INJURY TO THE DIAPHRAGM

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OVERVIEW – BLUNT FORCE INJURY

Rupture of the hemidiaphragm occurs in approximately 3.0% to 8.0% of patients undergoing celiotomy after blunt abdominal trauma [1 – 3] and occurs in 0.8 to 5.8% of patients with major blunt force thoracic injury [4 – 6]. Motor vehicle accidents are responsible for up to 90% of all diaphragmatic injuries from blunt trauma [4]. Several mechanisms have been proposed as causes of diaphragm tearing. These include sudden increase in intra-abdominal pressure transmitted throughout the abdomen at impact, avulsion of the diaphragm from its attachments, penetration by rib fracture fragments, and shearing of the stretched diaphragm dome. Kearney et al [4] have shown that patients sustaining left lateral impact are at three times higher risk of experiencing diaphragmatic rupture than those receiving a frontal impact, supporting a role for chest-wall deformation and shearing forces in producing this injury. Right hemidiaphragmatic injuries occurred in 50% of patients after right lateral impact, whereas 91% of left hemidiaphragmatic ruptures occurred after left lateral impact. Left hemidiaphragmatic rupture predominates in blunt injury, representing 75% of 44 diaphragmatic injuries diagnosed at thoracotomy by Morgan et al [1] and 72.3% of 83 patients studied by Kearney et al [4]. Rodriguez-Morales et al reported a 70% incidence of left hemidiaphragm rupture among a series of 60 patients with ruptured diaphragms from blunt trauma [5]. Herniation of abdominal viscera into the thorax occurs through the left hemidiaphragm in 95% of cases [7].

Several factors explain the increased incidence of left hemidiaphragm rupture from blunt trauma. The left hemidiaphragm is relatively unprotected by abdominal viscera, such as the live on the right side and it therefore represents an area of relative weakness among the structures containing the abdominal viscera. The right diaphragm is stronger than the left and consistently requires a greater force to rupture [8, 9]. The left hemidiaphragm is weaker due to a line of embryonic fusion between the costal and lumbar parts predisposing this site to injury [10]. Finally, right hemidiaphragm injuries are under-diagnosed in non-surgical series [4]. A positive pressure gradient of 7 to 20 cm of water exists between the peritoneal and pleural spaces. This gradient facilitates herniation of abdominal viscera through left diaphragm tears. Herniation markedly increases the potential for imaging diagnosis of the injury. On the right, the bulk of the liver blocks herniation of abdominal visceral unless the entire liver or a substantial portion herniates through a large gap in the right hemidiaphragm. The lack of herniated visceral markedly decreases the chances of direct imaging diagnosis. Tears of the left hemidiaphram tend to be 10 cm or more in length, are usually located along the posterolateral aspect between the spleen and abdominal aorta and extend medially in a radial orientation toward the central tendon. Cardiac subluxation through a simultaneous tear in the diaphragm and pericardium has been described [2]. Also, visceral herniation into the pericardial space can occur through the same combination of injuries [11]. Bilateral injuries and injuries into the central tendon of the diaphragm are uncommon and reported in 2% to 6% of patients with diaphragm injury [6].

The central location of the diaphragm and its close proximity to other structures accounts for the frequent association of diaphragm rupture with other injuries that are present in 52% to100% of cases [1, 5, 9, 12, 13]. Common concurrent injuries include pelvic fractures (40-55%), splenic injury (60%), and renal injury. Liver trauma occurs in 93% of patients with right and 24% of patients with left hemidiaphragm rupture. Intrathoracic injuries commonly associated with diaphragm rupture include multiple rib fractures, pneumo- and hemothorax, and lung contusion [12, 14]. The presence of displaced left lower rib fractures should particularly increase concern for possible left hemidiaphragm tears. Aortic injuries have a weak association with diaphragm tears occurring in about 5% of cases [8, 15].

CLINICAL DIAGNOSIS

Unfortunately, the clinical diagnosis of rupture of the diaphragm is difficult and is missed in 7% to 66% of patients [4]. Morgan et al. [1] established the diagnosis preoperatively in only 43% of 44 patients with this injury. Physical findings were nonspecific, consisting primarily of chest and abdominal-wall contusions seen only in 16% of patients [1] and respiratory distress seen in 52% of 60 patients reported by Rodriguez-Morales et al. [5]. As noted above, the force required to rupture the hemidiaphragm often produces significant associated injuries. In the series of Morgan et al. [1], 59% of patients had major intraabdominal visceral injury and 45.5% had major intrathoracic injury. Voeller et al. [13] reported associated abdominal injuries in 82% of 33 patients with hemidiaphragmatic rupture. These injuries draw attention away from, and delay recognition of diaphragmatic rupture. If there are no indications for celiotomy, the diagnosis can be further delayed since direct inspection of the diaphragm is not performed [16]. Diagnostic peritoneal lavage (DPL) is falsely negative in up to 34% of patients with diaphragm disruption [13, 17, 18] perhaps due to negative intrapleural pressure drawing blood into the pleural space rather than the peritoneal cavity.

IMAGING DIAGNOSIS

Chest Radiograph

Many radiologic modalities have been advocated for the diagnosis of traumatic hemidiaphragm rupture, but the chest radiograph serves as the initial imaging study for evaluating the integrity of the hemidiaphragm after trauma [19]. The preoperative radiographic diagnosis of traumatic diaphragmatic rupture (TDR) due to blunt trauma is often difficult. This is particularly likely when there is no herniation of abdominal contents through the tear in the hemidiaphragm [20]. Initial chest radiographs may be completely normal or non-specifically abnormal in 25% to 50% of patients [18]. Admission radiographs are diagnostic for TDR in 27% to 62% of patients with left-sided and 33% of right-sided diaphragm injury [5, 18] and suggestive of the diagnosis in another 18% of cases [18, 22].

Plain radiographic findings suggestive of the diagnosis of TDR include elevation of the apparent hemidiaphragm, obliteration or distortion of the diaphragm contour, contralateral displacement of the heart and mediastinum, and an ipsilateral pleural effusion [18]. The demonstration of gas-containing viscera within the thorax, particularly with a focal constriction (“the collar sign”) across the air-containing structure, is pathognomonic of the diagnosis. Clear demonstration of the stomach or nasogastric tube in the lower thorax in the setting of acute blunt trauma should be regarded as diagnostic of the injury until proven otherwise (see below). Herniation of the gastric fundus into the chest cavity may be misdiagnosed as a loculated pneumothorax and treated with thoracosotomy tube placement. Rupture of the diaphragm can be mimicked or masked on chest radiography by superimposed lung pathology. Confusing pathology includes atelectasis of the lower lobe that elevates the stomach and hemidiaphragm, pleural effusion, pulmonary contusion with multiple traumatic lung cysts, aspiration, total or partial diaphragm eventration, acute gastric distension, phrenic nerve palsy, loculated hemopneumothorax, subpulmonic fluid collections, and chronic esophageal or paraesophageal hernias [23]. In some cases serial chest radiographs will demonstrate herniation of abdominal contents as a result of the persistent negative intrapleural pressure gradually pulling abdominal contents into the thoracic cavity. Also, some acute pulmonary and pleural abnormalities will have resolved or diminished on follow-up studies and may improve recognition of superimposed diaphragm injury. Positive pressure ventilatory support may delay herniation of abdominal viscera and postpone recognition of the injury. Post-extubation radiographs should be performed in blunt trauma patients to exclude delayed herniation after intrapleural pressure reverts from positive to negative.

GASTROINTESTINAL CONTRAST STUDIES

The introduction of an esophagogastric tube may be very helpful in diagnosing intrathoracic gastric herniation: a nasogastric tube serves to outline the location of the gastric fundus in relation to the hemidiaphragm. The addition of barium contrast via hand injection into the stomach through the esophagogastric tube will outline the stomach in relation to the lower thorax and can occasionally reveal constriction of the stomach at the level of the torn hemidiaphragm. Of course, barium should be suctioned from the stomach after the diagnostic study to prevent aspiration. If air-fluid levels are detected in the lower thorax by radiography and are not attributed to the stomach or proximal small bowel after upper gastrointestinal contrast study, a barium enema should be performed to exclude herniation of the colon. A draw back to the use of barium contrast is that its high density will create artifacts during subsequent CT studies. For this reason, dilute water-soluble contrast is the preferred gastrointestinal contrast agent or CT should be obtained prior to barium contrast studies.

Cross-sectional imaging

Use of sonography to diagnose acute diaphragm rupture may be limited by the presence of gas in the splenic flexure and stomach, creating an acoustic barrier to the more frequently injured left hemidiaphragm. In several instances in the current author's experience, subcutaneous emphysema accompanying chest trauma has limited the use of sonography in imaging either hemidiaphragm. Ideally, if the entire hemidiaphragm contour can be imaged sonographically, then a defect and/or herniation can be detected [24]. Of course this method is highly dependent on the skill and expertise of the examiner and requires some degree of patient cooperation. In general sonography has not been used extensively for diagnosis of acute injury of the left hemidiaphragm, but has been reported to have had success on the right using the liver as a acoustic window [25, 26]

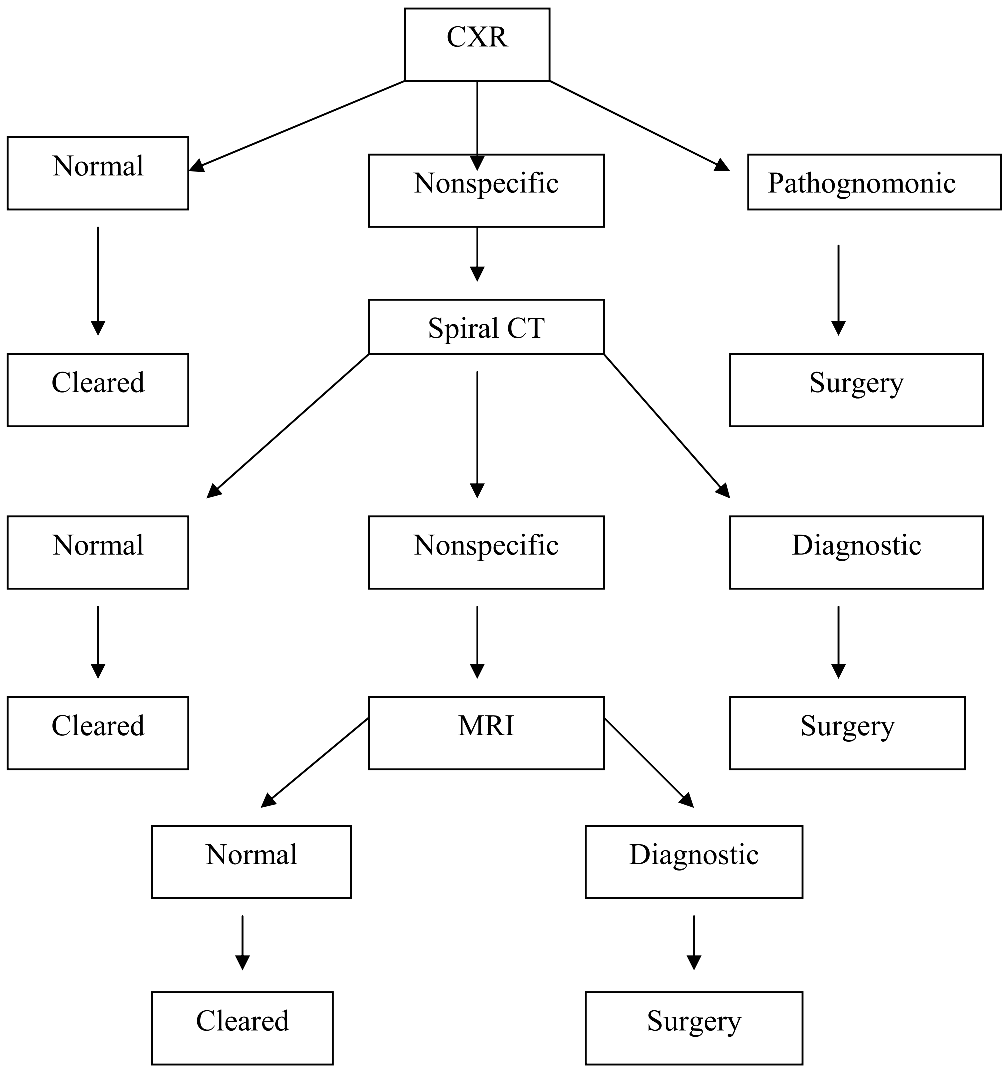
Both CT and MRI have be successfully utilized to diagnose or exclude TDR [27 – 29]. Cross-sectional imaging is most successful at assessing injury of the left hemidiaphragm since it is more commonly accompanied by herniation of abdominal contents. Both CT and MRI have been used successfully to demonstrate right hemidiaphragm rupture with herniation of bowel or liver and for the rare intrapericardial herniation as well. In cases in which the diagnosis of TDR is suspected based on plain radiographs, spiral CT is performed after administration or dilute oral contrast material. A special “diaphragm protocol” is used with spiral scanning from the lung bases to the upper abdomen with a 5 mm effective slice thickness and 3 - 5mm/sec table incrementation. Axial images are reformatted from 2 - 3mm reconstructed images into the sagittal and coronal planes. Whenever possible patient breath-hold through the scan is encouraged to minimize diaphragm motion. Axial and reformatted 2D sagittal and coronal plane images can show direct localized disruption of the diaphragm with herniation of abdominal contents. Using multi-detector row CT (Philips 8000 or IDT, Philips Medical Systems, Best, The Netherlands) images are acquired at 1.25 mm or 2.5 mm as part of the routine chest-abdomen-pelvis protocol and used directly to reformat into the coronal and sagittal plane. Conventional (non-spiral) CT with 8-10mm slice profile is often compromised by motion artifact and inadequate 2D reformations limiting its diagnostic value for reliably diagnosing TDR. However, interpretation of even high quality spiral axial and 2D CT can also be confounded by concurrent pulmonary or pleural-based pathology. CT signs of diaphragm injury include herniation of abdominal contents across a disrupted diaphragm, usually accompanied by the collar sign, a focal discontinuity of the diaphragm, the “visceral” sign, and thickening of the hemidiaphragm due to hemorrhage [6, 28, 30]. Hemorrhage into fat adjacent to the diaphragm on the abdominal side also often accompanies diaphragm rupture.

Conventional single slice helical CT is 14% to 61% sensitive and 76% to 99% specific for diagnosing diaphragm rupture [13, 18, 22, 28] A focal defect in the diaphragm is the most sensitive sign described on conventional CT seen in 71% to 73% of patients with TDR. [22, 28]. Care must be taken not to mistake an interruption in the diaphragm that is a normal variant seen particularly in elderly women [28, 32] or an acquired Bochdalek hernia [33] as an acute injury. Usually hemorrhage is seen at the site of an acute diaphragm injury.

Conventional CT is limited in the diagnosis of TDR because of relative thick, 8-10 mm slice thickness and patient motion. These thick sections make it difficult to distinguish a diaphragm injury from adjacent lung or pleural space pathology. Also, the multiplanar reformations are compromised by poor spatial resolution. Spiral CT improves detection of diaphragm injury mainly by improving the quality of multiplanar reformations (MPR) based on thinner or overlapping axial sections with decreased patient motion. Significant improvement of MPR images results in improved accuracy for confident diagnosis of TDR by permitting evaluation of the entire diaphragm contour and its relationship to the abdominal viscera [9, 34]. It is anticipated that multi-detector spiral scanning will further improve CT accuracy. There has been a significant reduction in the number of patients with indeterminate multi-detector helical CT studies requiring MRI to evaluate the diaphragm for injury at our institution.

A retrospective study was conducted at the Maryland Shock-Trauma Center to evaluate spiral CT in 41 patients with suspicion of TDR based on radiographs. The study group included 32 patients with possible left-sided injury, 10 with possible right-sided injury, and one with suspected bilateral injury. Spiral CT was 78% sensitive for left-sided injury and 50% sensitive for right-sided injury with 100% specificity on both sides [35]. The collar sign was the single most common diagnostic finding with 63% sensitivity and 100% specificity for TDR. MPR images were particularly helpful in establishing the diagnosis on the right side. A similar study performed by Murray et al. [22] analyzed pre-operative abdominal CT scans 11 patients with diaphragmatic rupture (eight left and three right) and 21 patients with intact diaphragms after major acute blunt abdominal trauma. CT studies were reviewed independently by three observers without knowledge of surgical findings. Diaphragmatic discontinuity was seen in eight of the 11 cases of diaphragmatic rupture, visceral herniation was seen in six, and the "collar sign" was seen in four. Hemoperitoneum of hemothorax completely obscured visualization of the ruptured diaphragm in three cases. Individual diagnostic sensitivity among the three reviewers to detect diaphragmatic rupture was 54% to 73% and specificity was 86% to 90%. Average sensitivity for the three observers was 61% (95% confidence interval, 41% to 81%), and average specificity was 87% (95% confidence interval, 76% to 99%).

Whenever the interpretation of radiographic and CT studies is equivocal for diaphragm injury, MRI provides a useful alternative procedure [36, 37]. Among16 patients studied by MRI for potential diaphragm injury at the Maryland Shock-Trauma Center, seven had the diagnosis confirmed with surgical verification and nine patients had no evidence of diaphragm injury by MRI and none had clinical sequelae of a missed injury [27]. T1-weighted coronal and sagittal images through the hemidiaphragm in question are quickly obtained and typically adequate for diagnosis. Fast gradient-echo and inversion recovery MR pulse sequences have also been utilized, but in the author's experience do not improve upon the information obtained from the T1-spin echo images. On MRI the diaphragm appears as a continuous dark curvilinear line. Usually atelectatic lung or pleural fluid marginates the superior aspect of the hemidiaphragm when injured. The undersurface is contrasted against the liver on the right and the retroperitoneal fat, omentum, and viscera on the left. When ruptured the hemidiaphragm shows discontinuity in the dark curvilinear line and extension of abdominal contents above the disruption. Typically, a collar sign is seen at the point where the abdominal structure crosses the diaphragm tear. MRI is very useful to confirm an intact diaphragm in trauma patients in cases of eventration or dysfunction.



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