# Evaluation and management of abdominal stab wounds: A Western Trauma Association critical decisions algorithm

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**ABSTRACT:** This is a recommended management algorithm from the Western Trauma Association addressing the management of adult patients with abdominal stab wounds. Because there is a paucity of published prospective randomized clinical trials that have generated Class I data, these recommendations are based primarily on published observational studies and expert opinion of Western Trauma Association members. The algorithm and accompanying comments represent a safe and sensible approach that can be followed at most trauma centers. We recognize that there will be patient, personnel, institutional, and situational factors that may warrant or require deviation from the recommended algorithm. We encourage institutions to use this as a guideline to develop their own local protocols. (*J Trauma Acute Care Surg.* 2018;85: 1007–1015. Copyright © 2018 Wolters Kluwer Health, Inc. All rights reserved.)

**KEY WORDS:** stab wound; penetrating trauma; abdominal; algorithm; Western Trauma Association.

This is a recommended evaluation and management algorithm from the Western Trauma Association (WTA) Algorithms Committee addressing the management of adult patients with abdominal stab wounds. Because there is a paucity of published prospective randomized clinical trials that have generated class I data, these recommendations are based primarily on published prospective and retrospective cohort studies identified via structured literature search, and expert opinion of the WTA members. The final algorithm is the result of an iterative process including an initial internal review and revision by the WTA Algorithm Committee members, and then final revisions based on input during and after presentation of the algorithm to the full WTA membership. Of note, this work builds on several important previous WTA studies regarding a simplified algorithmic approach to abdominal stab wounds, with an expanded and more detailed algorithm to help guide the managing clinician.[1,2] The algorithm (Fig. 1) and accompanying comments represent a safe and sensible approach to the evaluation of the patient with an abdominal stab wound in any location. It provides several equally acceptable management pathways that can be selected based on the details of the patient presentation and injuries, the setting and available resources and expertise, and the judgment and preference of the managing surgeon. We believe that this approach is ultimately more useful versus a more restrictive "one size fits all" algorithm, and that it better considers the wide variability in practice patterns, staffing, resources, experience, and comfort level with penetrating trauma that exist between centers. We also recognize that there will be multiple factors that may warrant or require deviation from any single recommended algorithm, and that no algorithm can completely replace expert bedside clinical judgment. We encourage institutions to use this as a general framework in the approach to these patients, and to customize and adapt the algorithm to better suit the specifics of that program or location.

The overall incidence of penetrating trauma in the civilian setting has sharply declined over recent decades. Penetrating mechanisms now account for less than 10% of all trauma evaluations at most modern trauma centers in the U.S., with only a select few urban centers continuing to see higher rates of 20–30%.[3–5] Among these penetrating trauma cases, approximately half (50%) are caused by stab wounds, with the majority being from intentional assaults.[6] Data from almost 900,000 admissions in the 2016 National Trauma Data Bank report found that stab wounds represented only 4.1% of all trauma incidents, with an associated case fatality rate of 2.2%.[7] This low incidence has resulted in a decreased experience with the evaluation and management of abdominal stab wounds among physicians and other staff at many trauma centers. Thus, standardized protocols and an algorithmic approach supported by the best available evidence and expert opinion may contribute to optimize patient management and resource use.

The Western Trauma Association has generated several previous landmark studies on the management of abdominal stab wounds that serve as a starting point for this updated algorithm.

**Figure 1.** Western Trauma Association algorithm for the evaluation and management of patients with abdominal stab wounds. Circled letters correspond to sections in the associated manuscript. [1]The "gold standard" for abdominal exploration is via laparotomy. However, diagnostic and/or therapeutic laparoscopy may be performed in select stable patients and by a highly skilled surgeon experienced in minimally invasive surgical techniques. [2]Signs of operative injury include CT scan visualization of bowel injury or secondary signs (unexplained free fluid, free air, bowel wall thickening, mesenteric injury), diaphragm injury, abdominal vascular injury, or contrast extravasation indicating ongoing bleeding. Note that some of these may also be amenable to observation, angioembolization, or endovascular techniques.

In 2009, Biffl et al. reported the results of a multicenter prospective observational study that enrolled 359 patients.[1] The details of management or any algorithm/protocol were at the discretion of each institution, but used serial clinical examinations in the majority of patients. They demonstrated the safety of close observation and operation only for hard clinical signs of injury versus more liberal use of laparotomy, and proposed a simplified algorithm for management of these patients. This simplified algorithm was then studied in a second WTA multicenter trial published in 2011 that enrolled 222 patients, and again confirmed the safety and reliability of using serial clinical exams in most patients without immediate hard indications for laparotomy.[2] Although these publications provided some of the best available evidence, it is important to note several factors that may limit their generalizability. They enrolled only patients with anterior abdominal stab wounds and thus do not provide guidance on flank or back locations. The proposed simplified algorithm was largely based on local wound exploration (LWE), which may not be applicable all types of stab wounds. Finally, the algorithm does not take into account the wide variability in staffing, resources, expertise, experience, and comfort level among surgeons and centers. Even within this relatively select group of expert surgeons and centers, there was a 49% incidence of deviations from the study protocol, suggesting either disagreement with the algorithm or that the algorithm did not adequately cover a significant percentage of patients.[2] We have attempted to address these concerns in this new and more comprehensive algorithm, which includes guidance for various stab wound locations, and provides several management pathway options that could be better tailored to the specific setting and available resources. The following lettered sections correspond to the letters identifying specific sections of the algorithm shown in Figure 1. In addition, in each section, we have provided a brief summary of any key points or areas that generated significant discussion and debate among the members of the committee.

## STAB WOUNDS ALGORITHM

### A. Initial Evaluation and Indications for Immediate Operation

The role of abdominal exploration for penetrating trauma, and particularly for stab wounds, has evolved significantly over the past 50 years. The earlier approach of liberal laparotomy for most penetrating wounds has now given way to "selective nonoperative management", with a resultant significant decrease in the incidence of negative and/or non-therapeutic laparotomy.[8–11] Similar to any other trauma evaluation, the initial evaluation of patients with abdominal stab wounds should focus on identifying those with immediately life-threatening pathologies or injuries that require prompt surgical repair. With penetrating trauma to the abdomen, this will most often include large-volume hemorrhage or hollow viscus perforation with intra-abdominal spillage. Hemodynamic instability with signs of shock (evidence of inadequate end-organ perfusion) is a clear warning sign for ongoing massive hemorrhage and should prompt immediate exploratory laparotomy along with blood product resuscitation. Although there is no consensus definition of "unstable", the majority of studies have used hypotension with systolic blood pressure less than 90 or 100 mm Hg for adult patients. We would further characterize this as age-specific hypotension with either no response to initial

resuscitation or a transient response as characterized by the Advanced Trauma Life Support course. Other immediate indications for operation include evisceration (high predictor of operative injuries)[12–14] or impalement (removal of object under operative control). The initial physical examination then should focus on eliciting signs of peritonitis, which should also prompt immediate exploration if positive. Other less common associated findings that usually should prompt immediate surgical exploration include hematemesis or gross blood in the gastric aspirate attributable to the stab wound, or gross blood per rectum. In one of the few studies examining each of these factors independently, the factors with the highest reported positive predictive values for the need for therapeutic laparotomy were development of hypotension after initial normotension (86%), shock on presentation (83%), and generalized peritonitis (81%).[15] When considered as a group or constellation of indications, these findings are 80–90% predictive of the need for therapeutic laparotomy.[1,2,9,12,15,16]

The role of additional bedside radiologic studies in the evaluation of abdominal stab wounds remains an area of controversy, and with little evidentiary support. A chest x-ray may provide additional important diagnostic information, including the presence and amount of any free intraperitoneal air as well as the presence of thoracic injury including pneumothorax or hemothorax. An immediate chest x-ray should be obtained in all upper abdominal stab wounds (between nipple line and costal margin). Although this study is otherwise optional, if performed it should be done in the upright position (either sitting or bed in reverse Trendelenburg) to maximize the ability to visualize free air under the diaphragm. Free air under the diaphragm, indicating a likely perforated hollow viscus, should usually prompt immediate surgical exploration. Areas of debate among the committee included whether abdominal free air should mandate laparotomy and the role of abdominal sonography. Consensus was reached that free air should usually prompt surgical exploration, but stable patients with a benign examination and small or questionable free air could undergo additional imaging or close observation. The committee was in full agreement regarding the importance of performing a pericardial ultrasound to assess for cardiac injury in any upper abdominal or thoracoabdominal stab wound, but felt there was no well-defined role for routine abdominal sonography. This position is also supported by the Eastern Association for the Surgery of Trauma practice management guidelines (EAST PMG) on penetrating abdominal trauma.[9] Finally, the role of diagnostic peritoneal lavage (DPL) as a modality for diagnosis of both abdominal hemorrhage and hollow viscus injury was reviewed. Although DPL has been shown to be relatively sensitive for identifying hollow viscus perforation, it has been shown to add little to the management of abdominal stab wounds using modern clinical and diagnostic algorithms.[17,18] DPL was felt to be primarily of historic interest in the modern era, with the caveat that there is likely still a role for selective DPL in austere or highly resource-constrained settings where other diagnostic modalities may not be available and close serial examinations are not practical or possible.[16,18]

### B. The Unreliable or Unexaminable Patient

Although patients with a prolonged altered mental status caused by brain or other associated injuries are less common in penetrating versus blunt trauma, there are multiple factors that

could interfere with the clinical examination such as intoxication, psychiatric illness, spinal cord injury, intubated status, etc. There is again little scientific evidence for this specific cohort, particularly as most studies evaluating selective nonoperative management excluded these patient populations. Some centers/surgeons prefer to perform routine surgical exploration in this patient population, which is certainly acceptable and preferable to a significant delay in diagnosis of a major intra-abdominal injury. However, it is important to note that the two previous WTA multicenter studies both included patients with intoxication or other complicating factors, and demonstrated that clinical judgment and selective radiologic imaging was still safe and effective.[1,2] In the present algorithm, we recommend liberal use of diagnostic studies aimed at identifying peritoneal penetration and/or operative abdominal injury. Studies that can provide direct or indirect evidence of peritoneal penetration include a positive abdominal sonography, positive LWE, computed tomography, and diagnostic laparoscopy. LWE (to evaluate the anterior rectus fascia for penetration) is also a useful bedside decision-aid, as no further evaluation or intervention is required if the LWE is clearly negative. For equivocal imaging or equivocal/positive LWE, then the decision for proceeding with operative exploration versus serial clinical assessments must be based on the degree of the impaired examination, the expected duration of impairment, and the available resources and expertise. As a general rule, patients with a Glasgow Coma Scale (GCS) score of 13–15 can be considered "examinable" and followed with serial assessments, and those with a lower GCS should be considered as unexaminable. For transient impairment in an awake patient, such as alcohol intoxication or short-duration intubation, a strategy of close serial clinical assessments appears to be safe and reliable.[1,9,19] This is also a patient population where diagnostic laparoscopy has been suggested as an alternative to laparotomy and is highly accurate for ruling out peritoneal penetration.[9] However, if peritoneal violation is identified, then the safety and accuracy of laparoscopy for identifying all significant injuries remains an area of study and debate.[20–22] Several series have reported excellent results with therapeutic laparoscopy when performed by skilled and experienced surgeons and using a systematic approach to complete abdominal exploration and injury repair.[21,23] As noted in the algorithm and footnotes (Fig. 1), "abdominal exploration" may include either an open or laparoscopic approach as determined by the managing surgeon.

## C. Assessing Injury Location and Location-Specific Management

There are several important anatomic, pathologic, and diagnostic concerns that will vary significantly based on the location of the stab wound(s). The primary grouping that has been relatively consistent in the literature divides stab wounds into anterior (anterior axillary lines laterally and from costal margins to groin crease), flank, and back.[24–26] The vast majority of the literature on stab wounds has focused on anterior abdominal wounds, with less robust data on flank and back. For the purposes of this algorithm, and consistent with much of the literature, we have grouped flank and back stab wounds together. The other critical anatomic distinction is for upper abdominal and thoracoabdominal stab wounds, as they have the potential to also injure the diaphragm and thoracic structures. For anterior

abdominal stab wounds, the options for subsequent evaluation and management are outlined in sections D, E, and F, corresponding to the three options or clinical pathways that can be followed. For stab wounds to the flank and back, the primary concern in addition to those listed above is for injury to retroperitoneal structures, including major blood vessels, solid organs, and colon/duodenum.[24,25] In addition to having the potential for major mortality or morbidity, these injuries can have much subtler (or even absent) initial symptoms or findings, and a slower progression to become clinically obvious. We recommend proceeding to the diagnostic imaging pathway with performance of high-quality abdominal/pelvic computed tomography (CT), and with particular attention to the area of the entrance wound. Although reconstruction of the stab wound tract via fine-cut CT imaging or "CT tractography" may provide valuable information and should be attempted when possible, it may be of limited use or reliability in certain wound types and should not be used as a sole criteria to rule out peritoneal penetration.[24,27] There was significant debate about the use of "triple contrast" (rectal, oral, and intravenous) versus single- or double-contrast CT scans. Triple-contrast CT scan has been reported to have sensitivity of 100%, specificity of 96% to 100%, and accuracy of 98% for identifying injuries requiring operative or angiographic intervention in several studies.[25,28,29] However, others have reported similar good results with either double contrast or with rectal contrast only.[30–32] Hauser et al. also describes assessing the CT scan for secondary findings such as the integrity of the peri-colonic fat stripe to better identify all potential retroperitoneal colonic injuries.[29] The final consensus among the committee was that the details of the type of contrast to administer should be at the discretion of the attending surgeon and radiologist, and that close attention to the wound tract and adequate imaging of the structures at risk is paramount.

For stab wounds located in the upper abdomen (between umbilicus and costal margins) or thoracoabdominal region (costal margins to nipple line), there is the potential for major injuries in either the thoracic or abdominal cavity (or both). In addition to evaluation for abdominal cavity injuries, a focused and rapid strategy should be used to rule out the potentially life-threatening thoracic problems including pneumothorax, hemothorax, and cardiac injury. Fortunately, these can all be reliably identified or excluded with a portable chest x-ray and pericardial ultrasound. In patients who may have proceeded immediately to laparotomy for signs of shock and did not have adequate thoracic imaging, or in cases where the pericardial ultrasound was equivocal, an intraoperative sub-xiphoid or trans-diaphragmatic pericardial window can be performed. Similarly, an ipsilateral chest tube may be placed if there is clinical suspicion or concern for a pneumothorax. In addition, these patients should be evaluated for a potential diaphragmatic injury (see section H), and any patient with an upper abdominal stab wound who has an associated pneumothorax or hemothorax should be considered to have a diaphragm injury and managed appropriately.

## CLINICAL PATHWAYS FOR ANTERIOR ABDOMINAL STAB WOUNDS

As noted above, this algorithm contains several acceptable options, or clinical pathways, for the management of the patient

with an anterior abdominal stab wound. The following three sections describe each of the three pathways, which can be used to better tailor the management strategy to the specific scenario. This process includes consideration of the patient status and type/nature of stab wound(s), the available local resources and expertise, and the individual provider preference and comfort level in terms of both training/experience and tolerance for the potential of a delayed diagnosis or delayed therapeutic intervention. Each of these approaches has been demonstrated to be safe, effective, and reliable, although there are differences in factors such as cost and resource use that must be considered. This approach also recognizes that a "one-size fits all" algorithm will not be applicable to select subgroups of patients or may be overly restrictive and therefore limit their use and applicability.

## D. Clinical Pathway (CP) 1—Local Wound Exploration

LWE was one of the earliest advances in the evaluation of anterior abdominal stab wounds that helped to reduce the incidence of unnecessary laparotomy.[33–35] A classic LWE involves exploration of the stab wound to determine if the anterior fascia was penetrated, although others have described attempting to determine penetration of the posterior fascia.[34,35] If fascial penetration is detected, then this was assumed to be a proxy for likely peritoneal penetration, and historically this would then prompt an exploratory laparotomy. There are two critical points to successful modern use of LWE: (1) a clearly negative LWE can rule out abdominal injury and the patient can be safely discharged home, which is the primary use of this approach; and (2) a positive LWE in an examinable patient should NOT be considered an indication for laparotomy. Rather, it should prompt either further diagnostic imaging or admission for serial clinical examinations (progress to either CP2 or CP3 on the algorithm in Fig. 1).[9,33] This is based on the reported 30–50% incidence of non-therapeutic laparotomy even with a positive LWE, and that this incidence is significantly higher among patients with a benign abdominal exam. Finally, it is important to understand that select types of patients and stab wounds are not amenable to an accurate LWE, and thus an alternative approach should be used in these patients. This includes small puncture type wounds (i.e., ice pick), long tangential stab wound tracts, significant obesity with very deep subcutaneous fat layer, and multiple stab wounds. Patient cooperation and tolerance of the procedure is also required, and this can frequently be difficult or impossible in intoxicated, combative, or otherwise non-cooperative patients.

## E. Clinical Pathway (CP) 2—Serial Clinical Examinations

Among the most important evolutions in the management of all penetrating abdominal trauma over the past several decades has been the transition from liberal exploratory laparotomy to a highly selective approach to operative intervention.[11,19,36] The foundation of selective nonoperative management is the performance of close and careful serial clinical examinations (SCEs). This includes repeated serial abdominal examinations, vital sign monitoring, and laboratory assessments that are primarily focused on identifying signs of new or ongoing hemorrhage, or the development of peritonitis from a hollow viscus perforation or other operative organ injury. SCE is appropriate for any examinable patient with an abdominal stab wound and no indication for immediate laparotomy as the primary method of management, or for patients with a positive LWE but no immediate indications for operation. SCE may also be a reasonable option for patients with a short-duration impairment of their examination (i.e., intoxicated, short intubation) who have no immediate indication for urgent operation and who can be safely followed as their intoxication or other impairment resolves.

The critical aspect to successful SCE is close monitoring with an appreciation for changes in the clinical picture that indicate bleeding or peritonitis. As noted by multiple authors, this is best performed in a well-resourced setting and when the examination can be repeated at frequent intervals and by the same practitioners.[1,8,37–39] Therefore, SCE alone may not be appropriate for centers where this cannot be reliably or safely accomplished and those practitioners or centers may opt to use more routine CT scan imaging or diagnostic laparoscopy in this patient cohort.[22,40–42] In one of the earliest studies of SCE, Mason et al. reduced their non-therapeutic laparotomy rate from 52% with routine exploration to 12% using SCE.[36] In a subsequent landmark prospective study of 651 patients, Demetriades et al. managed 47% with SCE.[19] Only 3.6% required subsequent laparotomy, with no mortality or increased length of stay, and a low overall rate of non-therapeutic laparotomy of 5%. Since this time, many additional studies have confirmed the safety and accuracy of SCE in a wide variety of settings, and with low reported failure rates of 2–10%.[2,8,39,43] This includes one small randomized trial that demonstrated the safety and superiority of SCE versus mandatory laparotomy.[44] Although SCE has been well validated, the optimal duration of observation remains an area of debate. The majority of published protocols have used a 24- to 48-hour observation period.[1,2,19,36,37,45] In one study of 650 patients specifically examining the optimal duration for SCE, all patients who required laparotomy were identified within 12 hours of admission.[46] However, other studies have demonstrated longer average time intervals between admission and the identification of the need for laparotomy, even up to 40 hours.[47,48] We recommend a minimum 24-hour period of observation for patients undergoing SCE, which is consistent with the time used in the previous WTA multicenter trials[1,2] and that recommended in the EAST PMG for penetrating abdominal trauma.[1,2]

## F. Clinical Pathway (CP) 3—Diagnostic Imaging

Patients selected for this clinical pathway should undergo CT scan that includes imaging of the lower chest, the abdomen, and the pelvis, and using high resolution (3 mm or finer slice thickness) with three-dimensional multiplanar reconstructions interpreted by an experienced trauma radiologist. Direct signs of operative injury should prompt immediate surgery, whereas secondary signs of possible operative injury should prompt either operative exploration or admission for close serial clinical examinations. A negative CT scan (no primary or secondary signs of any injury) may allow for safe discharge in completely examinable and reliable low-risk patients, versus admission for a period of observation and serial examinations. Any positive intra-abdominal finding on the CT scan related to the stab wound or potential abdominal injury, no matter how minor, should prompt admission and observation. CT has become universally available in modern trauma centers and widely used as

the preferred imaging modality to assess for intra-abdominal injuries after blunt trauma. However, the role of CT scan in penetrating abdominal trauma remains an area of controversy and debate, particularly for stab wounds. Proponents of CT scan cite its ease, speed, and accuracy for identifying most intra-abdominal injuries.[24,40,41,49,50] Opponents of CT for abdominal stab wounds cite concerns about the cost, radiation exposure, lower sensitivity for identifying hollow viscus injuries, the difficulty reconstructing a stab wound tract even with dedicated thin cuts, and the lack of benefit over routine serial clinical examinations.[19,43,51,52] Others have advocated for CT scan use only in select anatomic areas where a stab wound with peritoneal penetration may have a lower likelihood of requiring operative intervention. This would primarily apply to the right upper quadrant or right thoracoabdominal area, where many stab wounds may result in only a simple liver laceration than can essentially be managed similar to a blunt solid organ injury.[16,43,53,54]

The literature on this topic is clearly mixed, although many more recent publications conclude that CT scan is highly accurate and reliable for identifying most injuries that require any type of intervention, including penetrating diaphragm injuries (see section G). The varied interpretation of this literature and use of CT scan among different trauma surgeons and centers is highlighted by the two WTA multicenter studies. In the first study, CT scan was used as the primary decision-making tool in 50% of the stable patients without peritonitis and allowed early discharge in 21%.[1] However, there were 8 patients (out of 92 total) with initially negative CT scans that required subsequent laparotomy, and CT demonstrated lower overall sensitivity and specificity when compared with SCE. In the second study, using a common algorithm that did not include CT scan, there were protocol violations in 49% of patients, with the majority being caused by the use of CT scan and omission of LWE.[2] There is also an increasing body of literature on use of specialized CT scans including injection of contrast into the stab wound to perform "CT tractography",[24,40,55] the use of high-resolution fine cuts with multiplanar reconstructions,[56,57] and the use of intrapleural contrast to also rule out injury to the diaphragm.[58] Of particular interest are three studies that have found high sensitivity and a 100% negative predictive value for CT tractography in identifying peritoneal penetration and the need for operative intervention.[24,40,55] Based on the strength of the available CT scan literature, the EAST PMG recommends CT should be "strongly considered" in patients with penetrating abdominal trauma selected for nonoperative management. However, it is important to note that the bulk of supporting literature cited was for abdominal gunshot wounds and flank/back stab wounds.[9] Finally, Baron and colleagues performed a meta-analysis of the literature on CT scan for anterior abdominal stab wounds that included seven studies and 575 patients. They determined that CT scan provided valuable information when positive, but there was an 8.7% rate of false negatives across the studies.[54] This emphasizes the important point that a negative CT scan should not be used as the sole determinant for discharging an abdominal stab wound patient from the emergency department.

A final consensus among the committee members was that CT scan has become a commonly used diagnostic tool in the evaluation of select patients with anterior abdominal stab wounds, and has a primary role for posterior and flank stab wounds (see section C). In addition, it can provide either direct or indirect evidence of an associated traumatic diaphragm injury that would prompt surgical intervention. At the same time, it can have associated false negatives, particularly for small hollow viscus injuries and when performed shortly after the injury has occurred. In select patients, it can facilitate early discharge from the emergency department (with close interval follow-up and strict return instructions) or triage to the appropriate area for admission and observation. It may be particularly useful as an adjunct in settings where the strict criteria for frequent serial examinations performed by the attending trauma surgeon, and preferably by the same person, are difficult to meet due to staffing, work shifts, patient volume, and local experience with penetrating trauma. It is also a valuable adjunct in the patient with a compromised examination (intoxicated, brain injury, etc.) who does not otherwise have an indication for operative exploration. Finally, it is important to note that CT scan technology has rapidly evolved and improved over the past two decades. The date of publication and the generation of CT scanner that was used must be taken into consideration, and the more recent literature should be preferentially used in examining the likely accuracy and reliability for using CT-scan assessment of abdominal stab wounds. Although there has been no well-defined criteria for the minimal acceptable CT scanner generation or resolution, the committee consensus was that a 16-slice or higher CT scanner should be used.

## G. Traumatic Diaphragm Injury Evaluation

Traumatic diaphragm injury (TDI) is more likely with penetrating wounds compared with blunt trauma, and is highest among thoracoabdominal gunshot wounds and stab wounds.[59] TDI secondary to stab wounds is most commonly diagnosed on the left side, representing 75% of cases.[60] Right-sided TDI is diagnosed less frequently, with most series reporting rates of 20–30%, and is associated with lower morbidity and mortality rates.[61] This has led some to only recommend evaluation for TDI in left-sided wounds. However, the liver should not be considered as reliable protection against a diaphragm injury, and these may present years later with large and complex herniations of the liver and other organs, or may present more acutely with pleuro-biliary fistulae.[53,62] Because these injuries are typically small (over 80% being less than 2 cm) and not easily identified on x-ray or standard CT scan in the absence of herniated contents, it is critical to adequately evaluate all patients at risk of TDI.[63] CT has a reported sensitivity of 14–61% and specificity of 76–99%, particularly if a hernia is present.[56] The sensitivity and specificity improve to 77% and 98%, respectively, with the use of modern multidetector CT, but these studies include both blunt and penetrating injuries. Up to 90% sensitivity is reported with blunt TDI, but this decreases to 8–60% in penetrating TDI.[64,65]

Over the past two decades, the trauma community has recognized the high incidence of missed diaphragm injuries after penetrating thoracoabdominal trauma.[59] Some series have reported up to a 40% incidence of TDI with penetrating trauma to the left thoracoabdominal region, many of which are clinically silent.[60,65,66] A 1997 study by Murray and colleagues found an incidence of TDI of 42%, and most importantly they identified TDI on laparoscopy in 26% of patients who had no clinical signs

or symptoms.[66] Although most penetrating TDI can be diagnosed and repaired via laparoscopy, there is a role for thoracoscopy as an alternative in select patients. In one series of thoracoabdominal stab wounds, video-assisted thoracoscopic surgery (VATS) identified TDI in 40%, although all identified injuries were subsequently repaired via laparotomy.[67] Multiple other series have demonstrated that VATS can be used as an accurate diagnostic study or to both diagnose and repair TDI safely and effectively.[60,68–70] This also has the added benefit of simultaneously treating any coexisting thoracic pathology such as a persistent or retained hemothorax, and providing direct visualization for proper placement of chest tubes.[71–73] Our recommendation is for diagnostic laparoscopy as the standard modality for patients with thoracoabdominal stab wounds or upper abdominal stab wounds with suspicion for a TDI. VATS is a reliable alternative for diagnosis and simultaneous treatment of any co-existing thoracic pathology, particularly if there is a retained hemothorax present. Most TDI that are identified on laparoscopy or VATS are amenable to direct repair and do not require conversion to laparotomy or thoracotomy.

The primary controversial area of discussion was whether modern high-resolution CT scan has become accurate enough to use as a definitive study for determining the need for operative exploration for TDI. There is some more recent literature supporting this argument. A 2007 study of 803 patients found a 94% sensitivity and 96% accuracy with multidetector CT scan to identify or rule out TDI.[74] Another interesting 2014 study re-reviewed CT scans among patients with proven TDI and found that although 47% were missed on the initial read, the majority of these (92%) showed secondary signs of diaphragm injury on re-review.[64] Finally, a 2014 review of the literature and radiologic cases describes a number of more reliable secondary CT scan signs of TDI, and techniques for technical performance of the CT scan that markedly increase the sensitivity and accuracy.[57] All of these studies highlight several key points, including (1) CT reconstruction of the wound tract is critical, (2) a tract near or clearly through the diaphragm is the most important secondary sign, (3) additional signs include contiguous injuries on each side of the diaphragm and the presence of a hemothorax, and (4) thin sections with multiplanar reformatting should be performed to enhance the diagnostic yield.[56,57,64,74] However, this requires an expert radiologist who is intimately familiar with the unique issues related to CT interpretation for penetrating TDI. Consensus was reached that if this approach is selected to use as a decision-tool for ruling out TDI, close post-discharge follow-up and the performance of repeat imaging at 6–12 months should be performed to identify any missed TDI with subsequent visceral herniation.

## AUTHORSHIP

All authors meet authorship criteria for this manuscript as described below. All authors have seen and approved the final manuscript as submitted. The senior author (M.J.M.) had full access to all data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
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## DISCLOSURE

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