Radiology

# Focused Assessment with Sonography in Trauma (FAST) in 2017: What Radiologists Can Learn[1]

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Focused assessment with sonography in trauma (FAST) has been extensively utilized and studied in blunt and penetrating trauma for the past 3 decades. Prior to FAST, invasive procedures such as diagnostic peritoneal lavage and exploratory laparotomy were commonly utilized to diagnose intraabdominal injury. Today the FAST examination has evolved into a more comprehensive study of the abdomen, heart, chest, and inferior vena cava, and many variations in technique, protocols, and interpretation exist. Trauma management strategies such as laparotomy, laparoscopy, endoscopy, computed tomographic angiography, angiographic intervention, serial imaging, and clinical observation have also changed over the years. This state of the art review will discuss the evolution of the FAST examination to its current state in 2017 and evaluate its evolving role in the acute management of the trauma patient. The authors also report on the utility of FAST in special patient populations, such as pediatric and pregnant trauma patients, and the potential for future research, applications, and portions of this examination that may be applicable to radiology-based practice.

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**Learning Objectives:**

After reading the article and taking the test, the reader will be able to:

- Discuss the accuracy and utility of FAST in clinical decision making, as well as limitations and pitfalls
- Describe newer protocols such as eFAST and RUSH and their uses
- Discuss the use of FAST in special populations such as pregnant and pediatric patients

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Traumatic injury remains the leading cause of death of persons from age 1 to 44 years, with nearly 200 000 deaths per year in the United States (1). In 2013, there were 27 million patients treated in emergency departments, with 3 million hospitalized for their injuries (1). A substantial proportion of these patients have injuries from blunt abdominal and/or chest trauma. The advent of focused assessment with sonography in trauma (FAST) 3 decades ago enabled clinicians to rapidly screen for injury at the bedside of patients, especially those patients too hemodynamically unstable for transport to the computed tomography (CT) suite. The identification of free fluid within the peritoneal cavity, pericardium, and the pleural spaces can be accomplished immediately at patient arrival to the hospital. Other applications of FAST include detection of solid organ injury, pneumothorax, fractures, serial examinations, as well as use in prehospital transport and multiple casualty settings as a triage tool. However, there has been general reluctance of radiologists to embrace the use of ultrasonography (US) in trauma, as there is more reliance on CT. Much of this is due to the fact that the use of FAST has migrated to first responders and includes use of FAST in the field or during patient transport. FAST is also typically used as the patient's initial imaging examination at arrival to the emergency department. Since the original description of the use of US in the trauma patient, there have been several new applications of the use of US for these patients. We will review these newer developments of US in trauma victims and discuss those applications useful to radiologists.

## Essentials

- Focused assessment with sonography in trauma (FAST) and extended FAST (eFAST) are widely available and may be performed quickly in real time; FAST can help identify free fluid suggestive of hemoperitoneum, hemothorax, and hemoperidcardium, while eFAST can help identify pneumothorax, hemothorax, and atelectasis.
- FAST has acceptable sensitivity (69%–98%) for detection of free fluid and lower sensitivity (63%) for detection of solid organ injury; FAST may lead to underestimation of injuries and severity, especially in stable trauma patients without detectable free fluid.
- FAST has high specificity (94%–100%) for detection of free fluid and/or solid organ injury; serial FAST examinations increase overall sensitivity (72%–93%).
- Sensitivity of eFAST for pneumothorax and hemothorax is higher than that of chest radiography (11%–21% vs 43%–77%).
- Evaluation of the inferior vena cava during FAST can help distinguish between types of shock in hypotensive trauma patients.

## The Evolution of FAST

US was first utilized for the examination of trauma patients in the 1970s in Europe (2,3). It was not widely adopted in North America until the 1990s, during which time the FAST acronym was defined as "focused abdominal sonography for trauma" (4–6). As FAST evolved into a more comprehensive examination, the acronym was changed to "focused assessment with sonography for trauma" (7). Since then, FAST has become the common initial screening modality in the majority of trauma centers in the United States and worldwide, and it is included in the Advanced Trauma Life Support program for evaluation of the hypotensive trauma patient (8,9). A unique aspect of FAST is that it is routinely utilized by radiologists, emergency physicians, and surgeons with variable training and experience.

## Accuracy of FAST and Clinical Decision Making

In 1976, Asher and colleagues reported the sensitivity of US for detection of splenic injury from blunt abdominal trauma as 80% (four of five) (3). During the 1990s, myriad studies were published reporting sensitivities ranging from 69% (11 of 16) to 98% (52 of 53) and specificities from 95% (18 of 19) to 100% (259 of 259) for detection of hemoperitoneum (10). Much of this initial enthusiasm for FAST and its high sensitivity were due to the fact that FAST findings were initially compared with patients' outcomes and not CT. One of the first studies to compare FAST to CT showed a lower sensitivity of 63% (24 of 38) for FAST in detecting solid organ injuries (11). The lower sensitivity was due in large part to the fact that there was an isolated solid organ injury without the presence of free fluid. Since then, more recent critical evaluations of FAST have appeared, highlighting its high false-negative rate in stable trauma patients (12,13). Carter et al, in a retrospective study of 1671 blunt abdominal trauma patients, reported a sensitivity of 22% (25 of 114) in hemodynamically stable patients and 28% (nine of 32) in unstable patients, and they concluded a negative FAST study without follow-up CT may miss an intraabdominal injury (IAI) (14). The potential for underdiagnosis of IAI with FAST is now well recognized (15). In a prospective study of 772 patients, Chiu et al determined as many as 29% (15 of 52) of patients with negative FAST studies had IAI (16). Clinical suspicion, mechanism of injury, and change in clinical examination or hemodynamic status should always be included in deciding on further diagnostic testing in patients with negative initial FAST results (Fig 1). For patients with a negative FAST study,

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**Abbreviations:**
DPL = diagnostic peritoneal lavage
eFAST = extended FAST
FAST = focused assessment with sonography in trauma
IAI = intraabdominal injury
IVC = inferior vena cava

Conflicts of interest are listed at the end of this article.

**Figure 1**

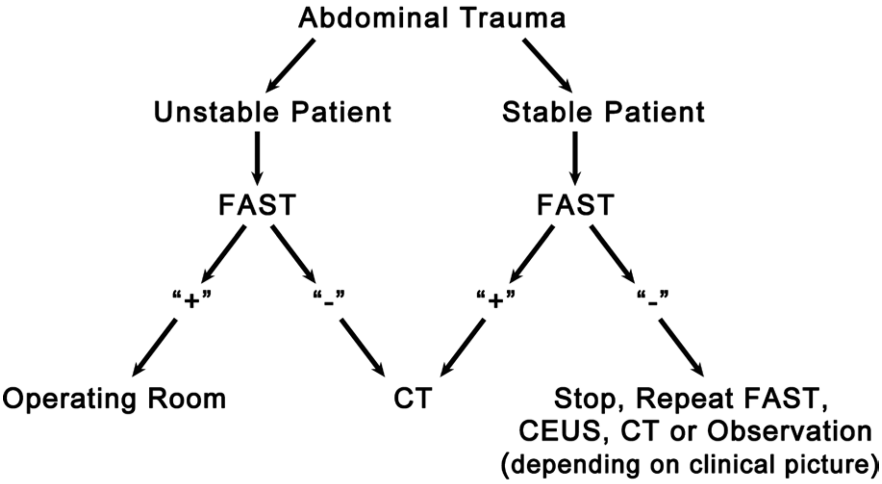


**Figure 1:** Diagnostic algorithm for the use of FAST for triage of trauma patients. *CEUS* = contrast-enhanced US.

observation, serial FAST, CT, or contrast material–enhanced US may be chosen.

Over time, a new role for FAST has evolved, in which its use in the evaluation of unstable, hypotensive trauma patients is emphasized (17). The most effective use of FAST has been rapid triage of hemodynamically unstable trauma patients to definitive intervention (17), leading to reduced time to appropriate intervention, shortened hospital stays, and lower costs (18). The FAST examination has also been shown to reduce the need for diagnostic peritoneal lavage (DPL), with one prospective study of 194 patients reporting a reduction from 9% (17 of 194) to 1% (two of 194) (19).

## FAST Technique and Interpretation

Probe selection in the evaluation of the trauma patient is dependent on what is the main focus of the examination. A sector probe (3–5 MHz) is best utilized as a multipurpose probe. It is appropriate for examining solid organs and determining presence of free fluid in the abdomen or pelvis. A sector scanner can be used to examine the heart for a pericardial effusion or hemorrhage. A sector scanner is also useful to scan between the ribs for pneumothorax. A curved-array transducer may be used in the abdomen for better resolution but is not ideal for imaging of the heart or lung, especially when scanning in the intercostal spaces. Linear-array transducers are not ideal because of their larger footprint in the abdomen and chest and often are of higher frequency with limited depth penetration. The linear-array transducer probe is placed parallel to the ribs in the intercostal space for detection of pneumothorax.

The original FAST scan included views of *(a)* the right upper quadrant, which included the perihepatic area and hepatorenal recess or Morison pouch (Movies 1, 2 [online]), *(b)* the left upper quadrant, encompassing the perisplenic view (Movies 3–5 [online]), *(c)* the suprapubic view (pouch of Douglas), and later *(d)* a subxiphoid pericardial view (Fig 2; Movies 6, 7 [online]). The preferred initial site for detection of free fluid with FAST is the right upper quadrant view, scanned by using a lower frequency (3.5–5 MHz) sector or curved-array transducer. A sector transducer with far field optimized is ideal for best penetration when examining the hepatorenal fossa or deep pelvis. A curved-array transducer may also be optimized for deep penetration. However, linear-array transducers are rarely utilized in the abdomen. The liver serves as a convenient acoustic window to interrogate the hepatorenal space and liver parenchyma. Hemoperitoneum usually appears anechoic or hypoechoic compared with adjacent solid organs. Prolonged hemorrhage may organize and become more echogenic. For the left upper quadrant view, the spleen is targeted for examination of the splenorenal fossa and perisplenic area. Cephalad scanning enables visualization of the left pleural space. Moving the probe caudally brings the inferior pole of the left kidney and paracolic gutter into view. The perisplenic area may be inadequately scanned due to difficult physical access. Rolling the patient to the right side is helpful in evaluating this area, as small amounts of free fluid may collect superiorly to the spleen.

The suprapubic view allows assessment of the most dependent space in the peritoneal cavity. The transducer is placed above the pubic symphysis in a sagittal plane and swept side to side then rotated transversely and repeated. Reverse Trendelenburg positioning may enhance detection of free fluid in the pelvis. In female patients of reproductive age, small amounts of free fluid of up to 50 mL in the pouch of Douglas are considered physiologic, and amounts exceeding 50 mL should be regarded as pathologic in the setting of trauma (20,21). Thus, assuming there is no injury or other pathologic condition present, free fluid should not be found at the rectovesicular space in men. Only small amounts of fluid should be found in the recto-uterine space in women of childbearing age. Detection of free fluid in the pelvis is aided by the presence of a fluid-filled bladder. When free fluid is present, it is most frequently located posterior or superior to the bladder and/or the uterus. Free fluid in the pelvis can be missed when a foley catheter is placed to empty the bladder, as the acoustic window for examining the pelvis is compromised, allowing detection of only large amounts of pelvic fluid. The optimal examination for detection of smaller amounts of pelvic free fluid requires a more distended bladder (11).

**Figure 2**

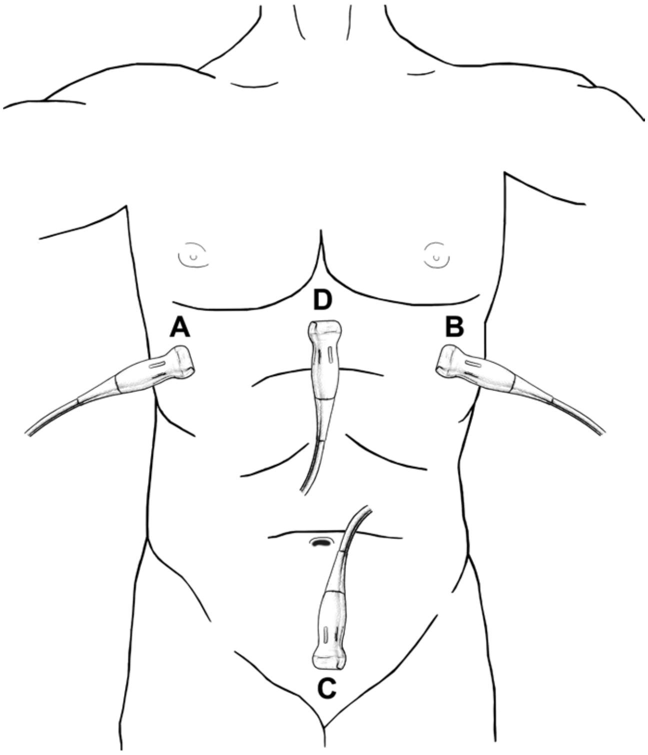


**Figure 2:** The four views for the original FAST scan: *A* = right upper quadrant, *B* = left upper quadrant, *C* = suprapubic view, *D* = subxiphoid view of the heart.

There are limitations to the FAST examination regardless of protocol used. For the abdominal examination, detection of blunt mesenteric, bowel, diaphragmatic, and retroperitoneal injuries can be difficult, as well as isolated penetrating injury to the peritoneum. False-positive scans may result from detection of ascites, peritoneal dialysate, ventriculoperitoneal shunt outflow, ovarian hyperstimulation, and ovarian cyst rupture. Massive intravascular volume resuscitation may result in a false-positive FAST examination from intravascular-to-intraperitoneal fluid transudation (22). Although free fluid detected with FAST in trauma patients is assumed to be hemoperitoneum, it can also represent injury-related urine, bile, and bowel contents. Bowel gas, subcutaneous emphysema, and obesity represent common obstacles to full US visualization. Patients with delayed presentation after trauma may have hemoperitoneum containing clots (Movie 2B [online]), which can have mixed echogenicity and be missed. Perinephric fat, which widens the hepatorenal and splenorenal interface, may be misinterpreted as free fluid or subcapsular hematoma, also known as the "double-line" sign (23). Comparison views of each kidney may be helpful in these cases.

The volume of free fluid necessary to enable detection with FAST represents a limitation of FAST. Branney and colleagues determined that the mean minimum detectable free-fluid volume during FAST examination in 100 patients undergoing DPL was 619 mL in the Morison pouch (24). Trendelenburg positioning may improve visualization of free fluid in the splenorenal and hepatorenal interface. Abrams and coworkers demonstrated that FAST performed in the Trendelenburg position enabled detection of smaller amounts of hepatorenal free fluid than supine (median, 400 mL vs 700 mL) (25). In another DPL study, Von Kuenssberg Jehle et al determined even smaller volumes were required for detection in the pelvic views of FAST, with median minimal volume of fluid of 100 mL (26). However, other studies have shown limited capability of detection of small amounts of free pelvic fluid with the transabdominal approach after bladder decompression with foley catheterization. Scoring systems to record the estimated amount of free fluid detected with US and clinical correlation with outcome have been investigated. Past studies included protocols to assign scores based on anatomic location, number of free fluid sites, or vertical height of free fluid (27–29). A common theme among these studies is the larger the amount and number of sites of free fluid, the greater the likelihood of injury or need for surgical intervention. These scoring systems provide some standardization of fluid quantification but do not take into consideration other clinical variables involved in surgical decision making.

## Newer Protocols

In the mid-2000s, the addition of US evaluation of the thorax to detect pneumothorax to the traditional FAST examination resulted in extended FAST (eFAST) (30,31). There are several other protocols developed for evaluation of shock, respiratory distress, and cardiac arrest, some of which feature echocardiography (30–48). These are listed in Table 1. Other protocols for evaluation of dyspnea include BLUE (bedside lung US in emergency) and RADIUS (rapid assessment of dyspnea with US). The BLUE protocol includes only lung US for detection of pneumothoraces, as well as pulmonary edema, consolidation, and effusion (49). The RADIUS protocol is similar but includes cardiac and inferior vena cava (IVC) evaluation (50).

A review of all protocols is not possible, but some merit further review. The authors of the RUSH protocol (an acronym for rapid US for shock and hypotension) simplified its conceptualization as an examination of the *(a)* pump, *(b)* tank, and *(c)* pipes (43). The "pump"

**Table 1**

**Summary of the Various US Protocols for Shock Assessment**

| Protocol | ACES | BEAT | BLEEP | ECHO (Boyd) | EGLS | Elmer-Noble | FALLS | FATE | FEEL: RESUS | FEER | FREE | POCUS | RUSH: HIMAP | RUSH Pump Tank Pipes | Trinity | UHP | CORE | CAVEAT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference No. | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 51 | 45 | 46 | 47 | 48 |
| Cardiac | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 1 |
| IVC | 2 | 2 | 2 | 2 | 3 | 2 | 4 |  |  |  |  | 4 | 2 | 2 |  |  | 7 | 4 |
| FAST | 4 |  |  |  |  | 3 |  |  |  |  |  | 1 | 3 | 3 | 3 | 1 | 8 | 5 |
| Aorta | 3 |  |  |  |  |  |  |  |  |  |  | 5 | 4 | 7 | 2 | 2 | 6 |  |
| Lungs PTX |  |  |  |  | 1 | 4 | 2 |  |  |  |  | 2 | 5 | 6 |  |  | 2 | 2 |
| Lungs effusion | 5 |  |  |  |  |  |  | 2 |  |  |  |  |  | 4 |  |  | 3 | 3 |
| Lungs edema |  |  |  |  | 4 | 5 | 1 |  |  |  |  | 6 |  | 5 |  |  | 4 |  |
| DVT |  |  |  |  |  |  |  |  |  |  |  | 7 |  | 8 |  |  | 9 |  |
| Ectopic pregnancy |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |
| Trachea |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 6 |
| Bones |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 7 |

Note.—Adapted, under a CC BY license, from reference 51. Numbers indicate examination sequence for each protocol. PTX = pneumothorax; DVT = deep venous thrombosis; ACES = abdominal and cardiac evaluation with sonography in shock; BEAT = bedside echocardiographic assessment in trauma/critical care; BLEEP = bedside limited echocardiography by the emergency physician; ECHO = echocardiography; EGLS = echo-guided life support; FALLS = fluid administration limited by lung sonography; FATE = focus assessed transthoracic echocardiography; FEEL: RESUS = focused echocardiographic evaluation in resuscitation; FEER = focused echocardiographic evaluation in resuscitation; FREE = focused rapid echocardiographic examination; POCUS = point of care US in the hypotensive patient; RUSH = rapid US for shock and hypotension; HIMAP = heart, IVC, Morison pouch, aortic aneurysm, pneumothorax; UHP = undifferentiated hypotensive patient; CORE = concentrated overview of resuscitative efforts; CAVEAT = chest, abdomen, vena cava, and extremities for acute triage.

evaluation includes parasternal long and short axis of the heart, plus subxiphoid and apical views. The "tank" evaluation involves interrogation of the IVC, FAST examination of the abdomen including pleural views, and US of the lung. The "pipes" portion of RUSH involves scanning the suprasternal, parasternal, epigastric, and supraumbilical aorta, with additional scans of the femoral and popliteal veins for deep venous thrombosis. The RUSH examination is not targeted specifically for trauma patients, thus the "pipes" portion of the protocol is usually not performed in the setting of acute trauma. To our knowledge, there are currently no published studies specifically evaluating the RUSH examination exclusively for hypotensive trauma patients (51). Ghane et al reported 100% sensitivity (16 of 16) for RUSH in the diagnosis of hypovolemic shock in 16 patients, five of whom had solid organ injuries secondary to blunt abdominal trauma (52). The remaining patients in their study were diagnosed with shock from acute medical conditions.

The number of different protocols for evaluation of the critically injured or ill patient is a source of confusion, especially as even more protocols are developed with creative acronyms and abbreviations (Table 1). Settling on one standardized examination protocol by consensus and based on large prospective studies and/or meta-analyses would be helpful. Of these protocols, the eFAST examination, which includes evaluation for pneumothorax, and portions of the RUSH examination, which includes a brief subcostal view of the heart and evaluation of the IVC, seem most practical and time-efficient in our opinion (Fig 3). The selective use of eFAST and RUSH specifically for the setting of trauma are discussed below.

## Heart

Subxiphoid images of the heart are obtained by placing the transducer on the upper abdomen and aiming superiorly toward the left shoulder. Fluid surrounding the heart is seen as an anechoic space surrounding the myocardium (Fig 4; Movie 7 [online]).

**Figure 3**

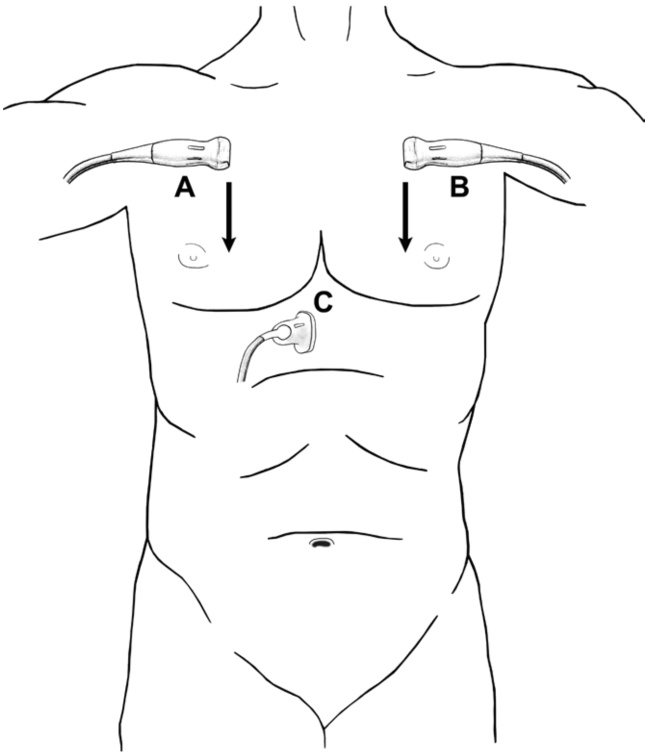


**Figure 3:** Additional views that may be helpful in the trauma patient: *A* = right parasagittal view of the lung for pneumothorax, *B* = left parasagittal view of the lung for pneumothorax, *C* = a longitudinal view of the IVC.

**Figure 4**

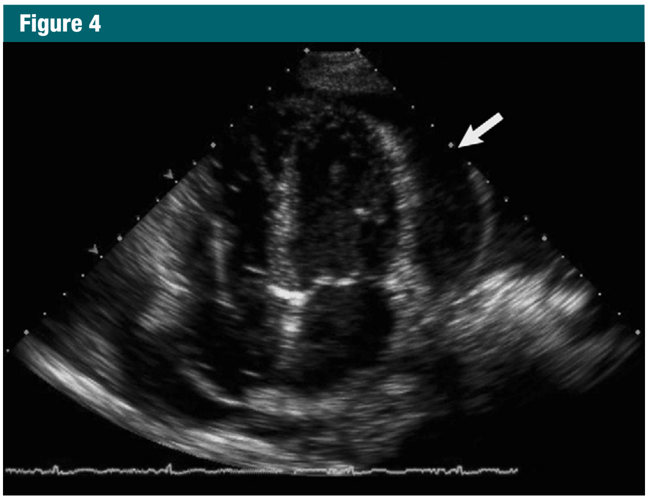


**Figure 4:** Pericardial effusion: Four-chamber view of the heart demonstrates moderate-size pericardial effusion (arrow).

The liver aids as an acoustic window. If there is difficulty obtaining the subxiphoid view, parasternal, apical four-chamber, and subcostal approaches may be attempted. If a substantial amount of hemopericardium is detected, cardiac tamponade is likely if there is diastolic collapse of the right atrium and/or ventricle. Fluid in the posterior pericardial space may be difficult to distinguish from fluid in the posteromedial pleural cavity. Distinction can be made by visualizing the descending thoracic aorta, as pericardial fluid is present anterior to the aorta whereas pleural fluid is posterior. False-positive results for hemopericardium include pericardial cyst, fat pad, and pre-existing effusion. The subxiphoid pericardial area may be inadequately scanned due to a suboptimal acoustic window. Increasing the depth for this view or performing a left parasternal longitudinal scan for pericardial fluid helps overcome these limitations.

### Hemothorax or Pleural Effusion

The right pleural space may be scanned for free fluid at this time, as well as the interface between the dome of the liver and diaphragm. This interface appears as an echogenic curvilinear line, and echoes similar to liver parenchyma can be seen superiorly. This mirror image artifact suggests the absence of pleural fluid. Normal lung may intermittently distort this interface during inspiration, referred to as the “curtain sign” (53). Pleural fluid may be anechoic or have mixed echogenicity based on its composition (eg, hemorrhage, exudate, transudate, empyema). Atelectatic lung can also be seen with this view (Fig 5). Upright or reverse Trendelenburg positioning may improve detection of pleural fluid.

### Pneumothorax

As eFAST is a relatively new protocol, there are fewer studies evaluating its accuracy in detecting pneumothorax. The diagnosis of small-to-moderate size pneumothoraces with physical examination and supine chest radiography is challenging, and these occult injuries may be missed in up to 76% (81 of 107) of blunt trauma patients (54). In studies using CT as the reference standard, the sensitivity of eFAST is better than that of supine chest radiography. Kirkpatrick and colleagues performed a prospective blinded study of 225 trauma patients with eFAST and reported a sensitivity of 48.8% (21 of 43) for chest US versus 20.9% (nine of 43) for chest radiography (31). Ianniello and co-workers investigated 368 unstable trauma patients with eFAST and reported a sensitivity of 77% (67 of 87) for detection of pneumothorax (55). Another study of 305 trauma patients concluded eFAST had a sensitivity of 43% (32 of 75) compared with chest radiography (11%, eight of 75) (56).

**Figure 5**

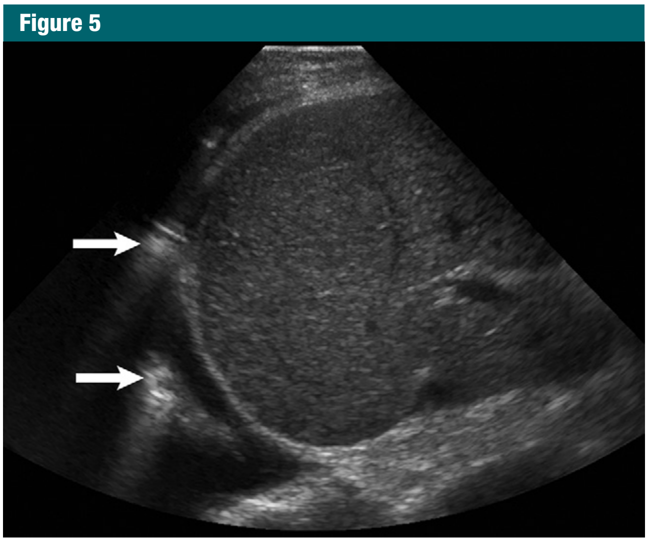
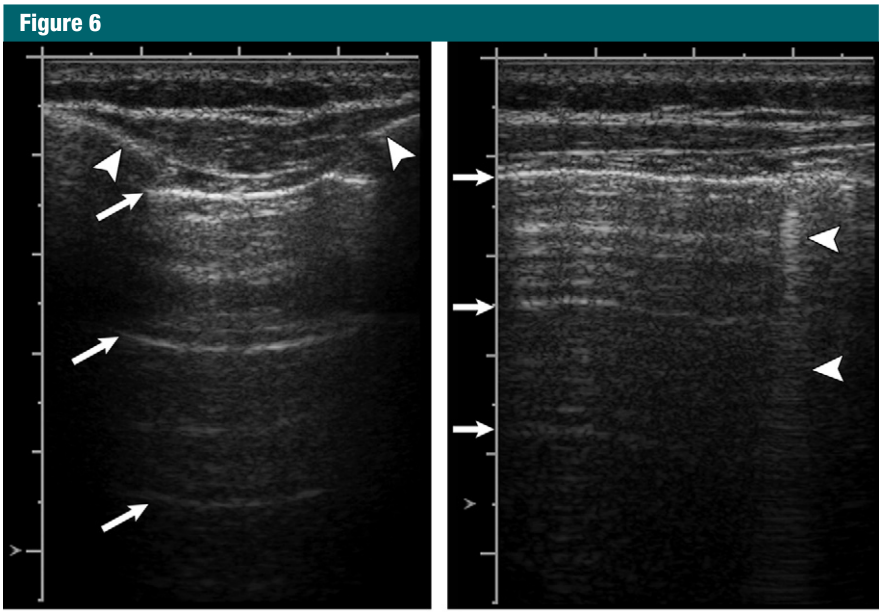


**Figure 5:** Pleural effusion and atelectasis. Scan through the liver shows free fluid in the thorax that surrounds the more echogenic lung (arrows).

**Figure 6**



a.

b.

**Figure 6:** Normal lung. **(a)** Parasagittal view of the lung between the ribs shows shadowing at the anterior ribs (arrowheads). The most anterior echogenic line (arrow just below arrowhead) is the junction of the parietal and visceral pleura, where motion of sliding lung is observed. There are also A-lines (lower two arrows), which are equally spaced reverberation artifacts and decrease in echogenicity with depth. **(b)** Scan between ribs shows the most echogenic line (anterior arrow), or the junction of parietal and visceral pleura which represents the "sliding lung" sign in real time. Multiple reverberation artifacts are noted (posterior arrows). A B-line or "comet tail" artifact is also seen (arrowheads).

For detection of pneumothorax, a high-frequency (>5 MHz) linear transducer probe is preferred, but lower frequency sector transducers and even a curved transducer may also be used. The transducer is placed in the second or third intercostal space in the midclavicular line in sagittal orientation, then moved inferiorly (Fig 3). The probe can also be placed in an oblique fashion between the ribs to obtain a larger view of the lung. The probe should be placed in different positions in the anterior chest and compared with the opposite side to check for pneumothorax. The most helpful US finding in demonstration of normal lung is the "sliding lung" sign (Fig 6; Movies 8, 9 [online]). The echogenic line representing the normal visceral/parietal pleural interface is always observed with US: As the parietal pleura is fixed, sliding of the visceral pleura can be visualized. If the sliding lung is seen, this excludes pneumothorax at that site. Absence of the normal sliding lung is highly suggestive of pneumothorax but may also be seen in any situation where there is no lung movement (57,58). This includes apnea, atelectasis, chronic obstructive pulmonary disease, bullous changes, pleural thickening, postpleurodesis, unilateral mainstem bronchus, or esophageal intubation. Subcutaneous emphysema can obstruct attempts at US of the underlying pleural cavity and is frequently associated with pneumothorax (53). Severity of illness may be a factor, as the positive predictive value of absent lung sliding for detecting pneumothorax is 87% in the general population, 56% in the critically ill, and 27% in patients with respiratory failure (48,59,60).

Other findings observed in lung US include so called "A-lines" seen with normal lung. Confusion may arise, as there are both normal and abnormal A-lines. Normal A-lines are reverberation artifacts from the visceral and parietal pleura. These lines are always

**Figure 7**

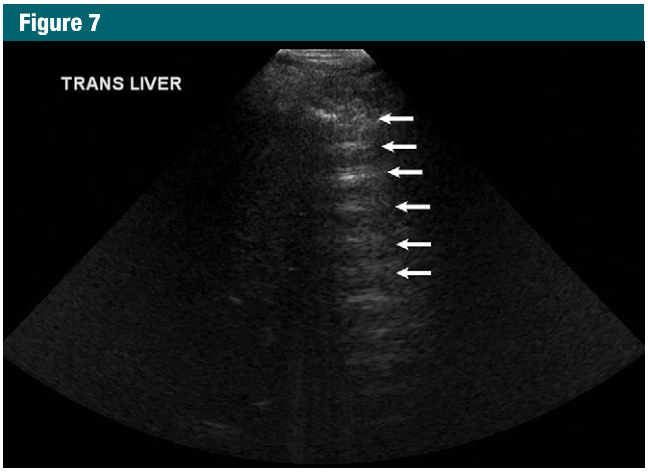


**Figure 7:** Pneumothorax. Note the presence of multiple echogenic A-lines (arrows) but lack of anterior echogenic "sliding lung" interface of parietal/visceral pleura in this small pneumothorax.

**Figure 8**

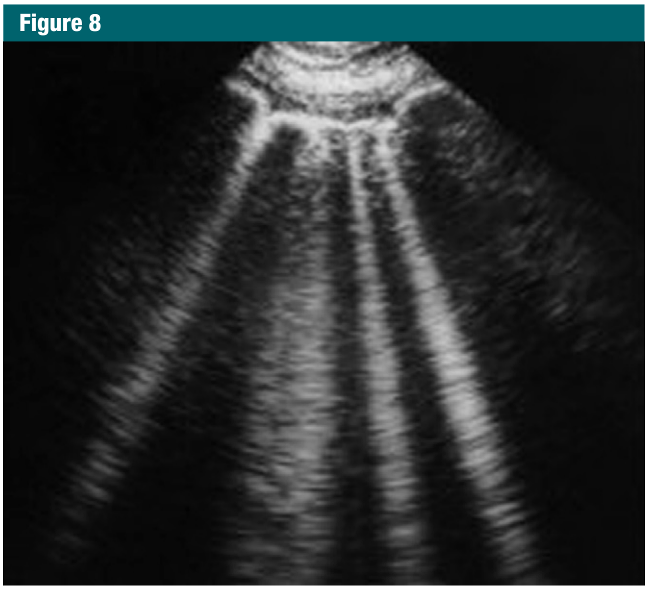


**Figure 8:** Lung rockets. These more numerous B-lines are identified in patients with parenchymal lung disease. If present, these exclude a pneumothorax, especially if "sliding lung" is seen. (Reprinted, under a CC BY license, from reference 57.)

equally spaced and are a predominant feature with normal lung (Fig 6). However, other A-lines may be seen in a patient with a pneumothorax (Fig 7; Movie 10 [online]). In simple terms, A-lines are simply horizontal echogenic lines running parallel to the transducer (61). Other US signs are "B-lines," vertical lines running from the transducer that may extend to the edge of the screen. Both A- and B-lines can be seen in both normal and abnormal lung, but there is a distinction. In normal lung there is always sliding detected, the A-lines are perfectly spaced, and the B-lines are very small. It is thought these B-lines may be small subpleural blebs or trapped fluid. There are many variants of B-lines, including "comet tails," which are thin vertical lines extending only a short distance from the transducer. However, B-lines extending even lower are occasionally seen in normal patients (62). With pneumothorax *(a)* there is absent sliding lung; *(b)* A-lines are present, more numerous than normal, and not evenly spaced; and *(c)* B-lines are no longer present (Fig 7; Movie 10 [online]).

While small B-lines that do not extend all the way through the image are seen in normal patients, longer and more numerous B-lines are seen in patients with pneumonia or pulmonary edema. Visualization of B-lines with absent sliding lung is not diagnostic of a pneumothorax, as B-lines usually are never present with a pneumothorax; if present, this indicates the lung is not moving but may be diseased. Both comet tails and B-lines move with lung sliding. Comet tail and B-line artifacts occur only when the lung surface can be reached by sound waves, thus represent a reassuring finding. More numerous B-lines starting at the pleural surface and extending through the image are termed "lung rockets." These may be seen with either consolidation or pulmonary edema (Fig 8) (63).

The profile of the upper rib, pleural line, and lower rib has the appearance of a bat and is referred to as the "bat sign," which is a normal finding (64). The junction between normal and abnormal lung can be seen and is called a "lung point" (Fig 9; Movie 10 [online]). The lung point can be used to estimate the size of the pneumothorax. There is also the M-mode equivalent of lung sliding called the "seashore sign," and when absent, the "barcode sign" is seen corresponding to pneumothorax (Fig 10). Another term for the barcode sign is the "stratosphere sign." A pneumothorax can only be detected directly under the probe, and smaller, localized pneumothoraces may be missed. Apical pneumothoraces are more challenging to detect because there is a lesser degree of lung movement compared with the lower thorax. Comparison scans of the right and left chest wall may be helpful unless bilateral pneumothoraces are present.

**Figure 9**

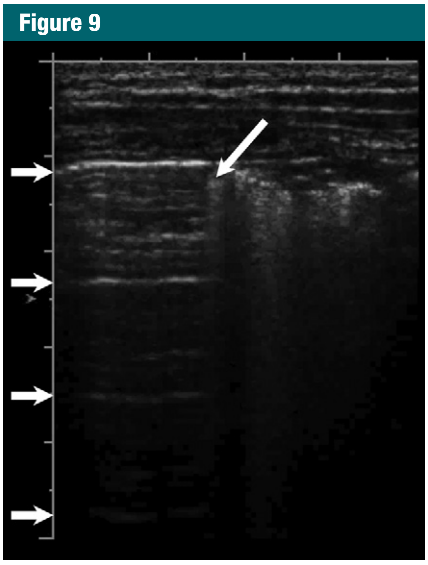


**Figure 9:** Lung point. Normal lung to the left with multiple, equally spaced A-lines (short arrows) and with normal "sliding lung" in real time. A "lung point" (long arrow) separates the normal lung from the abnormal lung to the right.

**Figure 10**

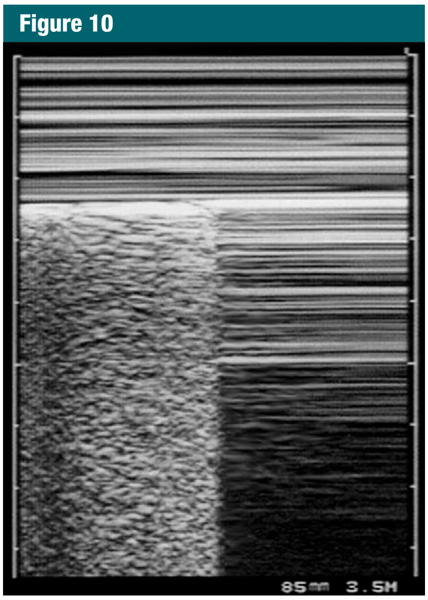


**Figure 10:** Lung point in M-mode. On the left the echogenic interface between the parietal and visceral pleural is seen, and posteriorly there is a granular appearance to the normal lung, the "seashore sign." To the right are numerous lines, termed the "barcode sign," representing pneumothorax. The interface between the normal lung and pneumothorax is the "lung point." (Reprinted, under a CC BY license, from reference 57.)

**Figure 11**

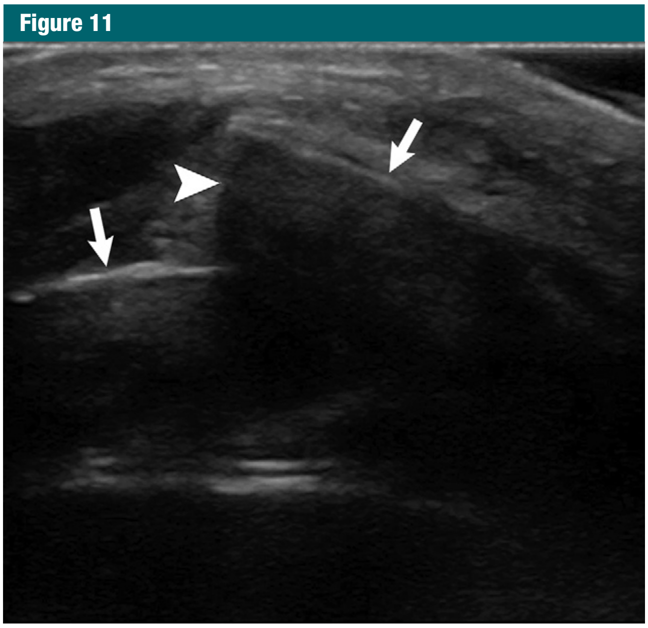


**Figure 11:** Rib fracture. The anterior and posterior echogenic lines (arrows) correspond with the two anterior rib margins and gap (arrowhead) from a displaced rib fracture.

The transducer may also be used to identify rib fractures by following the length of the rib longitudinally. Normal ribs appear as an echogenic thin interface below the soft tissues of the chest wall with posterior acoustic shadowing. Rib fractures may cause a disruption of this smooth, continuous interface (Fig 11; Movie 11 [online]). The sternum may also similarly be insonated if fracture is suspected.

## Inferior Vena Cava

At many trauma centers, FAST has been extended even further to include interrogation of the IVC during respiration as a noninvasive means of volume status assessment. Simonson and colleagues first reported the utility of US in estimating right atrial pressure in healthy volunteers in the late 1980s (65). This study group determined the negative intrapleural pressure generated during inspiration increased venous return to the right atrium. This decreased IVC diameter, with return to baseline during expiration (66). These findings were further developed as a US method to estimate intravascular volume status, especially in hypotensive patients. The most common cause of hypotension in trauma patients is hypovolemic shock from hemorrhage, but injuries to the heart or central nervous system may result in cardiogenic and neurogenic, or distributive, shock. These different forms of shock may be differentiated by performing US of the IVC. There is a general relationship between the IVC diameter and the central venous pressure; this forms the basic science of the way the IVC is measured, as a smaller diameter of the IVC may indicate volume depletion.

US of the IVC is performed with the patient in the supine position using the same low-frequency curvilinear transducer as for the abdominal views. A subxiphoid approach is made with the transducer in sagittal orientation. Superiorly, the IVC enters the right atrium at the cavoatrial junction. The IVC diameter is measured 2 cm below the cavoatrial junction (Fig 12). Inspiratory and expiratory diameters are obtained for comparison (Fig 13). The use of M-mode has been advocated by some to be a more precise method to measure the IVC.

**Figure 12**

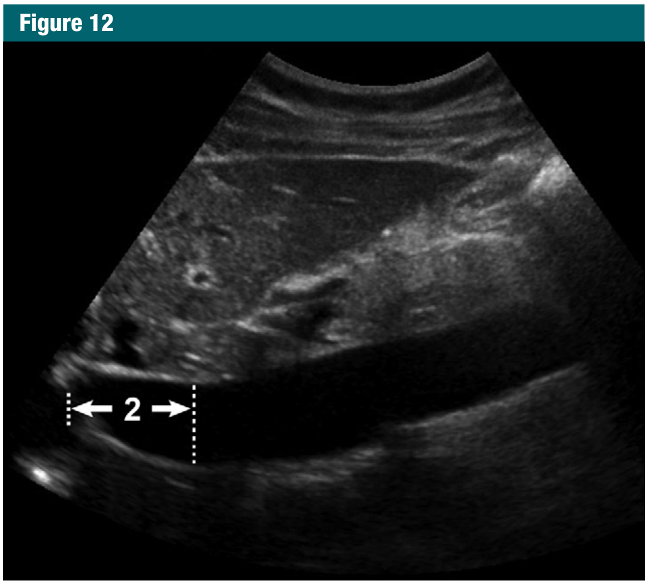


**Figure 12:** Normal IVC. The IVC diameter is measured 2 cm below the cavoatrial junction (arrows) on this parasagittal view.

**Figure 13**

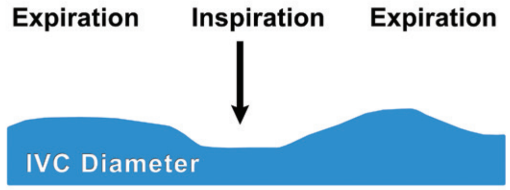


**Figure 13:** Normal variation of IVC diameter with spontaneous breathing in an otherwise healthy patient. This spontaneous change may not be present in certain disease states or positive pressure ventilation.

**Table 2**

**IVC Diameter Change and Correlation with CVP**

| Expiratory IVC Diameter (cm) and Respiratory Change | Estimated CVP (cm $H_2O$) |
|---|---|
| <1.5 | |
| Total collapse | 0–5 |
| 1.5–2.5 | |
| >50% collapse | 6–10 |
| <50% collapse | 11–15 |
| >2.5 | |
| <50% collapse | 16–20 |
| No change | >20 |

Note.—Adapted, with permission, from reference 68. CVP = central venous pressure.

Interpretation of IVC US is based on the diameter and degree of inspiratory collapse of the IVC in nonintubated patients or intubated patients not receiving positive-pressure ventilation (Table 2) (67). The normal expiratory diameter of the IVC is 1.5–2.5 cm, and in the patient with normal volume, the IVC collapses during inspiration to less than 50% of its expiratory diameter. The caval index is calculated as a percentage with the formula: [(IVC expiratory diameter − IVC inspiratory diameter)/IVC expiratory diameter] × 100 (68). An index approaching 100% indicates almost complete collapse and likely volume depletion, whereas an index close to 0% indicates minimal collapse, suggesting volume overload. Ferrada and co-workers studied 101 hypotensive acute trauma patients who underwent IVC US and reported poor prognosis for those patients with a collapsed IVC (69). For trauma patients, the simplest approach is to evaluate the IVC to see if it has substantial collapse with small diameter (< 1.5 cm), indicating volume depletion.

For IVC US, there are diagnostic limitations for its use in the estimation of shock in intubated patients with positive-pressure ventilation, as the IVC diameter will be increased. Severe chronic obstructive pulmonary disease, pulmonary hypertension, right-sided heart failure, cardiac tamponade, and tricuspid regurgitation may also increase IVC diameter and render an inaccurate estimate of shock. Additionally, the IVC can be difficult to detect in hypotensive trauma patients with hypovolemic shock owing to its reduced diameter.

## Serial FAST

As the initial FAST sonogram represents a snapshot in time, serial examinations performed in stable blunt trauma patients may be useful. Examination after stabilization gives the sonographer more time for a comprehensive scan. With active intraperitoneal hemorrhage, the amount of free fluid should theoretically increase with time. The value of serial US has not been fully investigated. Nunes et al reported that serial FAST examinations decreased the false-negative rate by 50% and increased sensitivity for free fluid detection from 69% (nine of 13) to 85% (11 of 13) (70). Other studies have confirmed this trend (71,72). One study group included an additional view of the “interloop” space, a triangular hypoechoic area between bowel, which improved the sensitivity of FAST in both primary and secondary examinations (72). We believe a baseline CT, with high sensitivity in the detection of IAI, could be augmented by FAST performed at the bedside if a patient becomes unstable (Fig 14). Serial FAST examinations may be a logical

**Figure 14**

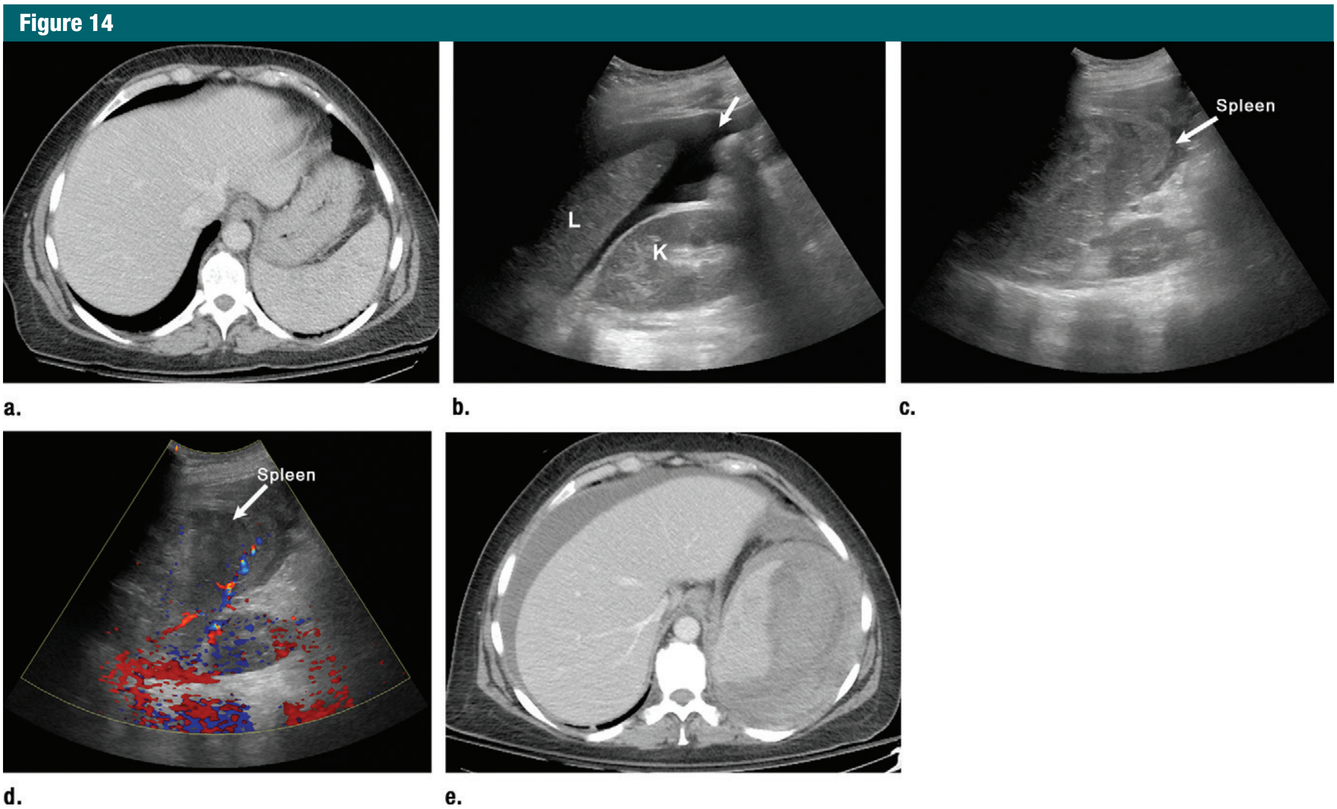


**Figure 14:** Serial FAST in a 44-year-old man with blunt abdominal trauma from a motor vehicle accident with abdominal pain. **(a)** Initial CT scan was interpreted as normal. Slight inhomogeneity of the spleen was thought to be due to normal enhancement of splenic pulp. **(b)** Nine hours later, the patient developed hypotension and a bedside FAST examination was performed, which demonstrated free fluid in the upper abdomen (arrow) and pelvis. *L* = liver, *K* = kidney. **(c)** Real-time images showed marked heterogeneity to the spleen. **(d)** Color flow demonstrated fairly avascular appearance of the spleen. **(e)** Patient was resuscitated and underwent CT, during which a large spleen laceration with subcapsular hematoma and free fluid was detected. Patient was rushed to the operating room for successful emergency splenectomy.

alternative for stable trauma patients, patients with sudden change in hemodynamic status or physical examination, and pregnant patients to mitigate radiation exposure.

## Solid Organ Evaluation

The FAST examination was originally intended to detect intraperitoneal free fluid. However, US is well suited to depict abnormalities of solid organ parenchyma indicative of injury, especially during serial studies. In 1983, vanSonnenberg and colleagues first reported the US appearance of blood as linear echogenic foci in solid organs after fine-needle aspiration biopsy (73). Since then, studies specific for blunt abdominal trauma have been published. The sensitivity for detection of solid organ injury with US has been shown to be limited, with two studies reporting sensitivities of 41% (24 of 58) and 44% (11 of 25) (74,75). During the first few hours after injury, fresh blood clots in the injured organ may have echogenicity similar to that of the parenchyma organs (76). Richards and McGahan and colleagues reported US findings of the parenchyma in solid organ injuries. A diffuse heterogeneous pattern is most commonly detected in splenic lacerations (Movie 4 [online]), whereas a discrete hyperechoic pattern (Movie 2 [online]) is seen most often in hepatic lacerations (77,78). Subcapsular splenic hematomas are detected as either hyperechoic or hypoechoic rims surrounding the parenchyma (Figs 14, 15; Movie 4 [online]), and splenic lacerations tend to become hypoechoic over a few days. For urological trauma, high-grade renal injuries have mixed echogenicity with a disorganized pattern, and bladder hematomas frequently appear echogenic (79).

## Bowel and Mesenteric Injury

Early detection of bowel and mesenteric injuries with FAST is notoriously difficult, as volume of hemorrhage and/or extravasated bowel contents is usually minimal just after time of injury (80). Loops of fluid-filled bowel should not be confused with free intraperitoneal fluid. Bowel loops can be distinguished from free fluid because they are round and have peristalsis. Additionally, pneumoperitoneum from bowel perforation can mimic air within

**Figure 15**

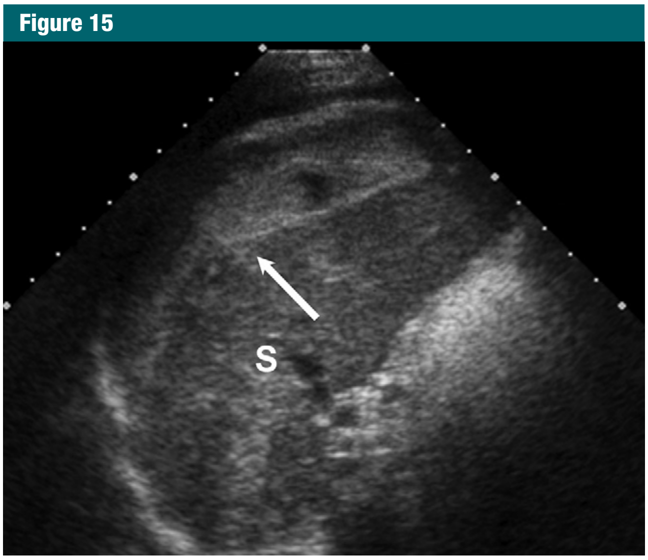


**Figure 15:** Echogenic subcapsular hematoma (arrow) of the spleen *(S)*.

small and large bowel loops at US or appear as echogenic lines, bands, or spots with posterior reverberation artifacts. Free air shifts to the least dependent areas of the peritoneal cavity with change in patient position and is referred to as the "shifting phenomenon" (81). When both free fluid and air are present in the peritoneal cavity, the "peritoneal stripe sign" may be visualized with US: Nondependent air may appear as a thickened echogenic peritoneal stripe with or without reverberation artifacts (82,83). US can depict pneumoperitoneum with high sensitivity and specificity based on two prospective studies (81,84).

## Pregnant Patients

Blunt and penetrating trauma is the leading cause of nonobstetric maternal mortality, affecting up to 7% of pregnancies (85). It is an important cause of fetal loss, and most obstetric complications from trauma occur in the third trimester. The most common mechanism of trauma is interpersonal assault (86). For pregnant trauma patients, US is advantageous in that there is no contrast material or radiation exposure to the mother or fetus. In addition to the rapid assessment for free fluid, US can be used to assess for fetal heart motion, fetal activity, amniotic fluid volume, approximate gestational age, and placenta. A small number of studies have shown FAST in pregnant patients with blunt abdominal trauma to have similar sensitivity and specificity to that in to nonpregnant patients (86–90). Placenta examination is very important, as abruption may have a variety of appearances, such as thickened or avascular regions in the placenta without accompanying free fluid in the pelvis (Fig 16) (91). Placental abruption was only detected with FAST as free fluid in one of seven cases in a series by Richards et al (86). Fetal cardiac activity should always be checked with M-mode, and the fetus should be examined for other injuries sustained during impact to the maternal abdomen (Fig 16). Furthermore, the gravid uterus may distort the usual US landmarks in the pelvic view of FAST. Thus, evaluation of the pouch of Douglas for hemoperitoneum in this patient subgroup requires careful technique and some experience. Distinguishing between intrauterine and extrauterine fluid can be challenging. Free intraperitoneal fluid may result from hemorrhage due to solid organ IAI, amniotic fluid from uterine rupture, or both. For patients with negative or equivocal FAST findings, continuous cardiotocographic monitoring should commence as early as possible to screen for placental abruption (85). While every effort should be made to reduce radiation to the fetus, low-dose CT with contrast material may be necessary in some situations, and intravenous contrast material is classified as a class B drug with no known teratogenic effect to the fetus (92).

## FAST and Pediatric Patients

There have been several studies of FAST utilization in pediatric trauma patients. Several studies have shown sensitivities, specificities, and accuracies similar to those in adults (93–96). However, a similar number have shown lower sensitivity. Fox et al studied FAST in 357 children with blunt abdominal trauma (97). Sensitivity for hemoperitoneum was 52% and specificity was 96%. The authors concluded a positive FAST examination suggests hemoperitoneum, but a negative FAST examination does not help in clinical decision making. A meta-analysis of the question determined pediatric FAST had an overall sensitivity of 66% and specificity of 95% for detection of hemoperitoneum (98). A survey of level 1 trauma centers and dedicated children's hospitals showed that FAST was used in 96% adult-only, 85% combined adult and pediatric, and 15% children's hospitals (99). The authors concluded the greatest impediment to the use of FAST in children's hospitals was the perception of its limited sensitivity and higher proportion of IAI without accompanying free fluid in injured children. The use of FAST in pediatric trauma patients has been used to decrease radiation exposure from CT. In one pediatric trauma study, the need for CT was determined by surgeons trained in FAST (100). In 48% (42 of 88) of patients, the surgeon did not order CT based on the FAST and physical examination. Menaker et al studied 887 hemodynamically stable children with blunt torso trauma and queried their

**Figure 16**

**Figure 16:** FAST in pregnancy. Images obtained in a 33-year-old woman, 34 weeks pregnant, involved in a high-speed car crash. **(a)** A prior 20-week fetal US demonstrated a normal appearing placenta *(P)*. **(b)** FAST showed the placenta to be thickened and heterogeneous, worrisome for placenta abruption. **(c)** Other images show a fractured femur of the fetus (arrow). **(d)** Patient underwent CT, at which a large avascular region was seen in the placenta (black arrows) and a fractured femur (white arrow) was confirmed. **(e)** An emergency C-section was performed that showed an abruption of the placenta, with delivery of a healthy infant with right femur fracture (arrow).

treating clinicians regarding suspicion of injury (101). They determined use of FAST increased as suspicion for IAI increased. Children with low or moderate suspicion of IAI were less likely to undergo CT if they had a negative FAST examination. Figure 17 demonstrates FAST of an infant.

## Training and Experience

Technical errors and level of operator training represent limitations of US detection of traumatic chest and abdominal injury. The level of training required to be considered "experienced" is not clearly defined and differs between organizations representing radiologists, sonographers, emergency physicians, and surgeons. One definition developed from the first FAST consensus conference in 1999 specifies at least 200 supervised examinations must be performed to be considered experienced. During the FAST learning curve, the majority of errors occur in the first 10 examinations (102). Thereafter, accuracy improves and levels after 25 to 50 examinations (103). Jang et al determined false-negative FAST examinations may result from inadequate gain and/or depth settings and incomplete anatomic interrogation by emergency physicians in-training (104). In a comparative study between experienced and highly trained operators (surgeons, radiologists, and sonographers) and resident surgeons with basic US training, the sensitivity of FAST for detection of solid organ IAI in the experienced group was nearly double that of the less experienced group (105).

## Future Applications

The use of FAST in the prehospital setting is becoming more commonplace as US equipment becomes more compact and lightweight. Its use in the field makes FAST ideal for rapid triage of injured patients in multiple casualty incidents or battlefield situations (106–108). The use of FAST after a natural disaster was first described by Sarkisian and co-workers following an earthquake that devastated Armenia in 1988 (109). As there was only one CT scanner in the main hospital, US was used exclusively for diagnosis of traumatic injury. In the 72-hour period after the earthquake, 530 FAST examinations were performed, 96 were positive for IAI, and 16 patients underwent surgical treatment. Other natural disasters in which the use of US for trauma have

**Figure 17**

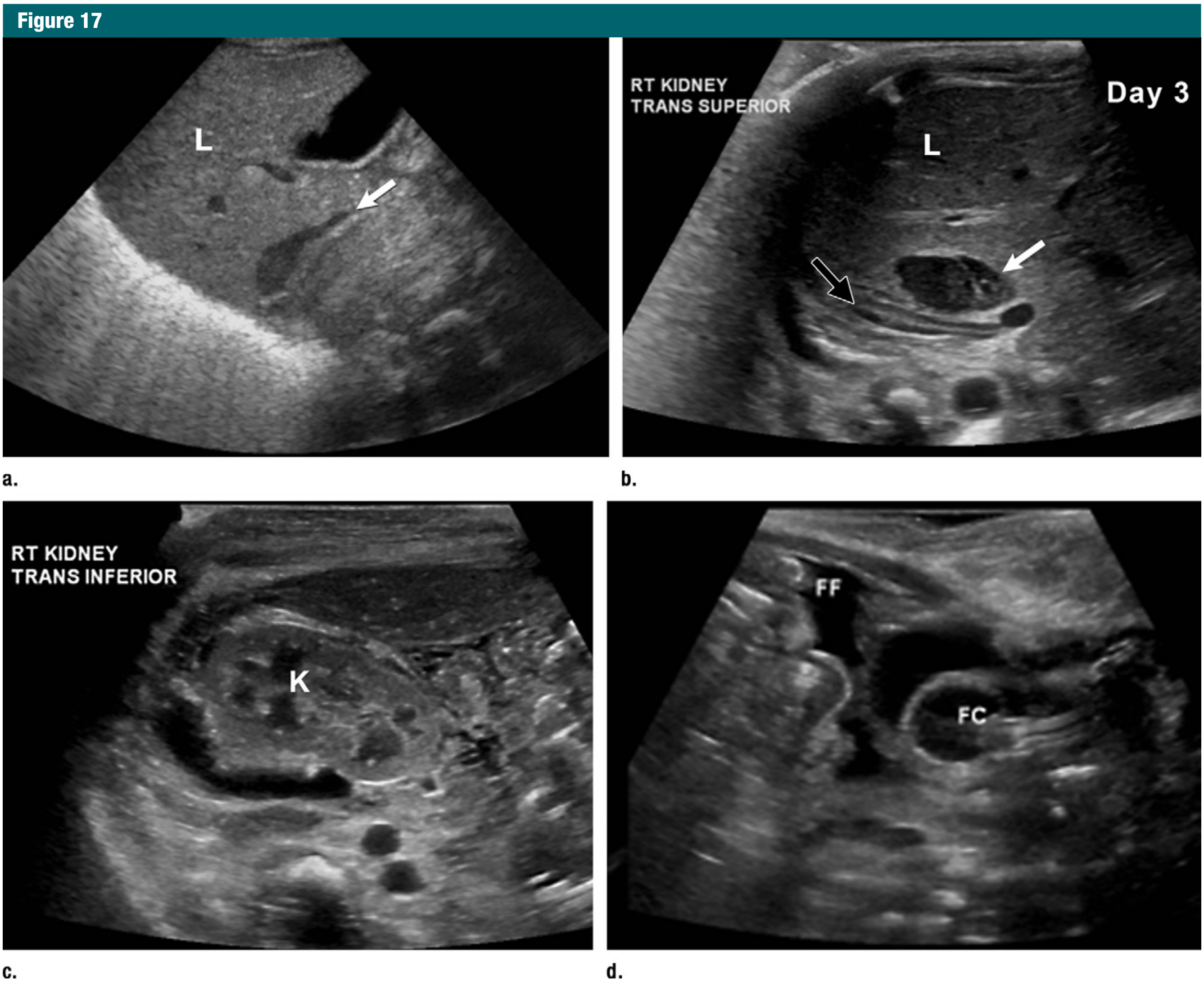


**Figure 17:** FAST in a newborn. Images obtained in the premature infant (born at 34 weeks gestation) from Figure 16. FAST was performed at the infant's bedside after delivery. **(a)** On day 1 there were multiple findings, including a small liver *(L)* laceration (arrow). **(b)** On day 3 the liver *(L)* laceration (white arrow) had increased in size (black arrow = adrenal gland). **(c)** Fluid was noted surrounding the right kidney *(K)*. **(d)** Free fluid *(FF)* was also noted in the pelvis. No CT was performed, and the newborn was treated conservatively. *FC* = Foley catheter.

been reported include earthquakes in Turkey (1999), China (2008), and Haiti (2010), floods in Guatemala (2005), and a cyclone in Australia (2007) (110–114). Terrorist attacks continue to increase in frequency worldwide. It is certain trauma US will take on an even more important role in triage of multiple casualties in these situations. Emergency providers performed FAST following terrorist attacks in Madrid (2004) and London (2005) (115,116). The use of US for detecting long bone and pelvis fractures, especially in mass casualty incidents, is being investigated (37). Outcome prediction for trauma patients arriving in pulseless traumatic arrest is another promising role of US (117,118). With worldwide deaths from injury approaching 6 million per year, the use of portable US in the care of trauma patients in resource-limited areas and situations will undoubtedly have an impact on mortality (119).

A recent systematic review showed moderate evidence supporting prehospital eFAST use (120). It has been used successfully in air medical transport of injured patients. Press et al reported moderate accuracy for helicopter paramedics performing eFAST, with 46% sensitivity and 94.1% specificity for detection of hemoperitoneum and 18.7% sensitivity and 99.5% specificity for detection of pneumothorax (121). Quick and colleagues studied the ability to identify pneumothorax with in-flight thoracic US (122). Nonphysician aeromedical providers were trained to perform and interpret thoracic US. Intubated patients underwent both in-flight and emergency department thoracic US

**Figure 18**

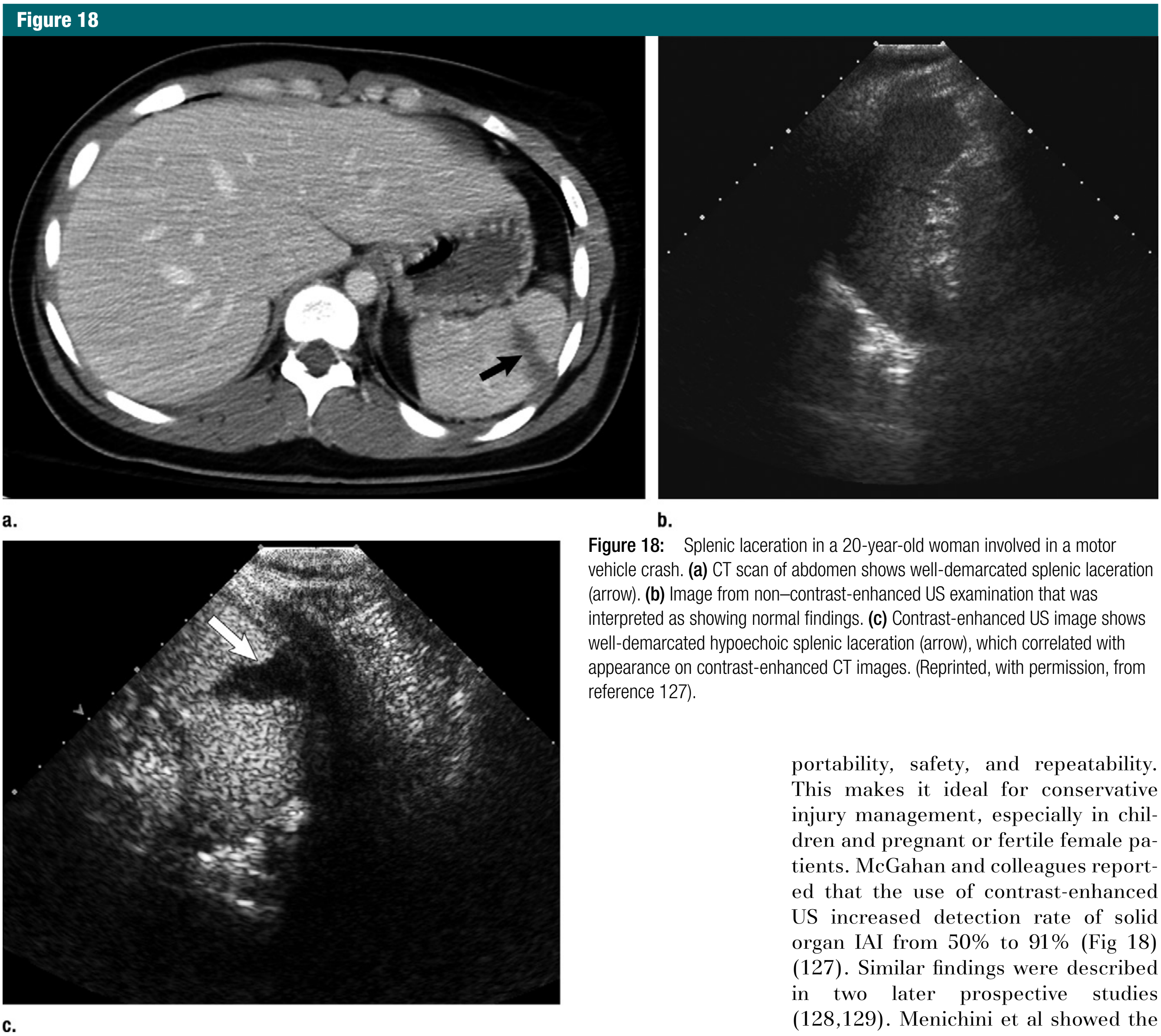


**Figure 18:** Splenic laceration in a 20-year-old woman involved in a motor vehicle crash. **(a)** CT scan of abdomen shows well-demarcated splenic laceration (arrow). **(b)** Image from non–contrast-enhanced US examination that was interpreted as showing normal findings. **(c)** Contrast-enhanced US image shows well-demarcated hypoechoic splenic laceration (arrow), which correlated with appearance on contrast-enhanced CT images. (Reprinted, with permission, from reference 127).

examinations, and findings were compared with chest radiography and CT. Among 149 subjects, 16 of 20 pneumothoraces were correctly identified in-flight, with sensitivity of 68%, specificity of 96%, and accuracy of 91%. In contrast, emergency department US had sensitivity of 84%, specificity of 98%, and accuracy of 96%. Prehospital transmission of FAST images through microwave, satellite, and LifeLink technology has been developed (123,124). The use of a wearable and portable telesonography robot that paramedics can attach to a patient's torso to provide real-time eFAST evaluation during longer transports has been developed and is being evaluated (125). US has also been utilized successfully in weightless situations and on the International Space Station (126).

The role of contrast-enhanced US for trauma is as yet unclear, but it appears to be a promising method to improve detection of parenchymal organ IAI (Movie 5 [online]). Advantages of contrast-enhanced US include lack of ionizing radiation exposure, portability, safety, and repeatability. This makes it ideal for conservative injury management, especially in children and pregnant or fertile female patients. McGahan and colleagues reported that the use of contrast-enhanced US increased detection rate of solid organ IAI from 50% to 91% (Fig 18) (127). Similar findings were described in two later prospective studies (128,129). Menichini et al showed the sensitivity of contrast-enhanced US approached CT in pediatric trauma patients (130). Potential applications of contrast-enhanced US include serial scanning of known organ injuries, follow-up imaging in patients with inconclusive CT findings, and use in patients with hypersensitivity to iodinated contrast agents.

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