly by the diaphragm muscle (Fig. 4). As the organs pass through the hernia mouth, the defect constricts them, representing the *collar sign*

Fig. 7. 40-year-old man with diaphragm injury after all-terrain vehicle accident. Note the elevation of the right portion of the liver (*asterisk*), representing elevated abdominal contents, an indirect sign of blunt diaphragm injury.

Fig. 8. 24-year-old man with left hemidiaphragm injury after motor vehicle collision. The torn edges of the diaphragm may be seen in this image (*arrows*); they tend to curl upon themselves, a finding known as the *dangling diaphragm sign*.

(Fig. 5). On the right side, the liver lies just under the diaphragm and may herniate through the defect, but typically only a portion of this organ will actually enter the chest. In the context of the liver, the *collar sign* is also known as the mushroom sign or cottage loaf sign, referring to the mound-like portion of herniated liver rising above the injured diaphragm (Fig. 6). The *band sign* is an associated sign describing an area of decreased enhancement within the liver at the level of the hernia, presumably related to constriction of the vascular supply or edema of the affected parenchyma (Figure 6).

Occasionally, particularly with blunt injuries to the right hemidiaphragm, the actual defect or herniation is difficult to discern directly on CT images. The diaphragm and abdominal contents may, however, be abnormally elevated in comparison to the contralateral side (Figure 7). A difference of 4–5 cm is felt to be an optimal threshold in these situations [18, 24, 26]. This represents an indirect sign of diaphragm injury.

Diaphragmatic defect

In blunt diaphragm injuries, the torn ends of the diaphragm muscle are often pushed apart by the pressure of the injury, and the defect itself can be seen as a discontinuity in the muscle on CT (Fig. 8). The torn ends may curl upon themselves, resulting in the *dangling diaphragm* sign (Fig. 8) [27]. These signs represent a direct finding of diaphragm injury and are virtually diagnostic for an injury.

In an individual case, radiologists should evaluate for the presence of all of these signs, as their sensitivity is not perfect. Overall sensitivity using combinations of signs ranges from 60%–100% in several studies [18, 19, 23]; the two studies specifically evaluating combinations of signs including discontinuity of the diaphragm found sensitivities of 90%–100% [18, 23]. As noted above, right-sided injuries may be more subtle, particularly because the liver does not change much in configuration as it par-

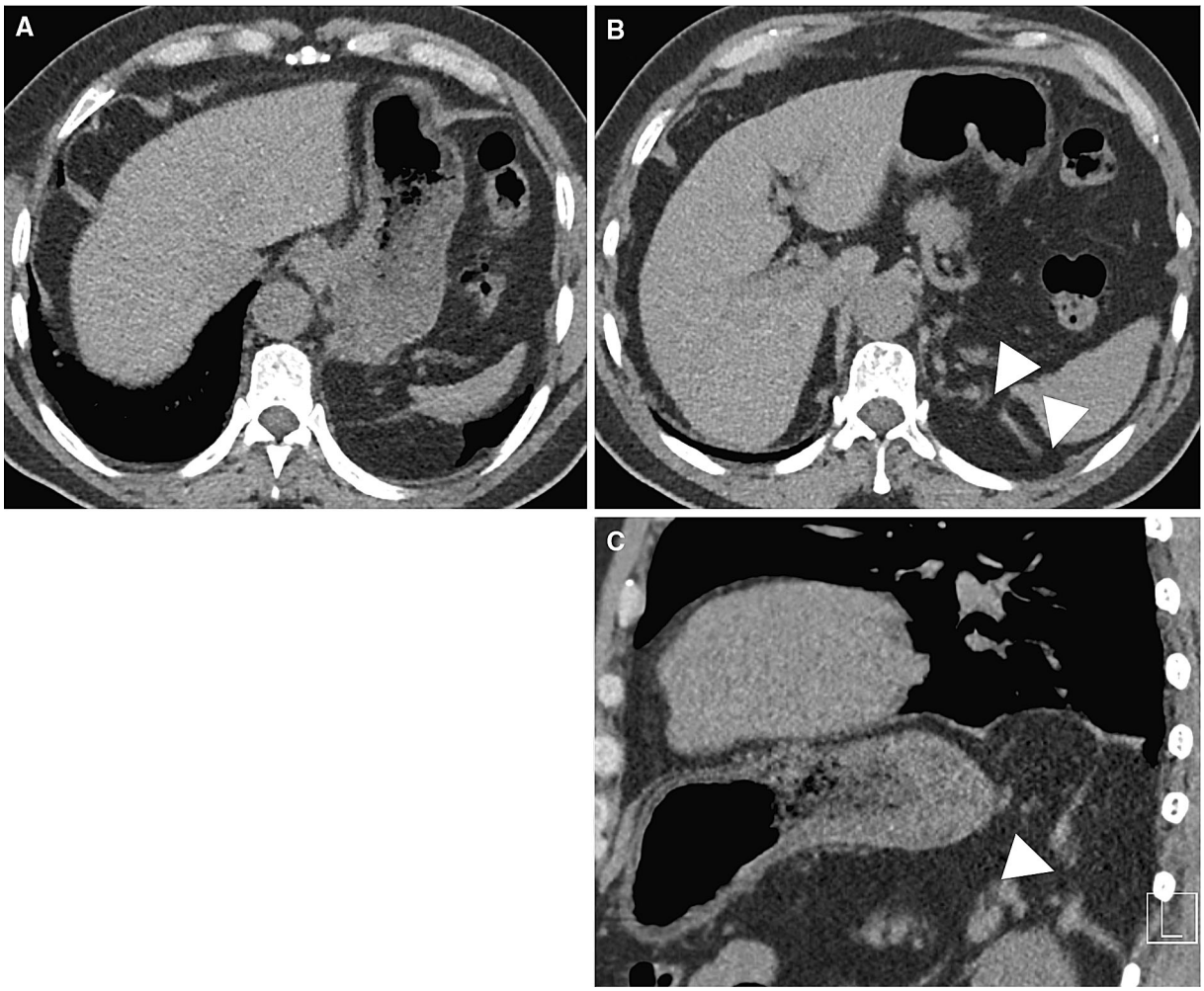

Fig. 9. 66-year-old man with a left Bochdalek hernia containing fat. **A**, **B** Transverse and **C** sagittal CT images demonstrate a small fat-containing lesion extending from the abdominal cavity into the chest, touching the posterior pleural surface. In this case, there are 2 narrow-necked diaphragmatic defects (*arrowheads*).

tially herniates into the chest, and radiologists should consider the possibility of diaphragm injuries in all cases of severe blunt trauma.

Variants that simulate diaphragm injury

Several congenital entities involving the diaphragm may simulate traumatic injuries. If no prior imaging is available to show that the finding was present prior to the trauma, they may be confused with a diaphragm injury. In particular, congenital diaphragmatic hernias and eventrations may simulate an injury [24].

Non-traumatic diaphragm hernias may be classified into several types, including the Bochdalek hernia, the Morgagni hernia, and the hiatal hernia. The hernia most commonly confused with traumatic injury is the Bochdalek hernia, which occurs along the posterior portion of the diaphragm muscle, more commonly on the left side [28, 29]. While large congenital diaphragmatic hernias are detected in infancy, small hernias are generally asymptomatic and found incidentally at CT. Features suggestive of a congenital (Bochdalek) hernia, rather than a traumatic injury, include a narrow neck, small hernia sac containing only fat, and typical location along the posterior aspect of the diaphragm (Fig. 9).

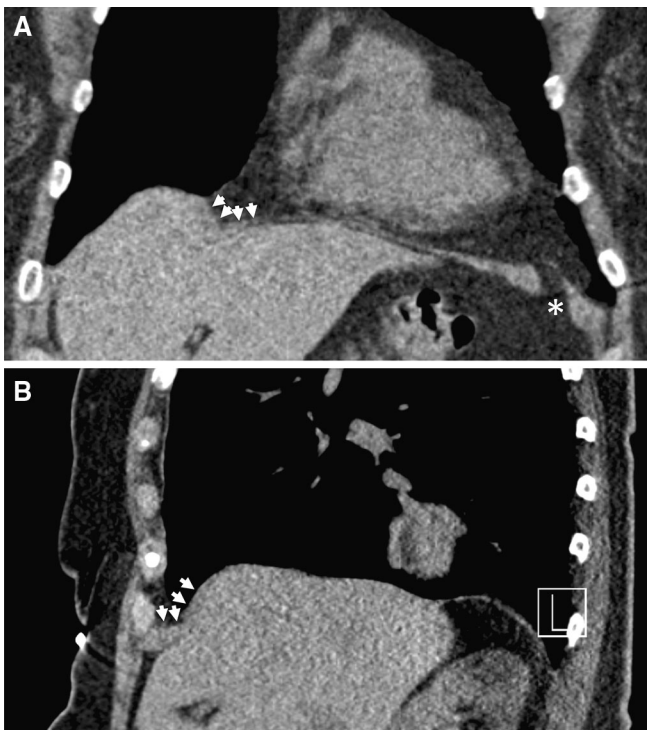

Fig. 10. 71-year-old woman with eventration of the right hemidiaphragm. **A** Coronal and **B** sagittal CT images demonstrate focal bulging of the anteromedial right hemidiaphragm over the liver. Close inspection reveals continuity of the diaphragm covering the eventration (*arrows*). Note also a slip in the left hemidiaphragm (*asterisk*).

As opposed to hernias, eventration of the diaphragm refers to a focal thinning of the diaphragm muscle without any defect. This focal thinning of the muscle leads to a bulge in the surface of the diaphragm, typically broad-based, which can simulate a hernia at imaging. Eventrations are most commonly seen in the anteromedial right hemidiaphragm, with consequent bulging of the liver [30]. Eventrations are probably best evaluated on CT using coronal reformats, which can typically demonstrate continuity of the diaphragm muscle over the eventration (Fig. 10).

Slips or scalloping of the diaphragm muscle are common as well. These are areas of focal thinning and undulation of the diaphragm muscle (Fig. 10), distinguished from injury by their long, linear configuration. Finally, a paralyzed hemidiaphragm could simulate a large hernia, but continuity of the diaphragm muscle can generally distinguish this from a diaphragm injury; multiplanar reformats may be helpful in this regard.

Penetrating trauma

In penetrating trauma, a foreign object causes a direct laceration of the diaphragm muscle, but there is typically not an abrupt increase in intra-abdominal pressure to push apart the torn edges or cause organ herniation. The diaphragmatic defects in penetrating trauma tend to be smaller but can lead to delayed hernias [6]. Thus, findings at CT typically do not demonstrate diaphragm discontinuity or organ displacement [20, 23]. In other words, direct signs of diaphragm injury are uncommon in penetrating trauma; indirect signs, such as the path of the bullet or stab wound, are the best features to diagnose penetrating diaphragm injury.

Wound trajectography

The most important factor in penetrating trauma is the path, or trajectory, of the foreign object as it passes through the body, sometimes referred to as *trajectography* [20]. This path can be inferred by soft tissue gas and blood products, metallic fragments, or solid organ injuries (lacerations, active extravasation, and hematomas). A wound trajectory crossing the diaphragm should be considered strong evidence suggesting diaphragm injury (Figure 11); it is moderately sensitive (68%–73%) and specific [20, 23]. The use of multiplanar reformats, particularly oblique images along the path, can help elucidate the trajectory and identify any organs that may be injured [31] (Fig. 11C).

A variant and ancillary sign of the wound path is the finding of contiguous injuries above and below the diaphragm. In essence, this simply implies that the trajectory crosses the diaphragm, and this finding may be helpful in cases where the trajectory is difficult to discern. For example, bullets that ricochet within the body may

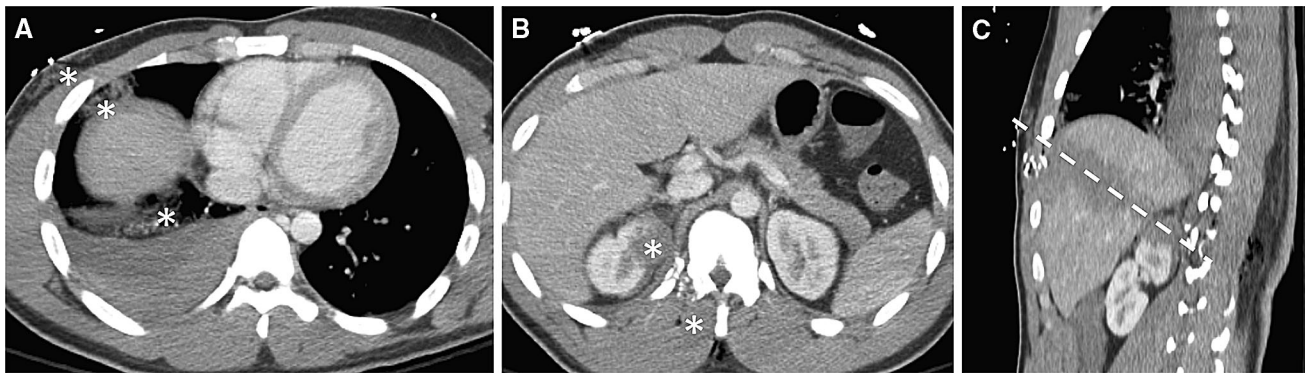

Fig. 11. 25-year-old man who suffered a gunshot injury with laceration of the right hemidiaphragm. **A**, **B** Transverse and **C** sagittal reformatted images demonstrate the bullet trajectory (*asterisks* and *dashed line*) passing across the diaphragm, consistent with penetrating diaphragm injury.

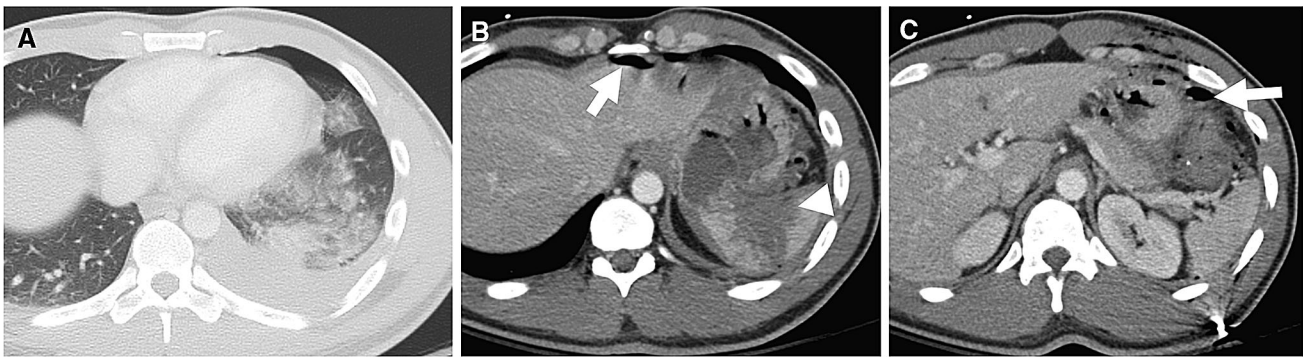

Fig. 12. 28-year-old man who suffered a shotgun injury to the *left* chest. Transverse images demonstrate injuries above (**A**) and below (**B**, **C**) the diaphragm, with pulmonary contusion, splenic laceration (*arrowhead*), and free intraperitoneal gas (*arrows*). The left hemidiaphragm was found to be injured at surgery.

have complex trajectories that are difficult to follow; injuries from pellet projectiles may also be challenging because of the number of missiles (Fig. 12). In these cases, the presence of injuries immediately above and below the diaphragm should be regarded as suspicious for diaphragm injury. This finding is more sensitive (80%–88%) although slightly less specific than the wound trajectory itself [16, 20, 23].

Diaphragm discontinuity

As discussed above, since the lacerations tend to be small and not distracted, the diaphragmatic defect itself is rarely seen on CT in penetrating trauma (Fig. 13). In two recent studies, this finding was only present in as few as 7%–8% of cases [20, 23].

Organ displacement

Again, organ displacement is uncommonly seen in penetrating trauma to the diaphragm, only present in 0%–13% of cases [20, 23].

Fig. 13. 29-year-old man with a stab wound to the left upper quadrant. CT images demonstrate a small left hemidiaphragm laceration (*circle*).

Thus, in penetrating trauma, radiologists must focus on the wound trajectory, which they may either directly visualize or infer based on contiguous injuries. The index of suspicion should be high since many of these injuries

are missed prospectively [23], and they may not manifest clinically until years later.

Summary

Diaphragm injuries are uncommon in trauma but are important because of delayed hernia formation. These injuries may be clinically occult, often requiring the radiologist for diagnosis. While large blunt diaphragm injuries may be identified on radiographs, CT is far more sensitive and can diagnose solid and visceral organ injuries as well. In blunt trauma, increased intra-abdominal pressure leads to diaphragm rupture, fragment distraction, and organ herniation. Findings of organ herniation and a discontinuity in the diaphragm muscle are the key to making the diagnosis. In penetrating trauma, herniation and discontinuity are typically not seen. Instead, the trajectory of the object, either observed or inferred based on adjacent injuries, is the best clue to reveal diaphragm injuries in these patients. Multiplanar reformatted images are often helpful in evaluating the diaphragm for injury and injury mimics. Radiologists must keep a high index of suspicion for diaphragm injuries in trauma and tailor their approach based on the mechanism of injury.

Compliance with ethical standards

Funding This study was not funded.

Conflicts of interest MMH declares that he has no conflict of interest. DAR declares that he has no conflict of interest. VMM declares that he has no conflict of interest. SB declares that he has no conflict of interest. CAR declares that he has no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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