The diagnosis and management of acute traumatic diaphragmatic injury: A Western Trauma Association clinical decisions algorithm

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The diaphragm is the large muscular division between the thoracic and abdominal compartments. It is the primary muscle used in respiration. Herniation of viscera can occur via a traumatic defect in the diaphragm, which may lead to complications, including visceral ischemia, perforation, and obstruction.[1]

Due primarily to the pressure differential between the positive pressure in the abdominal cavity and the negative pressure in the thoracic cavity, and from normal movement of the diaphragm that occurs during inspiration and expiration, significant injuries to the diaphragm may not heal without surgical repair. They can enlarge with time,[2] allowing for greater degrees of visceral entrapment and subsequent complications.[3] Nonetheless, there are also animal data supporting spontaneous healing of small diaphragm injuries.[4–6] Thus, even the concept that diaphragm injuries ought to be diagnosed and repaired surgically is controversial and further examination is needed to completely understand this important subject.

Acute traumatic injuries of the diaphragm occur after both blunt and penetrating trauma, with a reported incidence that varies dramatically based upon mechanism and anatomic location of injury.[7–9] Penetrating thoracoabdominal trauma comprises the majority of diaphragmatic injuries.[10] The thoracoabdomen is defined as the banded area demarcated by the nipples, the bottom of the scapulae, and the inferior aspect of the costal margins bilaterally. Penetrating diaphragmatic injuries occur predominantly following gunshot wounds as opposed to stab wounds.[11,12] This should be expected to vary regionally with differences in rates of gunshot wounds and stab wounds. For example, one South African study reported that 75% of penetrating diaphragmatic injuries followed stab wounds.[13] Blunt traumatic mechanisms produce diaphragm trauma less frequently but should raise particular concern for diaphragmatic rupture after significant blunt force transfer, including high-speed motor vehicle collisions (MVCs), auto versus pedestrian collisions, and falls from height. Motor vehicle collisions are the blunt mechanism of injury that produces diaphragmatic injuries most frequently.[11,12,14,15]

Diaphragmatic injuries, especially those that are small, are challenging to diagnose for several reasons. After penetrating trauma, these small injuries tend to be asymptomatic. Computed tomography (CT) is limited in its diagnostic ability for minor diaphragmatic injuries due to the thin nature of the diaphragm and the size of CT scan slices, allowing for small defects to be missed by captured images. It should be underlined that blunt injuries to the diaphragm are much easier to diagnose on CT scan than penetrating injuries to the diaphragm, due to the larger defect size.[16,17] Blunt diaphragmatic injuries also tend to be symptomatic, with patients noting vague but potentially severe pain, which may be felt in the abdomen, chest, or referred to the shoulder. Nonetheless, diagnosis of acute traumatic injury to the diaphragm can be challenging and the need for major trauma society recommendations exists.

A step-by-step approach to the diagnosis and management of acute traumatic diaphragmatic injury is presented here as a clinical decisions algorithm supported by the Western Trauma Association (WTA). Stratifications are made for patient stability, blunt versus penetrating mechanism of injury, and laterality of injury. The algorithm is intended for use in patients with acute full-thickness diaphragmatic injuries, that is, the American Association for the Surgery of Trauma (AAST) Grade II–V diaphragmatic trauma.[18] Patients with diaphragmatic contusions (AAST Grade I injuries) are unlikely to be diagnosed or necessitate intervention.

Western Trauma Association algorithms are drafted by the WTA Algorithms Committee. They are rooted in available data and, especially where data are unavailable or scarce, expert opinion. The process involves extensive revisions by committee members and, ultimately, presentation at the annual WTA meeting for commentary and suggestions by WTA members not on the Algorithms Committee and meeting attendees. The algorithm (Fig. 1) contains letters corresponding to lettered segments within this article. Clinical decisions algorithms should be viewed as suggestions to be complemented by clinical judgment and patient, institutional, or surgeon factors when necessary.

ALGORITHM

A. Initial Screening and Assessment

Trauma patients are evaluated and managed using the standard approach delineated by the American College of Surgeons Advanced Trauma Life Support principles.[19] Primary and

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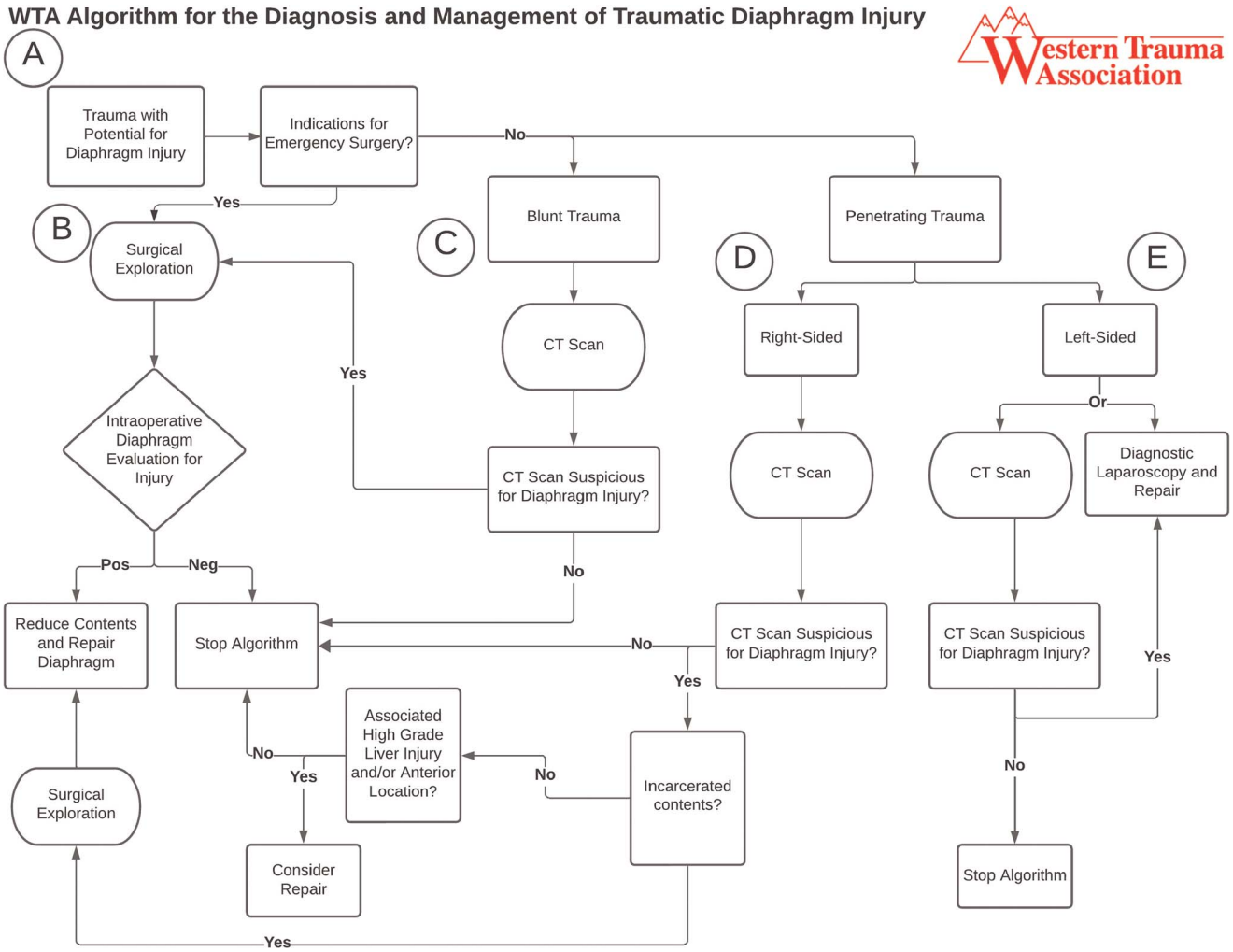

Figure 1. WTA algorithm for the diagnosis and management of traumatic diaphragm injury. Circled letters correspond to lettered article sections.

secondary surveys, as well as mechanism and anatomic location of injury, will provide the screening information necessary for the trauma surgeon or emergency medicine physician to inform concerns for potential acute diaphragmatic trauma based on the mechanism of injury, wounding trajectory, and patient presentation, as described above. Once an at-risk patient is identified, the resultant algorithm is stratified first by the patient's stability, next by blunt versus penetrating mechanism of injury, and lastly by laterality (right- vs. left-sided) for penetrating trauma.

B. Diagnosis and Management of Diaphragmatic Injury in Patients With Indications for Emergency Surgery

As with any trauma patient, hemodynamically unstable patients or those with peritonitis should proceed directly for surgical exploration. It cannot be overemphasized that unstable trauma patients do not belong in the CT scanner. As part of the rapid initial assessment, a chest X-ray is typically indicated. A chest X-ray may show evidence of diaphragmatic rupture, particularly after blunt trauma, with signs ranging from hemidiaphragm elevation to the presence of air-fluid levels within the ipsilateral chest cavity. A normal chest X-ray, however, does not exclude the possibility of a diaphragmatic injury. Penetrating trauma patients with diaphragmatic injury confirmed on CT scan or intraoperatively can be expected to have a normal chest X-ray in up to 60% of cases.[1,20–22] Therefore, intraoperative inspection of the diaphragm for injury is a standard component of every trauma laparotomy.

Surgical exploration is performed next. Direct intraoperative visualization of the diaphragm will permit diaphragmatic injury diagnosis and management. Because the diaphragm can be inspected and repaired from either the chest or abdomen, the surgeon should proceed with diaphragm assessment from within the cavity containing the suspected hemorrhage or other severe injury. For blunt trauma patients, this is typically accomplished through the abdomen. Trauma laparotomy should proceed in the standard fashion, with control of hemorrhage and gastrointestinal tract injury taking precedence over diaphragm repair. For penetrating trauma patients, intraoperative inspection for and repair of diaphragm injuries can occur through the abdomen or chest, depending on the operative cavity.

Technical considerations for diaphragmatic injury repair include reduction of any herniated contents back into their native

cavity and careful inspection of these contents for injury before proceeding. The hemithorax of the diaphragmatic injury should be thoroughly irrigated through the diaphragmatic defect before proceeding with repair if enteric contamination is a concern or if there is an associated hemothorax.

Although blunt diaphragmatic injury tends to be much larger and more irregular than penetrating diaphragmatic injury, the principles of repair are similar. Long Allis clamp placement on the defect edges helps deliver the injured tissue into the surgical field and facilitates repair. Once the edges are aligned, a non-absorbable suture[20] on a long needle driver is used to repair the defect. Running versus interrupted sutures and a 1- versus 2-layer repair are left to the surgeon's discretion. Two-layer repairs are not always feasible. Large blunt diaphragm injuries typically tear radially from the esophageal hiatus. Care needs to be taken in repairing such injuries, particularly at the medial aspect around critical structures including the heart, esophagus, and aorta. For this reason, some surgeons find that a medial to lateral approach to repair is best. In posterior blunt diaphragm injuries, there may be little tissue posteriorly to complete the repair. In such cases, the diaphragm may be sutured to the chest wall musculature.[23] In unusual circumstances of large blunt injuries with significant diaphragmatic muscle destruction or avulsion from the chest wall, bridging mesh placement[24] or reapproximation of the diaphragm to the chest wall a few intercostal spaces above the injury may be necessary.

C. Diagnosis and Management of Diaphragmatic Injury in Blunt Trauma Patients Without Indications for Emergency Surgery

The mainstay of the diagnosis of diaphragmatic injury among patients who do not have indications for immediate operative intervention is cross-sectional imaging with CT scanning and intravenous contrast, as would typically be pursued for an acute trauma patient. Intravenous contrast assists in diaphragm assessment as it allows for better delineation of structures from surrounding tissue, rendering abnormalities more conspicuous.[22] Intravenous contrast is especially useful to aid in diagnosis of right-sided diaphragmatic injuries as the liver is similar in attenuation to the diaphragm itself.[25]

Computed tomography scan is most clearly positive for diaphragmatic injury when herniated contents are visualized through such an injury, when the diaphragmatic musculature can be seen to be discontinuous, or when it is implied as a result of a single penetrating trajectory with injuries in both the chest and abdomen. However, there are multiple more subtle signs of injury, including diaphragm hypoattenuation, thickening, or surrounding inflammation. Various signs of diaphragmatic injury have also been described, including the dangling diaphragm and the dependent diaphragmatic signs, and are delineated in detail elsewhere.[20,26–28]

The algorithm diverges by blunt versus penetrating mechanism of injury at this stage due to the differing sensitivities of CT scan in the assessment for diaphragm trauma. After either mechanism, a CT scan has a specificity for diaphragmatic injuries that approaches 100%.[29] The sensitivity of CT scan as a screening investigation for diaphragmatic injury after penetrating trauma is approximately 40%, even with contemporary 256-slice scanners.[29] This may be related to the small size (2–3 cm) of penetrating diaphragmatic injuries,[21] rendering acute herniation of intra-abdominal contents through the defect (a factor that facilitates diagnosis) less likely. In a recent study of 126 patients with confirmed diaphragmatic injuries after penetrating trauma, only 44% had these injuries demonstrated on CT scan.[21] According to a similarly timed metanalysis on blunt diaphragmatic injuries, the sensitivity of CT scan approaches 80%.[30] Secondary signs of diaphragmatic injury, such as stranding or adjacent hematoma, may be present, although their absence does not exclude the possibility of injury. Because of the subtlety of diaphragmatic injuries on CT, it can be helpful to ensure that the diaphragm is closely inspected on all CT views (axial, coronal, and particularly sagittal) by both the radiologist and the trauma surgeon. A diaphragmatic injury missed on initial CT interpretation may subsequently be identified with careful and deliberate attention.

If CT scan reveals a diaphragmatic injury after blunt trauma, the patient should proceed immediately to trauma laparotomy. Diaphragm rupture can be considered a marker of force transfer, reflective of high energy impacts.[31–33] Consequently, and regardless of laterality, reduction of any herniated viscera and direct inspection of intraabdominal contents for potential injury should occur. In other words, even in the absence of other indications on CT scan for an emergent operation, the presence of a diaphragm rupture on either the right or left side should prompt immediate laparotomy. Unlike the repair of chronic diaphragmatic hernias, acute traumatic diaphragmatic hernias are most easily reduced back into their normal anatomic confines through the abdomen. This approach also allows for careful inspection of any herniated contents for ischemia or direct injury, as well as assessment of the abdominopelvic viscera for associated injuries that may have been occult on CT scan. Surgeons with advanced laparoscopic skills may accomplish these steps with a minimally invasive approach in the stable blunt trauma patient.

Because blunt diaphragmatic injuries tend to be large, blunt trauma patients without evidence of diaphragm trauma on CT scan need no further screening to exclude a diaphragmatic injury. However, it is possible that small blunt diaphragmatic injuries, for example from direct laceration related to adjacent rib fractures, are missed with this approach. Preliminary data among blunt trauma patients undergoing surgical rib fixation found that 16% to 20% of patients had diaphragm injuries that were missed by CT scan.[34,35] The clinical relevance of missing these small blunt injuries is unknown, as some small injuries are known to heal spontaneously.[4–6] This is an area in need of further investigation and is discussed below as an area of controversy.

D. Diagnosis and Management of Diaphragmatic Injury in Penetrating Trauma Patients Without Indications for Emergency Surgery: Right-Sided Wounds

Investigations and interventions for penetrating diaphragm injuries are predicated on the laterality of the penetrating thoracoabdominal trauma. The right diaphragm is largely shielded from contact with intra-abdominal viscera by the liver, which is relatively fixed in position. The risk of abdominal organ herniation through a defect caused by a penetrating mechanism in the right diaphragm is consequently much lower than that through an injury in the exposed left diaphragm.

The management of penetrating injuries to the right diaphragm is controversial, due in large part to the paucity of data

TABLE 1. Controversies in Acute Traumatic Diaphragm Injury Diagnosis and Management

Controversy	Corresponding Algorithm Section
Potential need for and optimal method of screening for small blunt diaphragm injuries	C
Screening and management of penetrating right-sided diaphragm injuries	D
Potential role for ultrasound in screening for diaphragmatic injury	—

to guide the management decisions for these patients as well as a lack of expert consensus. Indeed, a practice management guideline by the Eastern Association for the Surgery of Trauma highlights the particularly limited literature to guide the optimal management of the diaphragm in hemodynamically normal patients with penetrating right-sided thoracoabdominal trauma.[11] Ultimately, that organization recommends no intervention for the diaphragm in such patients, but again underlines the low quality of evidence available on this subject. In terms of available data, there is no literature to support the need for repair of right-sided penetrating diaphragmatic injuries, even if one is suggested or visualized on CT scan since the liver protects against herniation through a right-sided defect.

Application of surgical principles and common sense suggest that if herniated contents are visualized through such an injury on CT scan, that patient should undergo surgical exploration, reduction of herniated contents, inspection of contents for direct or ischemic injury, and repair of the diaphragmatic defect.

Similarly, repair of right-sided penetrating diaphragmatic injuries may be considered if the injury is anterior or lateral and thus unprotected by the liver. These injuries may be analogous to left-sided injuries, which typically necessitate repair (Section E). There may also be a role for delayed repair of a right-sided penetrating diaphragmatic injury in the context of an associated high-grade liver injury to preempt the development of a biliopleural fistula should a bile leak develop from the injured liver.[36,37] It should be emphasized that this does not suggest that a nonoperative liver injury should be managed with immediate trauma laparotomy for the sole purpose of exposing and repairing the diaphragm. In stable patients with a right-sided penetrating diaphragmatic injury and high-grade liver injury, delayed laparoscopic, thoracoscopic, or robotic diaphragm repair may be helpful if pursued once concerns for hepatic bleeding are resolved. A reactive, as opposed to preemptive, approach to diaphragmatic injury closure among these patients may also be appropriate, reserving intervention for the right diaphragm for only those patients who develop a bilothorax as evidenced by bile visualized within the chest tube. The optimal approach to such patients requires further study.

Although small injuries to the diaphragm will be missed on CT scans, penetrating trauma patients with right-sided thoracoabdominal wounds who lack CT evidence of diaphragmatic injury do not necessitate further screening for diaphragmatic injury.

E. Diagnosis and Management of Diaphragmatic Injury in Penetrating Trauma Patients Without Indications for Emergency Surgery: Left-Sided Wounds

Due to the anatomic vulnerability of the left diaphragm, patients with left-sided thoracoabdominal wounds are generally assessed for diaphragmatic injuries. Penetrating left-sided diaphragmatic injuries typically undergo repair at the index admission to prevent herniation and resultant ischemia or obstruction of abdominal contents through the diaphragmatic injury over time. After initial assessment in the trauma bay, patients with left-sided penetrating trauma who have no indications for emergent surgery may proceed either to CT scan or directly for diagnostic laparoscopy.

As discussed previously, CT scan is a useful but inconclusive screening investigation in this population. Most importantly, CT scan cannot exclude a diaphragmatic injury due to its low sensitivity for detection of these injuries. If CT scan demonstrates an extracavitary wounding trajectory or a trajectory that is clearly away from the diaphragm, the CT scan is not suspicious for injury to the diaphragm and the evaluation for potential diaphragmatic injury is therefore complete. Otherwise, the CT scan should be followed up with a delayed diagnostic laparoscopy to assess and repair the diaphragm after a hollow viscus injury has been excluded clinically via a period of close observation, although there is a lack of consensus regarding this approach. Based on the selective nonoperative management literature among patients with penetrating abdominal trauma, this delayed diagnostic laparoscopy should take place 24 hours after the initial trauma as this is the length of time required to clinically exclude a hollow viscus injury.[38–40] Laparoscopy is preferred over laparotomy for this purpose for its minimally invasive nature, the associated reduction in hospital and intensive care unit lengths of stay,[41,42] and mitigation of downstream consequences of laparotomy, including ventral hernias and adhesive small bowel obstructions. Robotic repair may be similarly beneficial, although this has not yet been studied for this purpose beyond case reports.[43] Any form of surgical intervention should be carefully considered in terms of risks and benefits to the patient. Although laparoscopy is minimally invasive, it remains a surgical procedure that should not be undertaken needlessly.

Alternatively, stable patients with penetrating left-sided thoracoabdominal trauma may be taken immediately for diagnostic laparoscopy and repair of any identified injuries without CT scanning.[44] It should be emphasized that if immediate laparoscopy is pursued, the surgeon must have the laparoscopic skills to exclude bowel injury intraoperatively with a minimally invasive approach. The immediate laparoscopy pathway eliminates the cross-sectional imaging step but will incur more nontherapeutic operations as the CT pathway will eliminate the need for laparoscopy in patients with trajectories that are extracavitary and those that are remote from the diaphragm. The immediate laparoscopy pathway also raises the possibility for missed hollow viscus injuries, and therefore careful consideration of surgeon skillset must be made when selecting an approach.

OTHER AREAS OF CONTROVERSY

There are several areas of ongoing controversy in the diagnosis and management of acute traumatic injury to the diaphragm, which are described in the above sections of the Algorithm and summarized in Table 1. Three are worthy of further highlighting here. The most notable relates to the need for screening and repair of diaphragmatic injuries following penetrating trauma to the right thoracoabdomen, which is the most controversial and least data-driven aspect of this algorithm. There are no data on which of these patients, if any, should be treated as left-sided thoracoabdominal penetrating trauma patients. Specifically, the need for repair of known injuries diagnosed on CT scans is unclear; the impact of associated liver injuries is unknown; the effect of anatomic location of injury on the need for repair is obscure; and as a consequence, the indications for screening or repair in this population is controversial. At present, clinical experience, surgical principles, and expert opinion form the basis for the recommendations among this patient subset. It should be underlined that there were differing opinions among the committee and membership, with some advocating for repair of all or none of the penetrating right-sided diaphragmatic injuries diagnosed on CT scan.

Next, it is possible that small blunt diaphragmatic injuries are missed on CT scan, as is known to be true for penetrating trauma. These smaller injuries may result from laceration from adjacent rib fractures. Two studies of blunt trauma patients undergoing surgical rib fixation lend weight to this theory. In these studies, the diaphragm was routinely inspected intraoperatively during rib fracture stabilization. These authors found the rate of diaphragm injury missed on CT scan to be 16% to 20% in this subpopulation.[34,35] Although this percentage is substantial, it should be emphasized that the clinical implication of these findings is presently unknown. Further work is needed to elicit the patient population at risk for clinically significant small blunt diaphragmatic injuries so that an approach to screening and intervention can be established.

Last, ultrasound has been investigated to a limited extent for diaphragm assessment in the acute trauma patient. In one such study, ultrasound demonstrated sensitivity of 50% and specificity of 100% in detecting diaphragmatic injuries after penetrating trauma, using intraoperative visualization as the gold standard.[45] For a screening investigation, a sensitivity of 50% is inadequate. However, as many trauma investigations shift to the bedside and toward ultrasonography as a diagnostic test of choice, this may evolve with time, experience, and further study.

SUMMARY

Acute traumatic injuries to the diaphragm remain difficult to diagnose and manage. This is due to limitations in noninvasive diagnostic methods and a lack of definition of specific patient populations who stand to benefit from diaphragmatic injury screening and closure among those with CT-occult injuries.

In general, concern for diaphragmatic injury should arise after high-energy blunt trauma mechanisms and penetrating thoracoabdominal trauma. Patients with indications for emergent surgical exploration should undergo direct intraoperative visualization of the diaphragm, with repair of any identified injuries after reduction of any herniated contents. From there, the algorithm diverges according to blunt and penetrating trauma mechanisms due to the increased ability of CT scan to diagnose large as opposed to small injuries of the diaphragm. Patients with blunt diaphragmatic injury on CT necessitate repair and otherwise need no further screening for CT-occult diaphragmatic injury.

Penetrating trauma patients with visualized or implied injuries to the diaphragm are managed according to laterality. Left-sided thoracoabdominal injuries generally need screening prior to hospital discharge with a diagnostic laparoscopy and repair of any identified injuries. Management of right-sided injuries are controversial and lacking in data regarding which, if any, ought to be repaired.

AUTHORSHIP

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