Beyond focused assessment with sonography for trauma: ultrasound creep in the trauma resuscitation area and beyond

Kazuhide Matsushima[a] and Heidi L. Frankel[b]

[a]Division of Trauma, Acute Care and Critical Care Surgery, Department of Surgery, Penn State Milton S. Hershey Medical Center, Hershey, Pennsylvania and [b]RA Cowley Shock Trauma Center, University of Maryland School of Medicine, Baltimore, Maryland, USA

Correspondence to Kazuhide Matsushima, MD, Penn State Milton S. Hershey Medical Center, 500 University Drive, P.O. Box 850, MC H075, Hershey, PA 17036, USA
Tel: +1 717 531 6066; fax: +1 717 531 0321; e-mail: kmatsushima@hmc.psu.edu

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Purpose of review

The use of ultrasound for the management of the injured patient has expanded dramatically in the last decade. The focused assessment with sonography for trauma (FAST) has become one of the fundamental skills incorporated into the initial evaluation of the trauma patient. However, there are significant limitations of this diagnostic modality as initially described. Novel ultrasound examinations of the injured patient, although useful, must also be considered carefully.

Recent findings

Increasing evidence supports the high specificity of FAST for detecting a pericardial effusion and intra-abdominal free fluid (hemorrhage) in the patient with blunt injury. On the other hand, a so-called negative FAST result still requires further diagnostic work up given its low sensitivity. Similarly, the role of FAST in penetrating abdominal trauma appears to be limited because of lower sensitivity for visceral injury compared to other modalities. Extended FAST (EFAST), that adds a focused thoracic examination, has high accuracy for the detection of pneumothorax comparable to computed tomographic scan, the significance of which is not currently known. Finally, the utility of intensivist-performed ultrasound in the ICU is expanding to limited hemodynamic assessment and facilitation of central venous catheter placement.

Summary

The indications for FAST and additional ultrasound studies in the injured patient continue to evolve. Application of sound clinical evidence will avoid unsubstantiated indications for ultrasound to creep into our clinical practice.

Keywords

cardiac function, central venous catheter placement, extended focused assessment with sonography for trauma, focused assessment with sonography for trauma, trauma, ultrasound, volume status

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Introduction

For over a decade, there has been unbridled enthusiasm for the use of ultrasound as an adjunct imaging methodology in the care of the injured patient [1,2,3•]. Accordingly, the focused assessment with sonography for trauma (FAST) and modifications thereof are currently a key component of the standard initial trauma evaluation [4]. However, as other modalities, such as multidetector computed tomography scanning (MDCT), become faster and more accurate, the indications for FAST are being challenged [5–7]. Others have extended the goals of FAST – that is, the detection of pericardial and intraperitoneal fluid – to further investigation of thoracic injury. In addition to evaluation of the pericardial space and intraperitoneal cavity, this extended FAST (EFAST) searches for traumatic pneumothorax and hemothorax [8]. Finally, the appropriate use of ultrasound techniques in the critical care setting for the care of the injured patient will be reviewed.

Focused assessment with sonography for trauma in modern trauma work up: current indications

Ultrasound has been utilized for the evaluation of injured patients in Europe and Japan since the 1980s (Table 1 [9–15,16••]) [17,18]. The first case series description of ultrasound usage in the trauma setting in the United States was published in 1992 by Tso *et al.* [19]. Subsequently, Rozycki *et al.* [9] demonstrated the efficacy of ultrasound with a sensitivity of 81.5% and specificity of 99.7% for detecting pericardial effusion and intraperitoneal free fluid (hemorrhage) in a large prospective study. The nomenclature of FAST was first described by their group [9,20] and this acronym for ‘Focused

Assessment with Sonography for Trauma' has gained consensus at an international conference held in 1997 (the 'A' had initially represented abdominal) [2]. In FAST, one pericardial and three intraperitoneal views are to be obtained within 5 min. This quickly performed bedside ultrasound technique is used exclusively for detecting fluid collections that can be seen as low-echoic areas (black).

Focused assessment with sonography for trauma for blunt injury

Blunt trauma patients with suspected abdominal or cardiac injury by history and physical examination typically require further imaging for diagnosis. As FAST is noninvasive and can be performed readily in the trauma resuscitation area, it is the diagnostic modality of choice for hemodynamically unstable patients. In this setting, if FAST demonstrates free fluid in the peritoneal cavity (presumably hemoperitoneum), emergent exploratory laparotomy is indicated [3•]. Neal *et al.* [21•] recently demonstrated that obtaining an abdominal computed tomographic (CT) scan during the initial work up of a hemodynamically unstable patient resulted in significantly higher mortality using data from the National Trauma Data Bank. In other words, the classical teaching 'never send an unstable patient to CT' is still true despite the rapidity of the study. However, one caveat of this strategy is the relatively low sensitivity of FAST in select unstable patients. Factors associated with a false-negative FAST include retroperitoneal injuries such as pelvic fracture or renal trauma [22]. Although early data suggested nearly 100% accuracy of FAST in hypotensive blunt abdominal injured patients, the sensitivity of FAST for intraperitoneal hemorrhage was reported to be only 26% in those with pelvic fractures in a later study [10,15]. Therefore, negative FAST results in hemodynamically unstable patients do not necessarily exclude an intra-abdominal source of hemorrhage. In addition to the search for other bleeding sources for the cause of hemodynamic instability, intra-abdominal investigation needs to be continued simultaneously and can be accomplished by diagnostic peritoneal aspiration/diagnostic peritoneal lavage (DPA/DPL). We prefer aspiration over lavage, as fluid instillation may ultimately be confusing, should a CT scan be performed at a later time once the patient has stabilized.

Key points

- Focused assessment with sonography for trauma (FAST) is most accurate in the evaluation of the hemodynamically unstable blunt injured patient. A negative examination in this setting should be followed up with a complementary study, such as a diagnostic peritoneal aspiration, particularly in the setting of a pelvic fracture in which the sensitivity of FAST is lower.
- FAST should only be performed in the hemodynamically stable blunt injured patient for the purposes of teaching and triage (i.e. in a multiple patient scenario).
- Because of its low sensitivity and high specificity, FAST should not be used as a primary diagnostic modality for penetrating abdominal trauma. FAST may assist in the triage of cavities in those with multiple wounds who require intervention.
- EFAST can accurately diagnose hemothoraces and pneumothoraces. However, the significance of these (and the need for intervention) is currently unknown. Therefore, we recommend that additional imaging be obtained to determine the appropriate clinical course of action.
- Ultrasound can be used to accomplish a focused echocardiographic examination of the injured patient in the ICU to determine volume status and cardiac function.
- Ultrasound should be used to guide (particularly internal jugular) central line insertion and can eliminate the need for a postprocedural radiograph.

Conversely, the role of FAST has always been questioned in hemodynamically stable patients because of its low sensitivity and inability to provide organ-specific information [16••]. The development of MDCT, which can be more quickly and accurately performed than previously, has made a tremendous impact on the management of the injured [5–7,23,24]. Whole-body MDCT (pan-scanning) enables rapid injury identification. Huber-Wagner *et al.* [7] have demonstrated significantly

Table 1 Reported results of focused assessment with sonography for trauma (abdomen)

Author	Year	*n*	End point	Injury type	Sensitivity	Specificity	Accuracy
Rozycki *et al.* [9]	1995	295	Fluid	Blunt	78.6	100	98
		76	Fluid	Penetrating	83.8	97.4	90.7
Rozycki *et al.* [10]	1998	1227	Fluid	Blunt	78.3	99.8	98.5
Boulanger *et al.* [11]	2001	72	Fluid	Penetrating	67	98	89
Udobi *et al.* [12]	2001	75	Fluid	Penetrating	46	94	68
Soffer *et al.* [13]	2004	177	Fluid	Penetrating	48	98	85
Kirkpatrick *et al.* [14]	2004	38	Fluid	Penetrating	71.4	95.8	86.8
Friese *et al.* [15]	2007	96	Fluid	Blunt	26.1	96.3	65.6
Natarajan *et al.* [16••]	2010	2105	Injury	Blunt	43	99	94.1

FAST, focused assessment with sonography for trauma.

better outcome in those who underwent pan-scanning as their initial imaging evaluation in their multicenter retrospective study. They showed that the usage of whole-body CT including an unenhanced head CT and contrast-enhanced chest, abdomen and pelvis CT with full spine imaging is shown to be a significant factor for patient survival after blunt injury. It had been suggested that FAST potentially could be a useful screening tool for blunt injured patients to reduce the use of CT scanning [4,25,26]. However, in addition to its low sensitivity for detection of free fluid in the hemodynamically stable patient, the inability to acquire organ-specific injury in the absence of hemoperitoneum that occurs in up to one-third of patients is problematic [27]. In hemodynamically stable patients, the sensitivity of FAST performed by residents under attending trauma surgeon supervision was 40.8%, compared to 57% in unstable patients. Furthermore, among 87 stable patients with a false-negative FAST, 19 patients (22%) required an exploratory laparotomy after positive CT scan [16••]. It is not surprising that an increasing number of stable trauma patients undergo CT scanning as the initial diagnostic imaging study [28].

Focused assessment with sonography for trauma for penetrating injury

Early studies suggested comparable results for FAST in penetrating as compared to blunt injury (sensitivity 83.8 vs. 78.6%, specificity 97.4 vs. 100%) [9,29]. Yet, even this work included patients with false-negative FAST examinations, with missed diaphragmatic and hollow visceral injury necessitating laparotomy. As these injuries are fairly common in penetrating trauma victims and can be life-threatening, the indication and utility of FAST in penetrating trauma has been questioned [11–14, 30•,31]. Although hemodynamically unstable patients with penetrating abdominal injury require laparotomy, various diagnostic modalities such as local wound exploration or DPL have been tried to reduce the rate of nontherapeutic laparotomy in stable patients [32,33]. Boulanger *et al.* [11] performed FAST in 66 stable penetrating injured patients and demonstrated a sensitivity, specificity and accuracy of 67, 98 and 89%, respectively. Likewise, Udobi *et al.* [12] concluded that a positive FAST in the face of penetrating trauma strongly predicted significant intra-abdominal injury; however, negative FAST required additional diagnostic testing based on low sensitivity (46%). Subsequently, Soffer *et al.* [13] questioned whether the findings of FAST changed initial management of penetrating torso injury patient in their prospective study. Of 177 patients, only three patients' management was effectively changed by positive ultrasound findings. They confirmed the low sensitivity (48%) of FAST, and noted a significant number of missed hollow viscus and diaphragm injuries (up to 67%). Finally, in a recent multicenter trial conducted by the Western Trauma Association, FAST was used as the primary management decision tool in only 4% of cases for the initial work up of anterior abdominal stab wounds [33]. It is noteworthy that the sensitivity of FAST for therapeutic laparotomy, not intra-abdominal-free fluid, was as low as 21%. It is also remarkable that 28% of patients with an abnormal FAST had a nontherapeutic laparotomy or did not require laparotomy. Ultrasound can be also used for detecting fascial violation in the abdominal stab wound patient [34,35]. However, a negative study should not preclude the further imaging work up due to its low sensitivity, 59%.

On the other hand, for the patient with suspicion for a penetrating cardiac injury, a single institution and a prospective multicenter study both showed consistently high accuracy of FAST (100 and 97.3%, respectively) [36,37].

Extended focused assessment with sonography for trauma

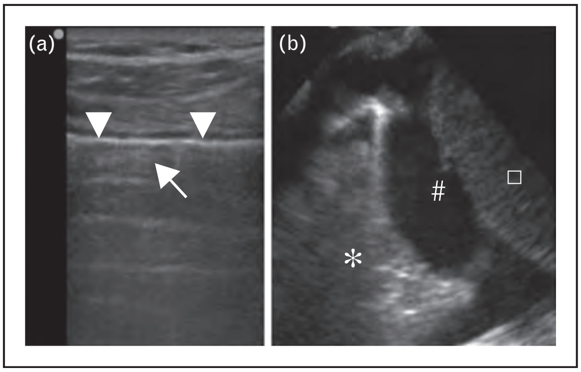
Pneumothorax and hemothorax are reportedly found in more than half of all trauma patients with thoracic injury (Table 2 [8,38,39,40••]) [41,42]. It is often difficult to appreciate the classic clinical findings of hemothorax, pneumothorax (decreased breath sounds, hyper-resonance or dullness in percussion, or associated subcutaneous emphysema) in the middle of a chaotic trauma resuscitation environment [43]. Not surprisingly, a chest radiograph taken with a patient in the supine position does not have favorable sensitivity for either hemothorax or pneuomothorax [8,39,40••,44•]. The incidence of the clinical entity of the occult pneumothorax that is not visualized on plain chest radiography but detected on CT scanning is reported to be approximately 5% of all trauma patients [45]. Further, Ball *et al.* [46] demonstrated that 55% of pneumothoraces were occult among patients with Injury Severity Score (ISS) at least 12.

Table 2 Reported results of extended focused assessment with sonography for trauma (pneumothorax)

Author	Year	*n*	Type of injury	Sensitivity	Specificity	Accuracy
Dulchavsky *et al.* [38]	2001	382	Blunt/penetrating	95	100	99
Kirkpatrick *et al.* [8]	2004	208	Blunt/penetrating	58.9	99.2	93.7
Soldati *et al.* [39]	2008	109	Blunt	92	99.4	98.6
Nandipati *et al.* [40••]	2010	204	Blunt/penetrating	95	99	99

EFAST, extended FAST.

Figure 1 Extended focused assessment with sonography for trauma findings



(a) Normal lung ultrasound. Comet tail sign (arrow) and lung sliding between hyperechoic parietal and visceral pleura (arrow head) can be observed. (b) Hemothorax/pleural effusion. Hypoechoic area (#) can be identified between lung parenchyma (∗) and liver (□). EFAST, Extended focused assessment with sonography for trauma.

In addition to FAST, thoracic imaging using ultrasound has been incorporated into the initial trauma evaluation at many institutions (Fig. 1). This thoracoabdominal sonographic evaluation is named the extended FAST (EFAST) [8]. More than 10 years after the first report of ultrasound usage for the diagnosis of pneumothorax in animals, Dulchavsky *et al.* [38] investigated the efficacy of lung ultrasound in human trauma cases [47]. Compared to chest radiography, the sensitivity of ultrasound was 95%. Kirkpatrick *et al.* [8] compared lung ultrasound with chest radiography utilizing CT findings as the gold standard. The sensitivity of lung ultrasound was superior to chest radiography (48.8 vs. 20.9%). Interestingly, Soldati *et al.* [39] have shown not only higher sensitivity of lung ultrasound for pneumothorax detection compared to chest radiography (92 vs. 52%), but also the ability to detect the extent of the pneumothorax by describing the location of the lung point – the border between normal lung parenchyma and the pneumothorax. There is long-term controversy whether an occult pneumothorax can be safely observed without thoracostomy tube placement [45,48•]. In a multivariate logistic regression model, only progression of pneumothorax in repeat chest radiograph and respiratory distress were significant risk factors [49••]. How EFAST will affect management of these occult pneumothoraces is unknown.

The use of ultrasound to diagnose an acute hemothorax was first described in 1993 [50]. Subsequent studies uniformly showed a high sensitivity and specificity for the detection of traumatic hemothorax [51–54]. A supine chest radiograph requires a minimum of 175 ml of fluid in chest cavity for diagnosis of a hemothorax as opposed to 20 ml by ultrasound [53]. The sensitivity of ultrasound for hemothorax detection was 97.5% and specificity was 99.7%, compared to 92.5 and 99.7%, respectively, for chest radiography in the study by Sisley *et al.* [51].

Table 3 Hemodynamic assessment of trauma/surgical intensive care unit patients with ultrasound

Author	Year	*n*	End point
Yanagawa *et al.* [55]	2005	35	Preload
Sefidbakht *et al.* [56]	2007	88	Preload
Yanagawa *et al.* [57]	2007	30	Preload
Carr *et al.* [58]	2007	70	Preload
Gunst *et al.* [59]	2008	85	Preload/cardiac function
Stawicki *et al.* [60]	2009	83	Preload
Ferrada *et al.* [61••]	2011	53	Preload/cardiac function

Ultrasound for the evaluation of hemodynamic status

Although bedside physical examination and basic vital signs are still crucial to evaluate the hemodynamic status of critically ill trauma patients who require resuscitation after the Emergency Department or operation, those are frequently unreliable for decision making in the ICU (Table 3 [55–60,61••]) [62]. As the use of the pulmonary artery catheter (PAC) for critically ill patients has failed to show improved outcomes in most randomized studies, alternate methods of assessing volume status and cardiac function have been described without reaching any clear conclusions [63–65,66•,67–69,70•].

Bedside echocardiography is a novel tool to be considered by intensivists in the evaluation of injured patients [71–73]. Most work is focused on the assessment of preload volume status and cardiac function including cardiac output [58–60,61••].

The diameter of inferior vena cava (IVC) on CT scan and ultrasound has been shown to be inversely associated with intravascular volume depletion in trauma cases [55–57,74]. Carr *et al.* [58] conducted a pilot study in the surgical ICU at a Level 1 trauma center to evaluate the efficacy of intensivist bedside ultrasound (INBU) for preload volume assessment. Of 89% cases in which IVC was successfully visualized, smaller IVC diameter (<1 cm) and higher IVC collapse index (IVC-CI), calculated by [max IVC diameter] – [minimum IVC diameter]/[maximum IVC diameter], greater than 50% correlated with clinical judgment in 67 and 65%, respectively. These correlations were not significantly different from that of invasive central venous pressure (CVP) monitoring.

Recent literature supports the notion that the evaluation of cardiac function can be performed accurately by intensivists with portable echocardiography [71–73]. The methods of cardiac function evaluation varied from subjective judgment to acquisition of objective values such as ejection fraction or stroke volume. The utility of

Table 4 Summary of the Bedside Echocardiographic Assessment in Trauma/Critical Care examination

	View	Task	Goal
Beat	Parasternal long	Stroke volume	Cardiac function
Effusion	Parasternal long	Subjective assessment	Pericardial effusion
Area	Parasternal short, apical four chamber	Subjective assessment	Right and left ventricular size, movement
Tank	Subcostal	IVC measurement	Volume status

IVC, inferior vena cava.

noncardiologist performed echocardiography of injured patients has been demonstrated at Level 1 trauma centers where resident or fellow trainees are usually involved in the management [59,61••]. Gunst *et al.* [59] showed significant correlation between echocardiographic data and PAC data in cardiac function and volume status assessment (Table 4). Ferrada *et al.* [61••] also demonstrated the encouraging result that an estimated ejection fraction could be obtained in 80% of patients. More importantly, the information from echocardiography answered the clinical question appropriately in 87% of cases and the management plan was changed based on the findings in more than half of cases. Of course, whether echocardiography-driven resuscitation will improve any measurable outcome in injured patients and, thus prove superior to PAC monitoring, remains to be seen.

Central line placement and detection of complications

Ultrasound guidance is considered standard of care for central venous catheter (CVC) placement especially when the internal jugular vein is approached [75,76]. Compared with the classical landmark technique, ultrasound-guidance results in a significantly higher success and lower complication rate [77,78]. CVCs are frequently required in critically ill trauma patients for the multiple reasons from massive transfusion to administration of vasoactive agents.

Even with standardized real-time ultrasound guidance, mechanical complications related to cannulation or catheter tip malposition are possible and could lead to serious sequelae [79]. Currently, chest radiograph is considered the gold standard as a postprocedure confirmatory image. Unfortunately, in a busy ICU, the delay in obtaining a chest radiograph and interpretation of the study can be considerable. Further, chest radiography may not be sufficiently sensitive to rule out complications effectively [80]. A novel technique that incorporates thoracic, vascular and cardiac ultrasound can be used to substitute for a chest radiograph as a confirmatory image [81••,82••,83]. This technique incorporates identification of a pneumothorax and hemothorax using the thoracic ultrasound performed in EFAST. Next, the catheter tip is localized using ultrasound windows from the bedside echocardiographic examination. In a series of surgical ICU patients with 83 catheter placements, our group demonstrated that this novel ultrasound technique, 'CVC sono', had a success rate of 71% [81••] (Table 5). Although no thoracic complications were identified in our series, the total accuracy of CVC sono was 90% with a significantly shorter examination time, from order to completion of interpretation compared to portable chest radiography (10.8 vs. 75.3 min, $P < 0.001$). Vezzani *et al.* [82••] used a similar technique in a mixed ICU with a similarly short study time. Their success rate for detecting the catheter tip in the right atrium was favorable with the use of a contrast enhanced technique [84]. Two pneumothoraces detected by chest radiograph were also identified with ultrasound. How these will be used in the wider injured patient population remains to be determined.

Conclusion

The indications for FAST should differ by injury type and hemodynamic stability for maximally efficient patient care, cognizant that alternate modalities are generally more sensitive, although potentially less safe. Although it is known that the sensitivity of EFAST is higher than chest radiography for diagnosis of

Table 5 Summary of CVC sono examination

Component of CVC sono	Complication to exclude	View
Mechanical complication screen	Pneumothorax/hemothorax	Anterior/lateral thoracic
Intravenous tip screen	Catheter malposition	Lateral neck: IJV Supraclavicular: INV Subcostal: IVC
Intracardiac tip screen	Catheter malposition	Parasternal short Apex four chamber Subcostal

IJV, internal jugular vein; INV, innominate vein; IVC, inferior vena cava.

hemopneumothoraces, further prospective study will be required to determine the value of this additional information. Finally, ultrasound will likely be utilized more extensively to assist in the resuscitation of trauma patients after operative intervention and insertion of invasive lines in the ICU.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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Papers of particular interest, published within the annual period of review, have been highlighted as:
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