Review

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Ultrasound in the evaluation of penetrating thoraco-abdominal trauma: a review of the literature.

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Abstract

The use of ultrasound in the evaluation of blunt thoraco-abdominal trauma is well described. Evidence for the use of ultrasound in the evaluation of penetrating cardio-thoracic and abdominal trauma, however, is more limited and varied. Current literature demonstrates that ultrasound is an excellent screening tool for penetrating thoracic and cardiac injuries with a high sensitivity for detecting injury requiring acute intervention. For abdominal injuries, however, the sensitivity for detection of injury is low and thus the utility of ultrasound as a screening tool is limited. This review summarizes the existing literature addressing the clinical utility of ultrasound for penetrating trauma to the pericardium, thorax and abdomen.

Keywords: ultrasound, echocardiography, hemopericardium, hemothorax, hemoperitoneum,

Ultrasound for the evaluation of blunt abdominal trauma was first described by Scandinavian interventional radiologist Kristensen et al in the early 1970s [1]. Twenty years later, in the 1990s, trauma surgeon Grace Rocyzki et al were using ultrasound as the primary modality for injured patient assessment [2]. Initially, called the FAST (focused abdominal sonography for trauma) examination, as the application expanded and it was incorporated into the Advanced Trauma Life Support Course, the acronym's meaning changed to the Focused Assessment for the Sonographic examination of the Trauma patient [3]. During this period, surgeons and emergency physicians rapidly adopted this noninvasive imaging method of evaluating trauma patients at the bedside [2,4]. Since then, the role of ultrasound in blunt trauma has been well studied. Level 1 evidence exists for the FAST examination to be considered the initial diagnostic modality to exclude hemoperitoneum in these patients [5-9]. Currently, practitioners accept the accuracy rate for ultrasound as nearly equivalent to that of diagnostic peritoneal lavage (DPL) and computed tomography (CT) [10-12]. However, the evidence is less clear for the use of ultrasound in the setting of penetrating thoraco-abdominal trauma.

This review presents the current literature on the role of ultrasound in the evaluation of a patient presenting with penetrating cardiac, pleural and peritoneal injury.

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Ultrasound for penetrating cardiac injury

A 1980 study by DeGennero et al advocated immediate surgical intervention in all patients with "*potential penetrating thoracic injuries in or near the cardiac silhouette*". The authors based their recommendations upon a comparison of the clinical course of 10 trauma patients treated with observation and conservative management with 33 trauma patients who went immediately for operative intervention. Survival rates increased from 20% to 67% after the direct to the operating room policy was instituted [13]. Consequently, through the late 1980s, diagnostic sub-xiphoid pericardiotomy was performed to evaluate for a pericardial effusion following a penetrating injury to the thorax [14]. This approach was very reli-

able but resulted in many negative procedures, one study reporting a rate of 76%, and potential complications as high as 54% in another study [15,16].

Ultrasound is very sensitive for the detection of fluid in the pericardial space. With optimal images and correct interpretation, as little as 20 cc of fluid can be visualized [17]. A 1984 case report was one of the earliest publications to advocate for the use of ultrasound in penetrating trauma. A patient with a stab wound to the chest presented with a left hemothorax diagnosed on chest radiograph and was treated with tube thoracostomy. After discharge, the patient returned with repeated syncopal episodes and negative chest radiographs until a sonographic cardiac examination demonstrated hemopericardium [18]. The actual number of patients that develop late pericardial effusions is unknown [19].

A 1988 case report provided another example of the utility of cardiac ultrasound in penetrating trauma. A patient with a stab wound to the right upper chest was found to have right-sided pleural fluid on chest radiograph. After tube thoracostomy did not improve his clinical status, a cardiac ultrasound revealed a pericardial effusion and the patient was taken to the operating room [20]. The authors concluded that with a penetrating thoracic injury, ultrasound examination was able to provide a fast and efficient way to demonstrate pericardial fluid. Similar results were reported in a case of a ventral septal defect diagnosed after detection of hemopericardium on bedside ultrasound [21]. Ultrasound evaluation offered an alternative to observation versus the aggressive straight to the operating room approach.

Further research was needed to determine a clear role for ultrasound in penetrating thoracic trauma. In 1990 the first prospective study demonstrating the accuracy, sensitivity and specificity of ultrasound was published. In this study, 73 patients with penetrating thoracic trauma and stable vital signs received an ultrasound followed by a sub-xiphoid pericardial window in the operating room. Overall, ultrasound was found to have an accuracy of 96%, specificity of 97%, and sensitivity of 90% for predicting cardiac injury [14]. Importantly, the authors concluded that the selective use of sub-xiphoid pericardiotomy only in patients with a positive ultrasound could eliminate unnecessary surgical procedures.

A 1991 study from the University of California, Davis et al, yielded similar results. Thirty six hemodynamically stable patients with penetrating precordial trauma received a cardiology department ultrasound examination to determine their disposition: directly to the operating room (large effusion), Intensive Care Unit for 48 hours (small effusion) or ward bed (no effusion). There was no evidence of missed cardiac injury during hospitalization or after hospital discharge [22]. Ultimately, the authors concluded that the high negative predicative value made from ultrasound an excellent screening tool allowing prompt detection of cardiac injury in the stable patient.

In 1992, the first article was published involving a large group of emergency medicine physicians trained to perform this procedure [23]. This 10-year retrospective review of 49 patients found that point of care (POC) cardiac ultrasound not only decreased time to diagnosis and disposition to the operating room (15.5 minutes in the ultrasound group versus 42.4 minutes in the non-ultrasound group), but also improved both the survival rate (100% in the ultrasound group compared to 57% in the non-ultrasound group) and neurological outcomes. This was thought to be due to more rapid diagnosis and prompt surgical intervention. There were no false negative examinations on chart review of patient outcomes.

In 1995, a second retrospective chart review from Cook County Hospital examined 121 clinically stable patients with penetrating wounds in the proximity of the heart following an institutional policy change [24]. Patients with evidence of sonographic pericardial effusion by the cardiology fellow immediately underwent a sub-xiphoid pericardial window, while those without were admitted and observed for 24-48 hours. The overall sensitivity, specificity and accuracy of ultrasound was determined to be 96.8%, 100%, and 99.2% respectively with a positive predictive value of 100% and a negative predictive value of 98.9%. The number of sub-xiphoid windows was reduced from 105 to 15 during this period and no clinically significant injuries were missed.

Despite the overwhelmingly positive literature during this period, two articles were also published warning of concerning false negative cases. A 1993 case series emphasizes that a cardiac ultrasound without significant pericardial fluid did not necessarily rule out major injury [25]. The article presented five cases of hemodynamically stable patients with penetrating pericardial trauma, all who had major intra-pericardial injuries. The missed diagnoses were thought to be due to the operator dependent nature of ultrasound and the difficulty in obtaining cardiac views in patients with chest wounds and/or bandages.

Similarly, in a 1995 prospective study of 105 hemodynamically stable patients with penetrating thoracic trauma, Meyer et al reported that ultrasound performed by the attending surgeon had significant limitations in identifying serious cardiac injuries in patients with an associated hemothorax (initial chest radiographic evidence of fluid within the pleural cavity) [26]. When compared to sub-xiphoid exploration as the gold standard, POC ultrasound missed four significant cardiac injuries making it only 56% sensitive in these patients. Two poten-

tial reasons were cited by the authors as explanations; first, an injury that lacerates the pericardium may allow decompression of intra-pericardial fluid into the pleural cavity, decreasing the accumulation of fluid collection at the pericardial-myocardial interface. Second, the complex echoes of adjacent pleural fluid/blood may alter the interpretability of the cardiac ultrasound.

Further research in the late 1990s seemed to reaffirm the utility of POC ultrasound. A 1996 study from Emory University achieved 100% sensitivity and specificity. In this study, surgeons performed pericardial ultrasound examinations in 247 hemodynamically stable patients with penetrating truncal wounds but no immediate indication for operative intervention [27]. Patients were followed during their admission, through discharge and as outpatients in clinic, and there here were no false negative or false positive studies. Unlike Meyer's findings, which suggested that ultrasound had limited sensitivity in patients with an associated hemothorax [26], four of the ten patients in this study with cardiac tamponade also had hemothoraces, and hemopericardium was easily identified on the initial pericardial ultrasound examination.

A larger multi-center study, which included prospectively collected data from cardiac ultrasound performed by surgeons or the cardiology department of five Level 1 trauma centers, was published in 1999 [28]. Patients with positive examinations underwent surgical exploration and those with negative examinations were admitted for observation and followed for a minimum of 23 hours. Of the pooled 261 patients, there were no false negative studies and seven false positive studies, all of which examined only a single subcostal view. Six of these patients had an associated hemothorax. Overall the sensitivity of ultrasound was 100%, the specificity was 96.9% and the accuracy was 97.3% for detecting hemopericardium. Furthermore, the mean time from ultrasound to operating room was 12.1 minutes. The authors concluded the study stating they "*routinely use ultrasound initially and almost exclusively for the evaluation of patients with penetrating injuries to the precordial or transthoracic region*" and that the "*indications for a sub-xiphoid pericardial window had narrowed substantially*."

As outlined by a 2015 study, the high sensitivities achieved in prior studies may be related to the small numbers of patients with actual cardiac injuries. One hundred seventy two patients presenting with penetrating chest wounds were examined by ultrasound followed by a subxiphoid pericardial window. There were a total of eighteen false negatives: eleven had an associated hemothorax, six had pneumopericardium, while one of the patients returned with a delayed cardiac tamponade after two negative studies (overall sensitivity of 86.7%). The authors found that, if there is presence or suggestion of either hemothorax or pneumopericardium, then further diagnostic testing is required [29]. Similarly, a 2009 study, found that the numbers of false negatives were increased with concurrent lacerations of the pericardial sac secondary to sequestration of the blood into the thoracic cavity therefore preventing accumulation of a hemopericardium [30].

Both authors conclude that if none of these conditions are suspected, the patient may be safely discharged home. A 2013 report from Cook County warns against this policy, citing that it is challenging if not impossible to determine the true incidence of missed cardiac injuries through retrospective studies [31]. Without a doubt further studies are required to determine whether ultrasound is a safe and effective screen tool for penetrating cardiac injury.

Ultrasound for penetrating pleural injury

Hemothorax

Ultrasound can serve as a diagnostic tool for the detection of hemothorax in penetrating thoracic injury. It is estimated that 50-100 cc of pleural fluid can be detected on upright chest radiograph [32], while 175 cc is usually necessary for detection when the radiograph is taken with the patient supine [33]. Even smaller quantities of fluid can be detected with ultrasound, with one study estimating that as little as 20 cc of pleural fluid can be visualized [34].

In 1995, Ma et al compared emergency medicine physician-performed thoracic ultrasound for free pleural fluid in 240 trauma patients to a gold standard of chest radiograph or tube thoracostomy drainage. In the 25 patients with hemothorax (from both blunt and penetrating injuries) all were detected by ultrasound and there were no false negative examinations in the patients with penetrating trauma [10].

Several of the same authors conducted a further study in 1997 comparing emergency medicine physician-performed ultrasound to the gold standard of computed tomography, tube thoracostomy or both [35]. Ultrasound accurately detected all 18 cases of hemothorax from penetrating thoracic injury. There were no false positive findings resulting in a sensitivity and specificity of 100%.

Pneumothorax

Multiple studies have evaluated the test characteristics of ultrasound for the detection of pneumothorax in blunt thoracic trauma with sensitivities ranging from 92-100% and specificities ranging from 94-99% when compared to a gold standard of computed tomography [36-38]. Several studies have also evaluated the test char-

acteristics of ultrasound for pneumothorax in the setting of penetrating trauma. In 2001, Dulchavsky et al compared surgeon-performed thoracic ultrasound to chest radiograph findings as a gold standard. In the 83 cases of penetrating thoracic trauma, 15 patients had a radiographic pneumothorax, all of which were detected by ultrasound, for a sensitivity and specificity of 100%. It was noted that in two cases the pleural interface could not be visualized due to the presence of subcutaneous air [39]. A 2004 study by Knudtson et al also compared surgeon-performed ultrasound to findings on chest radiograph in 21 patients and reported the sensitivity, specificity, positive predictive value, negative predictive value, and accuracy for pneumothorax to all be 100% [40]. The authors concluded from their findings that ultrasound could be used as an adjunct or precursor to chest radiography in the evaluation of the trauma patient.

A 2012 study by Ku et al compared thoracic ultrasound for pneumothorax by both surgeons and emergency medicine physicians to a more robust gold standard of computed tomography, tube thoracostomy output or supine chest radiograph followed by clinical observation. In 47 patients with pneumothorax (blunt and penetrating), ultrasound had a sensitivity of 57% and a specificity of 99%. The authors contributed the poor sensitivity to the diverse and varied prior ultrasound experience of their sonographer group, recognizing that most other previous studies were performed by a small number of highly trained sonographers [41].

Evaluating thoracic ultrasound for pneumothorax due to all causes, a 2012 meta-analysis by Alrajhi et al pooled data from 8 studies (6 trauma studies [both blunt and penetrating] and 2 iatrogenic) that all used computed tomography or tube thoracostomy drainage as the gold standard. Overall, the authors reported a sensitivity of 90.9%, a specificity of 98.2%, a positive predictive value of 94.4%, and a negative predictive value of 97.0% [42]. Ultrasound had excellent test characteristics for the detection of pneumothoraces in this large population of mixed etiology.

Ultrasound for penetrating thoraco-abdominal injury

Initially, most studies in penetrating trauma focused on pericardial fluid, but later, several studies evaluated its utility in abdominal trauma as well. A study by Ma et al in 1995 prospectively evaluated the use of a rapid trauma ultrasound examination in blunt and penetrating torso trauma patients. After emergency medicine residents, fellows and faculty underwent 10 hours of didactic instruction, case review and hands-on sessions, they were able to detect pericardial fluid with a sensitivity of 100% and a specificity of 99% and detected intra-peritoneal fluid with a sensitivity of 86% and a specificity of 99% when compared to the gold standards of CT, diagnostic peritoneal lavage, radiograph, operative findings, or cardiology department echocardiography. They concluded that regardless of the performing physician's specialty, the more important details were immediate availability and a desire to learn how to perform a trauma ultrasound examination [10].

A 2001 study from the University of Maryland examined 75 consecutive stable patients with penetrating injuries to the abdomen, back and flank. Twenty two of 54 patients with a surgeon-performed negative FAST had intra-abdominal injury at laparotomy yielding an overall sensitivity of 46%. There were two false positives (a hepatic vein thought to be free fluid and pleural fluid thought to be peritoneal fluid) yielding a specificity of 94%. When compared to other modalities, the FAST examination had the highest specificity and positive predictive value whereas computerized tomography (CT) had the highest accuracy [43]. The authors concluded that a positive FAST warranted immediate surgical intervention, whereas a negative study required further diagnostic imaging.

A similarly designed prospective observational study, also in 2001, demonstrated a slightly increased sensitivity of 67% with a specificity of 98% for the use of technician-performed sonography in penetrating torso injury. Despite the high specificity for detecting pericardial or peritoneal fluid, 6 of the 53 initially negative examinations had a significant abdominal injury detected by further diagnostic testing, 5 of which required surgical repair. The authors concluded that ultrasound should be used as one component of a diagnostic algorithm and should not be the definitive test in all cases [44].

A 2004 prospective observational study from Carolinas Medical Center reported a 100% sensitivity and specificity for evaluation of traumatic pericardial effusion and intra-peritoneal fluid. Thirty-two hemodynamically stable patients with penetrating trauma were evaluated by emergency medicine physicians and trauma surgeons. Of the 16 patients whose ultrasound was initially negative, no other diagnostic imaging revealed any further injury nor did any return to the hospital within six months with a missed injury. Although the high sensitivity in detecting hemopericardium had been reproduced in prior studies, this study was the first to show 100% sensitivity and 100% specificity for detecting intra-peritoneal injury [45].

Ultrasound does not usually detect the actual solid or visceral organ injury but rather relies on the evaluation of

free fluid in potential spaces as a marker of injury. A 2004 study noted that the presence of free peritoneal fluid does not always necessitate therapeutic intervention [46,47]. Thirty-eight patients with penetrating abdominal trauma underwent FAST examination by a surgeon and the results were compared to CT, operative findings, autopsy report, and hospital course. Ultrasound had a sensitivity of 91.7% and specificity of 100% for detecting free fluid, however, the sensitivity decreased to 71.4% with a specificity of 95.8% in the detection of cases that required therapeutic intervention.

As an alternative to evaluating for free fluid, one study used a direct comparison of edema surrounding the muscle bundle and fascia at the site of the injury by surgeons and emergency medicine physicians. They demonstrated a sensitivity and negative predictive value of 100% when compared to chest radiograph/diagnostic peritoneal lavage/CT scan depending on location [48]. The specificity and positive predictive values, however, were 48.7%, in contrast to the traditional FAST examination, which typically carries a high specificity [43]. The authors concluded that a simple side-by-side comparison of injured abdominal wall layers may help to increase the sensitivity of POC ultrasound.

Discussions

Ultrasound is the initial diagnostic tool for blunt abdominal trauma. It has additionally become an important tool in the evaluation of penetrating cardiac and thoracic injury. The 2008 American College of Emergency Physicians Emergency Ultrasound Guidelines states that "[ultrasound] *applies to both blunt and penetrating trauma in all ages*" [49].

Difficulties in the performance and interpretation of cardiac ultrasound in penetrating trauma appear to be in patients with a co-existent hemothorax [26,28] air in the pericardial sac [29], and also lacerations of the pericardial sac [30]. This may be because the fluid accumulates into the thoracic cavity rather than the pericardium, or that it the hemothorax obscures the pericardium and makes differentiation of anatomical planes difficult. Some authors suggest a role for repeat ultrasonography after an initial negative examination [19]. Without a doubt, care should be taken when performing cardiac ultrasound in this patient population and further prospective trials are necessary to determine the true accuracy to detect cardiac injuries in patients with concurrent injuries [31].

The utility of ultrasound in evaluating penetrating abdominal injury is variable. Although some studies have shown to be favorable [40,46,50] the data is still lacking. Ultrasound relies on the evaluation of free fluid in potential spaces as a marker of injury, not necessarily identification of the injury itself, leading to sensitivities ranging from 46-100%, specificities from 48-100%, and negative predictive values from 60-98%. The data is further complicated by the lack of standardization of anatomical landmarks between ultrasound scan protocols across studies.

Conclusion

This article summarizes the existing literature addressing the clinical utility of ultrasound for penetrating trauma. Current literature demonstrates that ultrasound is an excellent screening tool for penetrating thoracic and cardiac injuries with a high sensitivity for detecting injury requiring acute intervention. For abdominal injuries, however, the sensitivity for detection of injury is low and thus the utility of ultrasound as a screening tool is limited.

Conflict of interest: none

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