Clinician-performed focused sonography for the resuscitation of trauma

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Traumatic death remains pandemic. The majority of preventable deaths occur early and are due to injuries or physiologic derangements in the airway, thoracoabdominal cavities, or brain. Ultrasound is a noninvasive and portable imaging modality that spans a spectrum between the physical examination and diagnostic imaging. It allows trained examiners to immediately confirm important syndromes and answer clinical questions. Newer technologies greatly increase the fidelity, accessibility, ease of use, and informatic manipulation of the results. The early bedside use of focused ultrasound as the initial imaging modality used to detect hemoperitoneum and hemopericardium in the resuscitation of the injured patient has become an accepted standard of care. Widespread dissemination of basic ultrasound skills and technology to facilitate this brings ultrasound to many resuscitative and critical care areas. Although not as widely appreciated, the focused use of ultrasound may also have a role in detecting hemothoraces and pneumothoraces, guiding airway management, and detecting increased intracranial pressure. Intensivists generally utilize a treating philosophy that requires the real-time integration of many divergent sources of information regarding their patients’ anatomy and physiology. They are therefore positioned to take advantage of focused resuscitative ultrasound, which offers immediate diagnostic information in the early care of the critically injured. (Crit Care Med 2007; 35[Suppl.]:S162–S172)

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As evidenced by the contents of this supplement, ultrasound (US) is being used as an all-purpose diagnostic and therapeutic tool in the critically ill. There are many complementary medical imaging modalities available today that allow precise and detailed imaging of the human body. Computed tomography (CT), magnetic resonance, and angiography are options, but none are as accessible, safe, and repeatable as US. US can precisely delineate cardiac function, examine blood flow to the brain, direct percutaneous aspiration and cannulation, and detect venous thromboses, among a myriad of other utilities, when used by experts. In the early minutes to hours after severe injury, however, US can particularly assist the clinician by combining the physical examination with a focused goal-directed test that can immediately confirm life-threatening diagnoses. Although focused US is typically interpreted in real-time analog format, it represents anatomy and physiology captured in a digital format. US is also typically the first imaging that can be brought to the critically injured, often in remote or hostile settings (1, 2).

Epidemic Injury: A Continuing Epidemic

Despite progress, trauma remains the leading cause of death among people 15–44 yrs of age (3). Trauma is also a leading cause of death in low and middle income countries, constituting 16% of the world’s burden of disease (4). Although the concept of the “golden hour” is now >20 yrs old, the majority of preventable trauma deaths still occur early in hospitalization (5), constituting up to 48% of trauma deaths even in the Western world (6). These fatalities are time-dependent (7) and involve management of the airway (7), thoracic injuries (6, 7), and control of shock and hemorrhage (6, 8). Deaths from traumatic brain injuries (TBI) are more frequent (42%) than hemorrhage (39%) (9), but primary therapies for TBI remain limited at this time (10). Recognizing these areas are a critical focus for clinicians, this article will specifically examine the role of focused clinical US in the initial assessment and resuscitation of the injured.

Origins of the Focused Assessment with Sonography for Trauma

US is a simple, portable, repeatable test that involves no radiation and can be completed at the bedside in seconds to minutes. Its rapid ability to detect free fluid as a marker of serious injury has supported the dissemination of US into resuscitative suites around the world and introduced clinicians to the US-enhanced physical examination (11–13). The published evidence reflects the fact that any discipline that, or individual who, undertakes a commitment to learn, practice, and review their results can attain proficiency (14–22). A focused screen to identify free intraperitoneal and intrapericardial fluid constitutes the Focused Assessment with Sonography for Trauma (FAST) (23). The term itself emphasizes both the “focused” nature and the fact that it is not limited to the abdominal cavity. European and Asian investigators initially used US to examine injured patients, quickly accepting it into their practices and surgical curriculums (24). Although the first North American report
was in 1992 (19), the FAST became widely accepted so that within 7 yrs, it had replaced the diagnostic peritoneal lavage as the initial screening modality of choice for severe abdominal trauma in >80% of North American centers surveyed (25). The FAST is now taught in the Advanced Trauma Life Support course (26). Practice management guidelines from the Eastern Association for the Surgery of Trauma recommend it be considered the initial diagnostic modality to exclude hemoperitoneum (27).

The FAST has been reported to guide care, to save time and money, and to reduce radiation exposure (28–30). A prospective nonrandomized trial of FAST use recorded changes in management plans in 33% of cases after FAST (12). The FAST was quickly accepted into clinical practice, predominantly based on the premise that it could expedite triage of the seriously injured. Hemorrhagic deaths have been identified as the leading cause of potentially preventable injury-related death (31), causing 80% of early hospital deaths, being most frequently abdominal (32). Shock, synonymous with cellular hypoxia, is time critical. Unfortunately, the clinical abdominal examination is often inaccurate due to distracting injuries, altered consciousness, and nonspecific signs and symptoms (13, 33, 34). An autopsy study reported that abdominal injuries were the most frequently missed conditions in traumatic emergency department deaths, including a number of potentially salvageable patients who had been transferred from other hospitals (35). A patient who is exsanguinating and requires a splenectomy may have an identical physical examination to one who is dying from retroperitoneal bleeding, in whom laparotomy might be detrimental. Transporting such patients for CT scanning is contraindicated, and thus, the diagnostic peritoneal lavage had been favored as the preferred modality to confirm intraperitoneal blood. The diagnostic peritoneal lavage is generally safe, but it has complications, is time consuming, and forever changes the results of physical examination and subsequent imaging (36).

**Expediency**

With experience, the FAST can give almost instantaneous positive results when used to localize the major source of hemorrhage in unstable patients (21). In such circumstances, the primary goal is to detect large fluid collections, analogous to a grossly positive diagnostic peritoneal lavage. A number of authors have reported that among hypotensive cohorts requiring laparotomy, all had positive FAST examinations (20, 21, 37), including children (38) and adults examined with handheld machines (39). In hypotensive patients, a massive hemoperitoneum can quickly be detected with a single view of the Morison pouch in 82–90% of cases (21, 40), requiring a determination time of 19 secs on average (21). A negative FAST takes longer to perform, as the examiner can conclude a positive determination with identification of a single area, unless using a scoring system requires evaluation of all peritoneal sites. Although negative or minimally positive FAST examinations may still represent significant pathology, they direct the search for the major site of bleeding away from the peritoneal cavity (20, 41). Wherest et al. (21) reported that none of 47 hypotensive patients with a negative FAST required acute laparotomy for hemorrhage control. Further, the FAST was negative in all but one with a retroperitoneal bleeding source, in whom it was only trace positive (21). Recognizing that bedside US can address the detection of multiple life-threatening conditions, a number of groups have recently formalized resuscitative protocols for the patient with undifferentiated hypotension. These protocols emphasize the expedient detection of hemoperitoneum, pericardial effusion, and ruptured aortic aneurysms (42, 43) and the focused evaluation of cardiac function in trained hands (44).

When making such decisions, it is crucial that the sonographic windows have been well visualized—meaning determine. In a small but significant number of trauma patients, the FAST is indeterminate, as the examiner is unable to visualize the reference organs well enough to make a determination (45, 46). The most common causes are obesity and subcutaneous emphysema (45). In such settings, the clinician should not consider the FAST results in decision making.

**Conduct of the Examination**

The ultimate goal of the FAST is to quickly localize fluid contrasted against recognizable organs. For introductory and training purposes, the basic FAST technique was defined as the real-time examination of four torso regions (four Ps): pericardial, perisplenic, perihepatic (Morison pouch), and pelvic (pouch of Douglas) (13, 23). To interrogate these areas, the US probe is typically first placed in the subxiphoid area and directed toward the patient’s left shoulder to provide a four-chamber view of the heart. The Morison pouch is then identified using a right intercostal view to identify any anechoic fluid between the liver and right kidney (Fig. 1). The left intercostal view interrogates the interface between the spleen and left kidney, and pelvic views examine for fluid around a full bladder. Practically, the examination is done before a bladder catheter is placed, with the catheter placed and clamped, or with fluid instilled into the catheter if the bladder has been drained.

![Figure 1. Sonographic image of hepatorenal space (Morison pouch) demonstrating free fluid (arrow) contrasted between the liver and right kidney. The patient was found to have an intraperitoneal bladder rupture at laparotomy.](image-url)
Others have augmented these basic anatomic locations. Sisley et al. (47) and Ma et al. (16) have recommended adding supradiaphragmatic views for the detection of pleural fluid. Others routinely examine the pericolic gutters for fluid (28, 48). Maneuvers that increase the accuracy of scanning include repeated examinations intended to detect newly accumulated fluid from ongoing visceral leak or bleeding. Blackbourne et al. (49) demonstrated an increase in FAST sensitivity from 31% to 72% in a select population with few true positive scans by repeating the FAST within 24 hrs. This is supported by consensus recommending follow-up FAST examinations and ≥6 hrs of clinical observation before accepting a FAST as negative (23). The Advanced Trauma Life Support course recommends a “control” scan be repeated after a 30-min interval (26). The patient may also be positioned in Trendelenburg position to facilitate fluid accumulation in the Morison pouch (50). In practice, however, the most critically ill would typically be undergoing definitive interventions or able to undergo a CT scan within 30 mins of hospital arrival.

If the patient is stable, initial evaluation of the pericardial site allows gain settings to be optimized for blood (47). If the patient is unstable, the Morison pouch may provide the quickest clinical direction. A review of >10,000 patients confirmed that the right upper quadrant or the Morison pouch as the most likely place to detect major hemoperitoneum. The Morison pouch was positive 86% of the time, whereas the left upper quadrant and pelvis were only positive 55% and 43% of the times, respectively (47).

**Pericardial Component**

Cardiac tamponade is a form of obstructive shock for which clinical presentation can vary from subtle to catastrophic. Although penetrating wounds to the precordium are typically obvious, a high index of suspicion is required in blunt trauma. Classic signs such as tachycardia, muffled heart sounds, and increased venous pressure are easily missed (51). The FAST may quickly identify pericardial fluid, allowing for immediate bedside interventions or expedited transport to an operating room (16, 20, 52) (Fig. 2). Early FAST studies variably included an examination of the pericardial sac. Subsequently, consensus has been to consider this a standard region of the FAST (23). Some clinical series have reported sensitivities of 100% and specificities of 97–99% for identifying free pericardial fluid (16, 53).

Blunt cardiac injury refers to a spectrum of injuries ranging from simple electrocardiographic changes to free wall rupture (54). Cardiogenic shock from blunt cardiac injury is uncommon in survivors to hospital, although cardiac injuries are common in autopsy series (51). When pump dysfunction occurs after blunt injury, it presents an exceedingly difficult diagnostic challenge that may only be resolved with formal echocardiography (51, 55) (Fig. 3). Although detecting intrapericardial fluid is well within the capability of clinicians, evaluating cardiac function requires dedicated training. Although this skill level is currently largely unavailable during trauma resuscitation, the continued adoption and experience with echocardiographic skills in critical care provides an opportunity for expedited diagnoses that might improve the care of this group.

**FAST as the Definitive Abdominal Imaging Test**

In current practice, trauma US has taken on two congruous yet distinct roles. One is the early identification of unstable trauma victims requiring urgent surgical interventions (40), and the other more controversial role, is that of excluding stable patients from further abdominal imaging (14, 15, 56–58). A number of centers have reported on the efficiency of using the FAST as the sole abdominal imaging modality in hemodynamically stable patients without high clinical sus-
picion of injury. A number of larger series have shown this to be safe (20), with no deaths related to missed injuries being reported (37, 46, 59). Much of this evidence accrues from larger series of patients with low injury acuity or in whom there were few positive results (20, 37). Clinicians need to be keenly aware of the limitations of trauma sonography. It is a very user-dependent examination. The FAST may miss injuries that are not associated with free intraperitoneal fluid, such as hollow viscus, mesenteric, intraparenchymal solid, or retroperitoneal injuries (59–62). Some recent series have reported sensitivities as low as 31–42% (49, 62, 63). These injuries may also be missed by CT, emphasizing that no imaging test is foolproof. Although CT scanning will detect more pathology, injuries detected often have no clinical influence (49).

**Algorithms to Reduce the Risk of Missed Injuries**

Identifying markers may direct patients at higher risk of sono-occult injuries to undergo CT. These include severe or persistent abdominal pain, seat-belt signs or other abdominal wall contusions, pulmonary contusion, hematuria, or fractures of the lower ribs, spine, or pelvis (20, 20, 37, 46, 64). Centers that rely on sonography technicians have suggested bypassing FAST for a screening CT in these situations (37), although considering the FAST as a required component of the physical examination is an alternate philosophy.

**Organ-Specific Injuries and Focused Sonography**

Accurate depiction of organ injury in stable patients has revolutionized the care of hemodynamically stable patients, permitting successful nonoperative management in many cases. If the FAST examination is being used as a sole diagnostic test, the ability to delineate specific organ injuries is greatly diminished. Groups with greater skills, however, have demonstrated that US can detect specific organ injuries. Holm and Mortensen (65) set the stage for using US in the trauma setting in 1968, reporting the identification of a splenic rupture with associated hematoma. In experienced hands, a sonographic examination can identify specific parenchymal injuries (57, 66–69), generally finding a greater sensitivity the higher the severity of injury (63, 67, 68). Contrast-enhanced US may improve the accuracy of solid organ imaging and reveal active contrast extravasation related to active bleeding (70, 71). These studies often rely on technicians or radiologists (57, 67, 68), potentially reducing the availability. The emphasis of the FAST is simplicity, intended to be within the capabilities of an on-site clinician. Thus, US delineation of organ detail may warrant further evaluation at patient follow-up rather than at initial resuscitation.

**Evidence-Based Medicine**

Despite the enthusiasm for the FAST, well-validated scientific proof of utility remains sparse. This criticism is easily applied to the majority of care provided to the critically ill, given the complexity of the patients and inherent difficulties studying them. Stengel et al. (78–80) have performed a series of ongoing systematic reviews, concluding that there is insufficient evidence to justify the promotion of US-based clinical pathways in suspected blunt trauma (80). It is important to note that there were insufficient data to discriminate between hemodynamically stable and unstable patients (a critical distinction), trivial and nontrivial injuries, or initial and repeated examinations (79). An analysis of 62 publications with 18,167 patients revealed an overall sensitivity of 79% and a specificity of 99.2% for detecting free fluid, organ damage, or both (79). Methodologic rigor had a major effect on accuracy, with less rigorous studies reporting higher accuracy. Overall, they corroborate that the FAST has moderate sensitivity; when it detects injuries or fluid it is decisive, but a negative FAST should not be trusted because the likelihood ratios of a negative test were 0.2 to 0.35.

Inclusion in the Cochrane review required comparisons between the FAST examination and either diagnostic peritoneal lavage or CT scan (80). Although these analyses are methodologically correct if one considers the FAST a standalone diagnostic test, they may not reflect the utility of using the FAST as a subcomponent of an algorithm or as simply an extension of the physical examination. A dedicated effort to elucidate the true worth of the FAST would need to focus on specific homogeneous patient groups, notably hemodynamically unstable patients, and compare the physical examination with the FAST. All other aspects of care of these complicated patients would also need to be rigidly standardized, presenting a monumental challenge. The appropriate studies to allow meta-analytic study may never be done. Clinicians have come to depend on the FAST to the point that they would not accept a control group of patients. For example, a randomized trial of the FAST examination was terminated early because the investigators thought they could no longer justify as ethical the withholding of the FAST examination from eligible patients (28).

**FAST Examination for Penetrating Trauma**

The ability to quickly delineate major abdominal fluid collections after penetrating thoracoabdominal trauma directs operative planning. Asensio et al. (81) regretted a limited use of early FAST in directing surgical sequencing and strongly recommended its increased
use. A majority of surveyed US centers reported using FAST for penetrating trauma (25), and meta-analysis showed no accuracy differences between studies including and excluding penetrating trauma (79). Studies have demonstrated excellent specificities (94–100%) but only modest sensitivities (46–71%) (52, 82, 83). Thus, a positive FAST is a strong predictor of injury and should immediately direct patients to laparotomy, whereas negative tests should prompt another diagnostic strategy (83).

Hand-Carried Ultrasound

A number of portable handheld US units have recently become available to clinicians. The first such units were developed through a joint civilian–military initiative to provide portable US capabilities suitable for battlefield or mass casualty situations (84). The primary benefit of these devices for trauma care providers will be earlier diagnosis, potentially even in the prehospital setting, to expedite transport priorities and disposition. Although the fidelity and image quality of early hand-carried US units did not match that of the standard floor-based machines, their diagnostic performance regarding the FAST examination seems comparable (11, 39, 85). This class of US has been tested in many adverse environments and found to be clinically useful (2, 86–88).

Future of the FAST Examination

After an initial wave of enthusiasm, the limitations of the FAST have been more widely appreciated. These are mainly its inability to detect injuries not associated with free fluid and its general inability to quantify the degree of organ injury. In the decades since the North American introduction of FAST, CT scanning has made remarkable progress in capabilities to become indispensable in trauma care. This had led to routine use of nearly whole-body CT scanning (89). Although invaluable, CT scanning greatly increases radiation exposure (90, 91). With liberal use, this imparts a small but finite risk of later cancer, especially in younger patients (91). In one study, CT contributed 97.5% of the total effective radiation dose from all imaging in traumatized children (91). Optimal CT scanning also requires nephrotoxic contrast agents. US and CT scanning should thus be used as complementary tests, with CT being of higher fidelity but with US being readily repeated during the initial encounter and during routine reassessments. How much should the medical system pay to detect all the injuries detected on CT that do not influence medical care is a societal question that warrants formal economic analysis. Balancing the FAST’s limitations, however, is the rapidly increasing scope of the examination to encompass the entire primary Advanced Trauma Life Support survey.

Extended FAST and Thoracic Trauma

To save lives, the resuscitating clinician must efficiently address life-threatening thoracic injuries, which are responsible for 25% of trauma deaths (92, 93). Life-threatening thoracic injuries that should be detected during a primary survey include tension pneumothoraces (PTXs), massive hemothoraces, cardiac tamponade, and flail chest injuries (93). Rib fractures are the most common serious thoracic injury and pneumothoraces are the most common intrathoracic injury after blunt trauma (92, 93). In all these settings, focused US can provide rapid diagnosis.

Hemothoraces

Sisley et al. (47) demonstrated that thoracic sonography utilizing the same probe used for the FAST examination could accurately detect acute traumatic effusions. US was 97.5% sensitive and 99.7% specific compared with chest radiography’s (CXR’s) 92.5% and 99.7%, respectively. Ma et al. (16) also demonstrated a 96% sensitivity and 100% specificity. Medical students can be trained in short periods of time to detect pleural fluid collections in critically ill patients (47). This experience has led many investigators to augment the standard FAST examination with routine views of the pleural space.

Pneumothoraces

The direct depiction of a pneumothorax by US is physically impossible because air has extremely high acoustic impedance, which causes almost complete reflection of sound waves. Thus, only artifacts are seen deep to the pleura in the normal lung (94). As both hemothoraces and pneumothoraces are plural-based diseases, the underlying lung does not need to be seen to detect them. The concept of using US to exclude or infer the presence of a PTX relies on the premise that the pleural surfaces are in apposition, then intrapleural air cannot be present. The focused goal of the sonographer is simply to identify the contiguity of the visceral and parietal pleura using simple sonographic signs. We consider this to be an extended FAST (EFAST) (95).

Unless there are pleural adhesions from previous disease or injury (a condition thus reducing the risk of PTX), normal respiration is associated with a physiologic sliding or gliding of the two pleural surfaces on one another, known as lung sliding (LS) (95–98). LS is least at the apices and greatest at the lung bases (96). “Comet-tail” artifacts (CTAs) are reverberation artifacts that arise from dis tended water-filled interlobular septa under the visceral pleura. They can be considered the US equivalent of “Kerley B-lines” (96, 99). Being related to the visceral pleura, they can only be seen when the visceral pleura is in apposition to the parietal pleura (Fig. 4). The marked difference in acoustic impedance between the parietal pleura and a PTX creates a marked horizontal reverberation artifact seen as the mirror image of the chest wall. Lichtenstein et al. (100) designate this the A-line, a bright echo genic line recurring at an interval that exactly replicates the interval between the skin and pleural line.

Examining the pleural interfaces with the color power Doppler mode can enhance the depiction of LS by emphasizing motion, a finding designated the power slide (101). Color power Doppler documents a physiologic process as a single image, allowing for simpler archiving and teletransmission. Similarly, the use of M-mode documents the presence of LS (the seashore sign) (Fig. 5) or its absence with PTX (the stratosphere sign) (Fig. 6), as the pleural movement will normally generate a homogeneous granular pattern (96, 100). Another sign well documented in M-mode is the “lung point”; when the lung intermittently contacts the parietal pleura with inspiration, thus regularly alternating between the seashore and stratosphere signs (Fig. 7).

The first description of the use of US to investigate pneumothoraces was reported in a veterinary journal in 1986 (102). Subsequent descriptions followed after lung biopsy (94, 103, 104), in the medical intensive care unit (105–107),
and in a mixed group that included stable trauma patients (108). Thereafter, the focused use of US to assess PTXs received impetus from a space medicine problem (97, 109). The International Space Station supports US as the only diagnostic imaging modality in an environment with increased PTX risk (110, 111). This prompted further investigations to evaluate the diagnostic potential both on earth (95, 112), and in weightlessness (110), suggesting that US is equal if not more accurate than supine radiography for detecting PTXs (98, 110, 113).

Lichtenstein et al. (100, 105–107) have extensively studied the sonographic diagnosis of PTXs. The “meaningful” CTA (B-line) has five mandatory features: arising from the pleural line, well-defined (laser-beam like), spreading to the screen edge, erasing the A-lines, and moving with LS (Fig. 2) (100). These specific features distinguish it from the Z-line, a CTA that is ill-defined, vanishes after a few centimeters, does not move with LS, and that seems devoid of pathologic meaning (100). Subcutaneous emphysema creates specific CTAs that rise above the pleural line, resulting in an indeterminate examination. Subcutaneous emphysema itself carries a seven-fold increased risk and 98% specificity for occult PTX, providing an indication for chest drainage in the unstable patient (114).

**Occult Pneumothoraces**

Several groups have reported on the utility of US as an adjunct to the CXR (112, 115). By using CXR as the gold standard, however, these studies, by definition, ignore the issue of occult pneumothoraces, PTXs seen on CT but not on CXR (114, 116). Their prevalence may range up to 64% in intubated multi-trauma patients (117). In centers using frequent CT scan, more than one half of all PTXs may be occult (95, 98, 113, 116, 118). Considering only PTXs seen on CXRs considerably underestimates the potential of the EFAST. Due to the effect of gravity, the supine lung hinges dorsally, with air collecting anteromedially (119, 120). Supine PTXs are most commonly anterior (84%), apical (57%), and basal (41%), corresponding to the most accessible chest locations for US (121).

Lichtenstein et al. (100) retrospectively evaluated 200 consecutive intensive care unit patients corroborated with CT. The absence of LS alone had 100% sensitivity but only 78% specificity for diagnosing occult pneumothoraces. When an A-line was seen with absent LS, however, there was a 95% sensitivity and 94% specificity for diagnosing occult pneumothoraces. The presence of a lung point had 100% specificity for occult pneumothoraces. A prospective study of hand-
carried US focused on the most difficult to diagnose subset, those patients remaining after the obvious PTXs (CXR or clinical) were treated (95). In the remaining patients, EFAST had a 49% vs. a 21% sensitivity compared with CXR in the setting of very high specificities and positive likelihood ratio, being corroborated by CT (95). A pitfall, as in other studies, was bilateral PTXs, likely due to the loss of a patient-specific “normal” comparative examination (95, 122). Another study of 176 patients using similar methodology (US, followed by CXR and CT) used a protocol examining four thoracic locations, allowing a determination of PTX size (122). The investigators systematically searched for LS, supplemented by color power Doppler, assessing the relative size of the PTX through the relative topography of LS. There was a 98% sensitivity for US compared with 76% for CXR, a specificity of 99% vs. 100% for CXR, and a positive likelihood ratio of 121 for EFAST (122).

Magnitude of Pneumothoraces

Although PTXs are dynamic, management is often based on the perceived size. Allowing for factors such as transport and positive pressure ventilation, many small pneumothoraces are managed expectantly, whereas large ones are drained (116). The original description in horses described scanning from ventral to dorsal and noting the point where a static gas artifact met the respiratory motion of the lung (102). An early report by Sistrom et al. (94) concluded that US was of no use in determining the volume of PTX. This may have related both to the lack of real-time scanning and to using radiography as a control (95, 100, 110). Subsequent studies have suggested that sonography may have utility in determining not only the presence but actual size of a PTX. Lichtenstein et al. (107) subsequently described this fleeting appearance of either LS or CTAs intermittently replacing a PTX pattern as the lung point sign (Fig. 7). Sargsyan et al. (110) coincidentally described this as partial sliding, implying that smaller or occult pneumothoraces might be detected. Blaivas et al. (122) noted good correlation between the estimates of PTX size and CT findings (Spearman rank correlation, 0.82) using the relative thoracic topography of LS.

Probe Selection and Placement

Some groups favor high-frequency linear array transducers that provide the best resolution of the pleural interface and whose footprint fits well between the ribs (94, 95, 98, 123). This necessitates a largely transverse scan in the upper rib spaces that is perpendicular to the main axis of LS (100). Conversely, other groups have emphasized the practicality of using a lower-frequency probe that can also be used for the abdominal portion of the EFAST, decreasing time spent exchanging probes (122). The transducer is first placed longitudinally on the chest, perpendicular to the ribs, to identify the pleural interface in reference to the overlying (and acoustically impervious) ribs. Thereafter, the transducer is rotated transversely between the ribs to bring the echogenic pleural stripe into profile, generating the “bat sign” as a basic landmark (96, 100). Thereafter, the EFAST assesses whether LS or CTAs at the interface can be detected. If there is no LS and no comet tails are visible, the examiner should suspect the presence of a pneumothorax, a suspicion further heightened by the presence of the horizontal reverberation artifact (A-line). Color power Doppler may accentuate LS and provide documentation, as does M-mode. Detection of an image where partial sliding or a lung point is present marks the lateral aspect of the pneumothorax (lung point).

Airway Management

As US is increasingly available at the bedside in critically ill patients, it may aid in airway management. Endotracheal tube (ETT) misplacement in those arriving at emergency departments already intubated...
has been reported in up to 25% of cases (124, 125). Moreover, end-tidal CO₂, the gold standard in ETT confirmation, may be occasionally seen even with a mal-positioned ETT (124, 125). Kirkpatrick et al. (95) noted two false-positive PTX diagnoses when left-sided LS was absent after right main stem ETT placement. LS and moving CTAs returned after ETT repositioning. Subsequently, Chun et al. (126) described the potential utility of using US to confirm ETT placement. Weaver et al. (127) randomly inserted an ETT into the mainstem trachea, right main bronchi, or esophagus of cadavers. Using the presence or absence of LS distinguished esophageal from tracheal intubation with a 95–100% sensitivity and 100% specificity. Further, right main intubation was distinguished from mainstem with a 69–79% sensitivity and 93–100% specificity. Hsieh et al. (128) utilized a similar philosophy by bilaterally imaging the dia-phragmatic movements after intubation from a subxiphoid window, describing real-time correction of right main-stem intubations. Lichtenstein et al. (129) described CTAs oscillating with the cardiac pulsation, but not with respiratory effort, after selective right lung intubation as the “lung pulse.” The lung pulse indicated complete atelectasis of the left lung. In conclusion, it should be emphasized that sonographic evaluation is best utilized as either an adjunctive airway management technique or in austere situations in which no other technologies are available. These techniques may demonstrate ventilation but not the adequacy of such.

Posttraumatic Expanding Intracranial Pathology

Management of serious closed head injuries requires early identification of intracranial hemorrhage amenable to surgical intervention. It is possible that clinicians can quickly infer increased intracranial pressure from an early focused examination of the optic nerve sheath, which is anatomically continuous with the dura matter and through which cerebrospinal fluid percolates (130, 131) (Fig. 8). Although there is not great experience as yet, early reports are encouraging (132). A reference position 3 mm behind the globe is chosen to give the greatest US contrast, being the most distensible part of the sheath and giving the most reproducible results (133). Normal reference ranges are considered up to 5.0 mm in adults, 4.5 mm in children aged 1–15 yrs, and 4.0 mm in infants (130, 131).

Pediatric Patients

The use of the FAST is less established in pediatric trauma care, although the general principles remain unchanged. The FAST is clinically useful when it provides a positive result, especially among hypotensive patients, but should be suspect when negative (38, 79, 134). Theoretically, there may be specific advantages of US in children related to the thin body wall and lack of intraperitoneal fat stripes (135). The EFAST and other expanded techniques are also applicable to pediatric and even neonatal populations (128, 131, 136), who are both at risk of transportation to distant CT scanners and more sensitive to ionizing radiation.

Future Directions

Critical care medicine, like our society, lives in the information age. The majority of the information acquired and analyzed in the critical care unit is digital in nature (137). Most decisions regarding patient care in critical care medicine are now made on the basis of numerical information represented as bytes rather than atoms (39). Satava (138) has stressed the information system’s integration benefits of total body scans (holograms). Although conceptualized as separate tests, CT, US, and magnetic resonance imaging are thus simply information systems with different eyes (139). In the future, it is probable that all information acquired about a patient from the first prehospital assessment onward will be automatically compiled to build an increasingly elegant hologram. This will allow decision support, digital transmission, documentation, remote consultation, manipulation, and data fusion, without delaying or distracting the clinician from the clinical interaction. Despite these powerful technologies, the essence of the examination will remain the enhancement of the clinician’s bedside diagnostic capabilities.

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