Chapter 7
Ultrasound for Point-of-Care Imaging: Performing the Various Exams with Technical Tips

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Introduction

Ultrasound (US) use has increased dramatically in trauma patients over the last 30 years. It has uses in heavily resourced as well as remote, underdeveloped regions. Ultrasound is being studied everywhere, even on the international space station [1]. A good working knowledge of ultrasound is essential when caring for trauma patients.

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Focused assessment with sonography for trauma (FAST) is an important innovation in ultrasound, not because it is a technological advancement but because it redefines who can use ultrasound and when [2, 3]. The FAST establishes the safety and feasibility of using US to diagnose and manage trauma in real time, thus creating the concept of point-of-care ultrasound (POCUS). Currently, POCUS includes both diagnostic imaging, like the FAST, and ultrasound for procedural guidance, including central lines and percutaneous drains. More advanced Doppler capabilities make US useful as physiologic measurement tool as well. A variety of cardiac exams can be used to guide complex resuscitation from the trauma bay to the ICU [4–7]. Taken together, the US is a portable stethoscope, CT scanner, and pulmonary artery catheter in one.

History

Ultrasound has been used in medicine since the 1940s, but the technology was understood long before. In the 1700s, an Italian physicist, Lazzaro Spallanzani, first recognized that bats used echolocation. With the improved understanding of ultrasound physics and the discovery of the piezoelectric effect (the coupling of mechanical and electrical forces allowing the interpretation of ultrasound waves), the ability to use US for diagnostics was born. In 1942, Austrian Neurologist Karl Dussik used an "ultrasonic apparatus" to diagnose brain tumors. In 1948, George Ludwig, an American naval officer, first used US to diagnose gallstones. In 1958, Scottish physician Ian Donald pioneered the use of ultrasound for obstetrics. Through the 1950s, US technology advanced from large machines requiring submersion of the patient in fluid, to smaller devices, to modern handheld ultrasounds [8]. With the increasing access and availability, as well as the decreasing cost, US has spread across medical specialties. With telesonography and virtually guided sonograms, this market will only continue to grow [9].

Focused Assessment with Sonography for Trauma

Physical exam after trauma is frequently unreliable as 20–40% of patients with intra-abdominal bleeding will have a normal exam [10, 11]. Prior to the use of FAST, diagnostic peritoneal lavage (DPL) or surgical exploration was the primary assessment of intra-abdominal bleeding. In most institutions, the FAST exam has essentially replaced the DPL [12]. In the current 10th edition of ATLS, DPL has become an optional skill station [13], while ultrasound is considered an adjunct to the primary survey. Early investigators realized that fluid is easy to see on ultrasound and that FAST could be used to rapidly, noninvasively detect blood in the pericardium and abdomen [14–16].

The traditional FAST has four views: right upper quadrant (RUQ) or Morrison's pouch, left upper quadrant (LUQ), pelvis (P) or pouch of Douglas in women, and subxiphoid (SX) pericardium. The extended FAST (eFAST) adds anterior lung windows to evaluate for PTX [17]. Some centers have added functional evaluation of the heart and the inferior vena cava (IVC) to the eFAST [18, 19]. The eFAST is a reliable and repeatable exam, with a compressed learning curve. While experience yields improved accuracy, the ability to perform an adequate exam is obtained after only a few exams [20, 21].

In hypotensive patients with blunt abdominal trauma, FAST is 100% specific and sensitive for blunt abdominal trauma [14, 22]. In a blunt trauma patient with hypotension, a FAST showing fluid is an indication for operative exploration. Absence of fluid makes it unlikely that intra-abdominal, thoracic, or pericardial bleeding is the cause of hypotension. Furthermore, in stable patients with blunt trauma, FAST will miss up to 30% of injuries, as it misses isolated visceral injury without significant hemorrhage [23–25]. These patients should get further evaluation—usually a CT scan or serial abdominal exams.

In hypotensive patients with penetrating trauma, the FAST is 100% specific and 99.3% sensitive for precordial wounds [14, 22]. For all penetrating torso injuries, the FAST exam was highly specific (94.1–100%), but not adequately sensitive (28.1–100%) [26] for intra-abdominal injury [26]. The authors concluded that a positive FAST was adequate to prompt exploratory laparotomy, even in hemodynamically stable patients. A negative FAST exam does not rule out significant intra-abdominal injuries and should prompt further diagnostic imaging.

In 2004, Kirkpatrick coined the term eFAST and found that the eFAST was comparable in specificity to CXR but had superior sensitivity (48.8% vs. 20.9%) in diagnosing PTX. Other series confirm that US is superior to CXR to diagnose PTX but can fail to detect a small PTX [27, 28].

At the Shock Trauma Center, we perform an eFAST on almost all trauma patients. We believe that a positive FAST in a stable patient with blunt injury can result in more rapid workup and better triage. It may also provide important diagnostic information should a patient deteriorate prior to further diagnostic workup. A positive abdominal FAST in a stable patient with penetrating torso injury should likely prompt an exploratory laparotomy in almost every case. Furthermore, we believe that routine performance of the eFAST exam is necessary for trainees to obtain and maintain ultrasound skills.

General Tips for Learning Ultrasound

Regardless of the exam being performed, the following tips are suggested:

1. *Get to know your machine*: This is the most important factor in safely and reliably using ultrasound.
2. *Clean the transducer and keyboard*: Infection control and patient safety are key points that are often overlooked but are critical to patient safety.

3. *Turn the machine on*: All machines will have an on/off or power button. It is useful to keep the machine plugged in during and between uses. Machines left on may run low on battery power, and start-up can take longer.
4. *Enter the patient data*: Learn how to enter patient data and save the study. All ultrasound machines require a patient identifier to save images, even if it is a temporary identifier.
5. *Select the proper transducer*: The appropriate transducer for the desired exam should be selected.
6. *Select the proper exam type (preset)*: Generally, the machine will default to the last exam. Most machines can be set to start in a particular exam type that will optimize your imaging. Again, it is important to know your machine!
7. *Find the gain and depth controls*: Manipulate depth and gain to optimize images.
8. *Develop patience:* BE PATIENT! Even with the eFAST exam, slow and steady scanning through more than one plane is very important.

Which Transducer to Select for the eFAST?

There is much debate about preferred transducer selection for the eFAST exam. While there is no definitively correct answer, there are benefits and drawbacks of each of the transducers. In general, low-frequency transducers (commonly the curvilinear [C] and phased array [PA]) are best for deeper abdominal or thoracic imaging. High-frequency (HF) transducers (most commonly the linear) are best for imaging superficial structures, such as the pleural line or blood vessels for central line insertion. See Fig. 7.1a–c.

The phased array (frequently called the "cardiac") transducer may be best for imaging between the ribs in the RUQ and LUQ due to its small footprint. In the RUQ and LUQ, the curvilinear (frequently called the "abdominal") transducer may have difficulty maintaining contact with the skin on thinner patients with less subcutaneous tissue. The curvi-

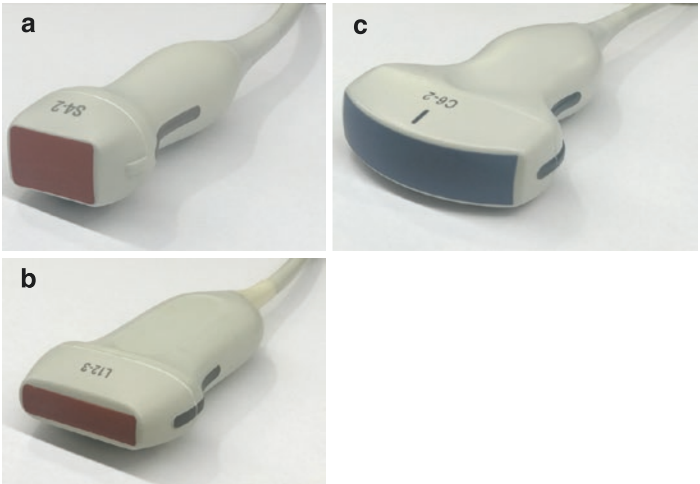

FIGURE 7.1 (**a**–**c**) Common ultrasound transducer types: (**a**) phased array, (**b**) linear, (**c**) curvilinear

linear transducer is best for imaging transabdominal structures such as the aorta, bladder, or gallbladder.

For pneumothorax detection, the sonographer is only trying to visualize pleural line. Thus, use of a high-frequency transducer may be most appropriate. In larger patients in whom the pleural line is several centimeters deep, a low-frequency transducer may be preferred.

In general, we suggest taking the time to use the optimal transducer for each of the six areas on the eFAST exam. This may mean taking several seconds to change transducers. However, we believe that improved image quality leads to more precise decision-making in critically ill trauma patients.

Pathology in the eFAST

Diagnosis of Hemorrhage

Fluid will appear black and collect in dependent areas. It is assumed that “fluid” is blood in a trauma patient; however, it

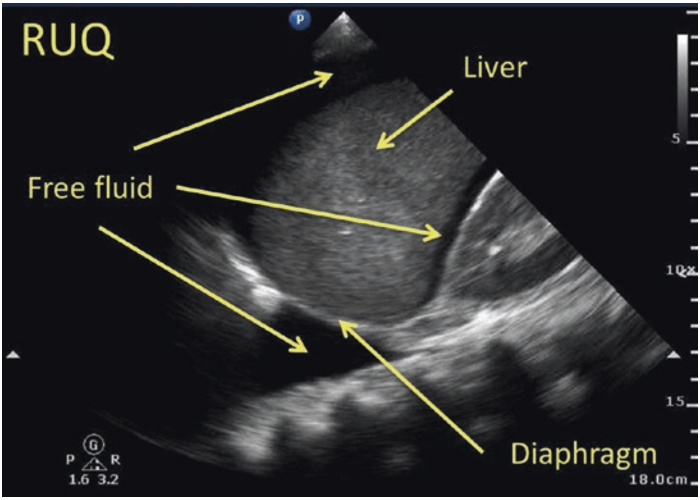

Figure 7.2 Free fluid in the right thorax and RUQ

could be ascites, free bladder rupture, or bowel contents in the abdomen (Fig. 7.2). In older patients, pericardial and pleural effusions are more common and must be considered as a possibility. In addition, clotted blood may have a similar echogenicity (or brightness) to solid organs and can mimic the appearance of those organs.

Diagnosis of Pneumothorax

Diagnosis of a PTX has a steep but short learning curve. A normal lung on the contralateral side makes comparative diagnosis easier. US cannot penetrate air, so the finding is a *loss* of signal in the potential space between the parietal and visceral pleura of the chest. Normally, the parietal and visceral pleural interface "slides," creating a sparkle or dancing effect, termed *sliding*. If pleural surfaces are intact, transmitted cardiac pulsations can be seen in the pleural line – this is called lung pulse. When a PTX is present, lung sliding and lung pulse are lost. A *lung point* occurs when the transition

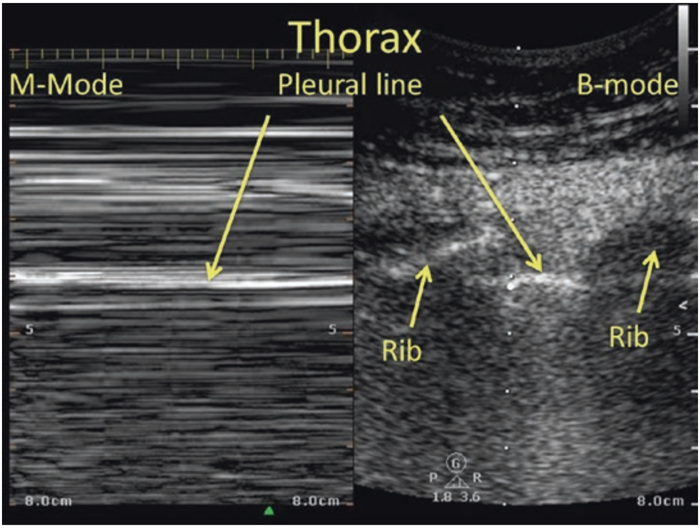

FIGURE 7.3 B-mode on right with cursor placed in between adjacent ribs through the pleural line. M-mode imaging on left with "barcode sign"

from sliding to no sliding can be clearly seen; it is 100% specific for the diagnosis of PTX [29]. Lack of lung sliding alone can be caused by other processes including pneumonia, bullous disease, and other pleural pathologies.

M-mode can help confirm the PTX diagnosis and may be very helpful when initially learning to detect it, but the assessment can be entirely made from 2D imaging. On M-mode, a normal pleural interface will show the bright line of pleura with a smattering of signal returning to the probe from the lung parenchyma, called *seashore sign.* If air is present from a PTX, it will stop the signal, and instead of seashore sign, there will be a series of horizontal lines sometimes called *barcode* or *stratosphere sign* (Figs. 7.3 and 7.4).

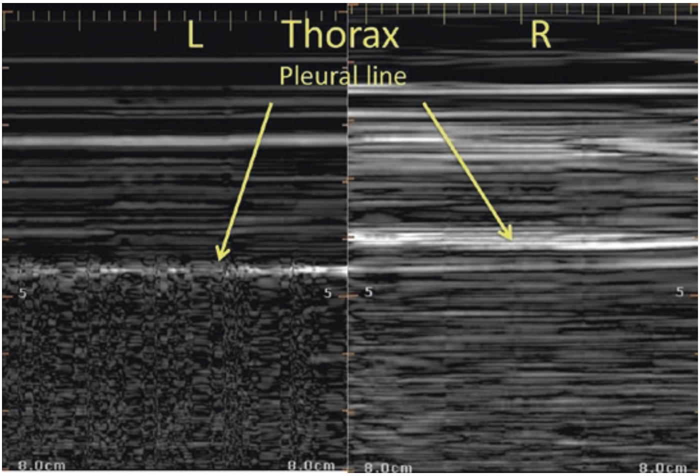

FIGURE 7.4 M-mode on right with "barcode sign" versus a normal M-mode image of lung sliding on left

eFAST Views

Hepatorenal Space or Right Upper Quadrant (RUQ)

The probe is placed along the ribs at the midaxillary line, oriented vertically as in the LUQ view. The right kidney is more anterior than the left. The liver appears as a homogenous gray, and the fascia of Glisson's capsule is a bright white line. Once the kidney is identified, fanning across the area can reveal any free fluid. Visualizing at the caudal tip of the liver maximizes sensitivity. As with the LUQ, the probe is angled cranially to view above the diaphragm to look for free fluid in the thorax. See Figs. 7.5, 7.6, and 7.7.

Critical Image Imaging down to the caudal tip of the liver (or spleen in the LUQ) improves the sensitivity of identification of free fluid (Fig. 7.8).

FIGURE 7.5 Curvilinear transducer positioned in the midaxillary line to view the hepatorenal space

Splenorenal Space or Left Upper Quadrant (LUQ)

The transducer is moved to the posterior axillary line, below the costal margin on the left side. It may be necessary to press your knuckles into the gurney and angle the transducer anteriorly, as the view can be very posterior. Start at the

Figure 7.6 Transducer now angled up to view diaphragm and possible presence of hemothorax in the right thorax

costophrenic angle and then move caudally until the kidney comes into view. The probe should be fanned across the entire kidney. The space between the spleen and diaphragm should be viewed to avoid missing fluid above it. A simple cephalic sweep allows visualization of posterior diaphragmatic recess to assess for hemothorax. See Fig. 7.9.

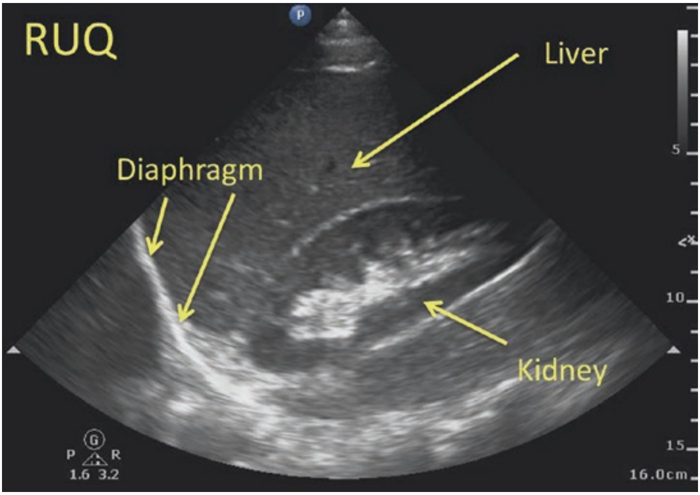

FIGURE 7.7 Negative imaging of the RUQ with views of both R thorax and hepatorenal space

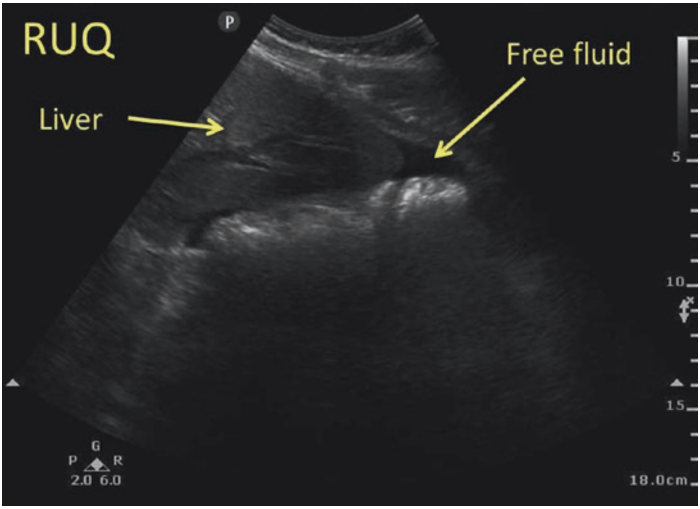

FIGURE 7.8 Imaging down to the caudal tip of the liver (or spleen in the LUQ) improves the sensitivity of identification of free fluid

FIGURE 7.9 The curvilinear transducer is slightly more superior and posterior when compared with the RUQ

Critical Images Free fluid present in both the splenorenal space and above the spleen (Fig. 7.10). Left hemothorax present in the LUQ (Fig. 7.11).

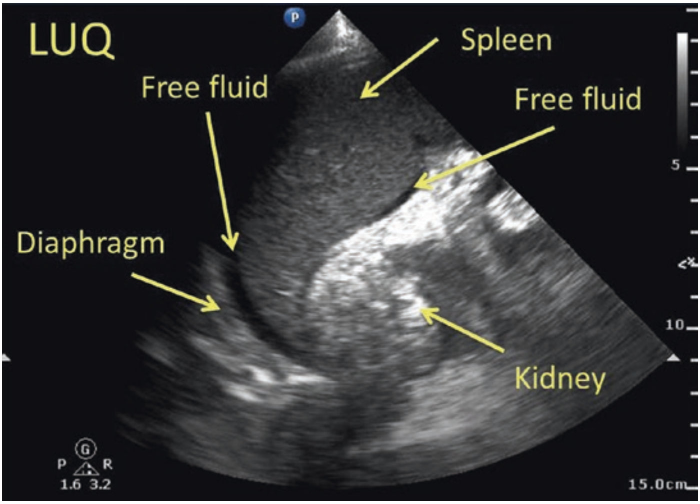

FIGURE 7.10 Free fluid present in both the splenorenal space and above the spleen

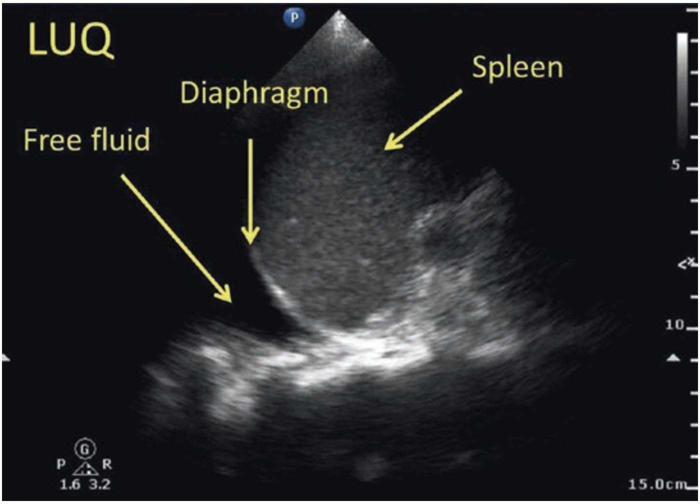

FIGURE 7.11 Left hemothorax present in the LUQ

Pelvis (P)

The transducer is placed just above the pubic symphysis along the midline abdomen, angled toward the feet. The indicator is oriented to the patient's right. The fluid-filled bladder is identified (appearing more square in shape), and a caudal-cranial sweep is performed to obtain adequate transverse views. Longitudinal views can be added to improve sensitivity. The transducer is rotated 90° so the probe marker is now toward the patient's head. A lateral (left to right) sweep is then performed. The goal is to evaluate for fluid in the retrovesical space in men (between the pelvic floor and bladder) or pouch of Douglas in women. See Figs. 7.12, 7.13, 7.14, and 7.15.

Critical Image Positive pelvic FAST with fluid in pouch of Douglas, posterior to the uterus (Fig. 7.16). Positive longitudinal view of the bladder with free fluid posteriorly. Note the Foley balloon in the bladder (Fig. 7.17).

FIGURE 7.12 Curvilinear transducer with transverse view of bladder. Note how the transducer is angled down into the pelvis

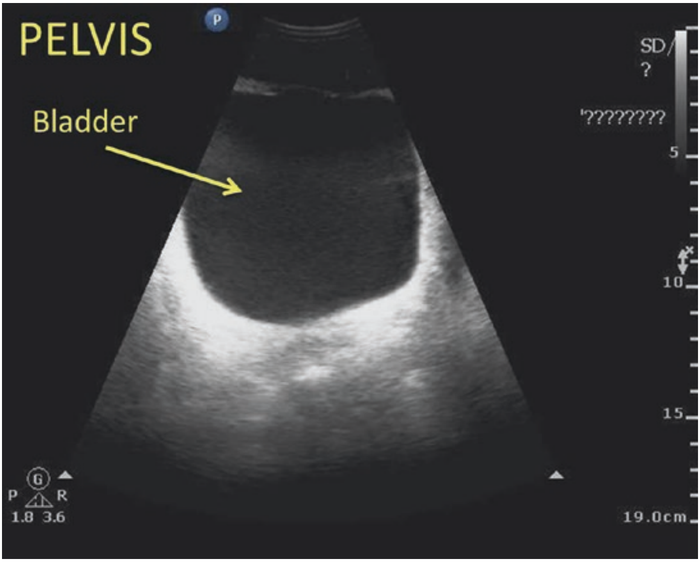

Figure 7.13 Transverse view of the pelvis with urine-filled bladder

Figure 7.14 Transducer now with indicator toward the patient's head for a longitudinal view of the bladder. The transducer remains angled into the pelvis

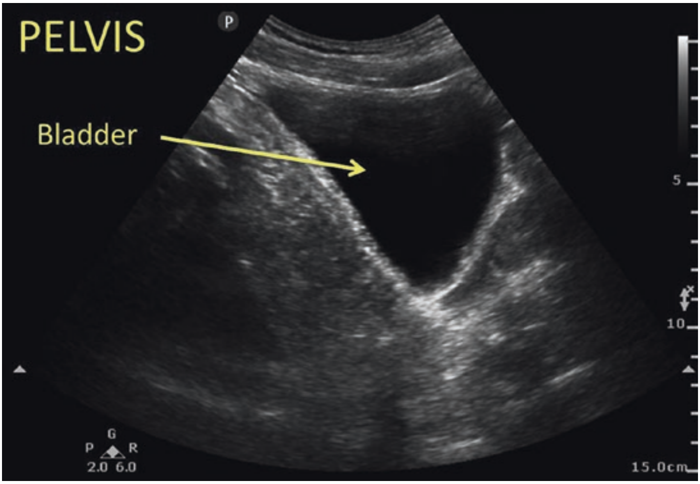

FIGURE 7.15 Negative longitudinal view of bladder

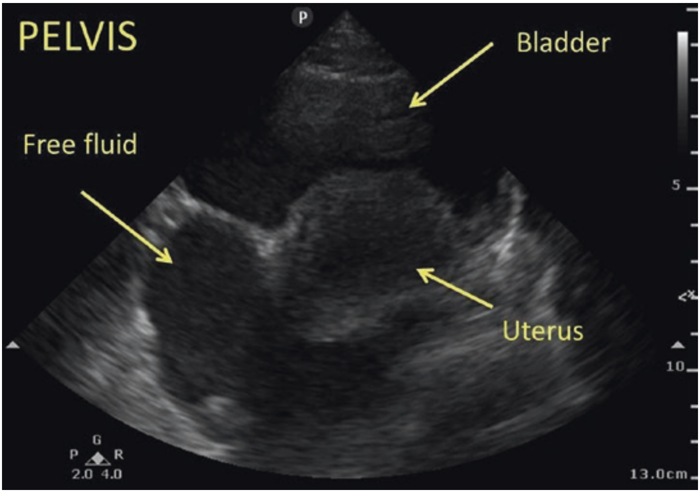

FIGURE 7.16 Positive pelvic FAST with fluid in pouch of Douglas posterior to the uterus

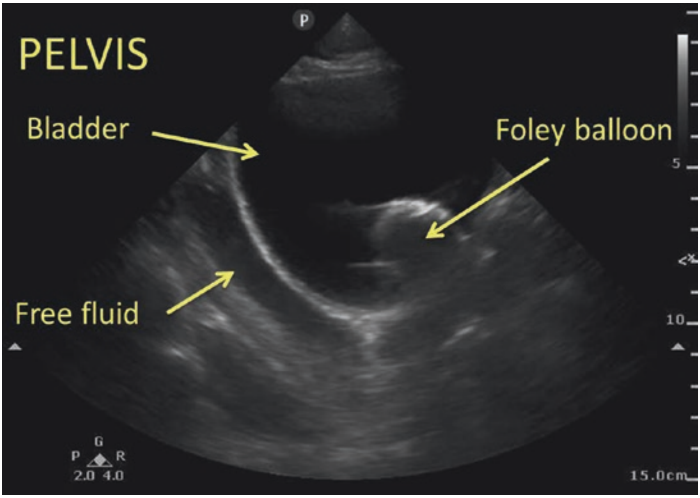

FIGURE 7.17 Positive longitudinal view of the bladder with free fluid posteriorly. Note the Foley balloon in the bladder

Pitfall The transducer should be angled caudally, down toward the patient's feet. The pelvic structures cannot be seen if the transducer is angled perpendicular to the abdomen.

Note Multiple view of the pelvis improves sensitivity. Small amounts of fluid in women can be physiologic. This window is best obtained with a full bladder. An empty bladder can mimic free fluid. Identification of landmarks (bladder/uterus) is necessary to determine a "negative" pelvic FAST.

Pericardial Space or Subxiphoid (SX)

Classically, the transducer is placed about 2–3 cm below the xiphoid, with the indicator to the right, and pointed to the left shoulder, attempting to look "under" the xiphoid to the heart.

The transducer should be nearly flat against the abdomen, when compared with a more perpendicular angle in the other views.

When SX imaging is difficult due to bowel gas, the transducer should actually be moved toward the RUQ under the costal margin, using the liver as an acoustic window. See Figs. 7.18 and 7.19.

Critical Image In the space between the right ventricle and the liver, blood will appear as a black stripe below the pericardial bright white strip (Fig. 7.20).

FIGURE 7.18 SX with phased array transducer

FIGURE 7.19 SX with transducer moved to RUQ to use liver as acoustic window

Pitfall When performing a SX analysis after the abdominal views, the depth on the US machine needs to be increased to see the beating heart.

Parasternal Long (PSL)

Frequently, a SX view is difficult or impossible due to patient body habitus, bowel gas, or abdominal guarding. A PSL view

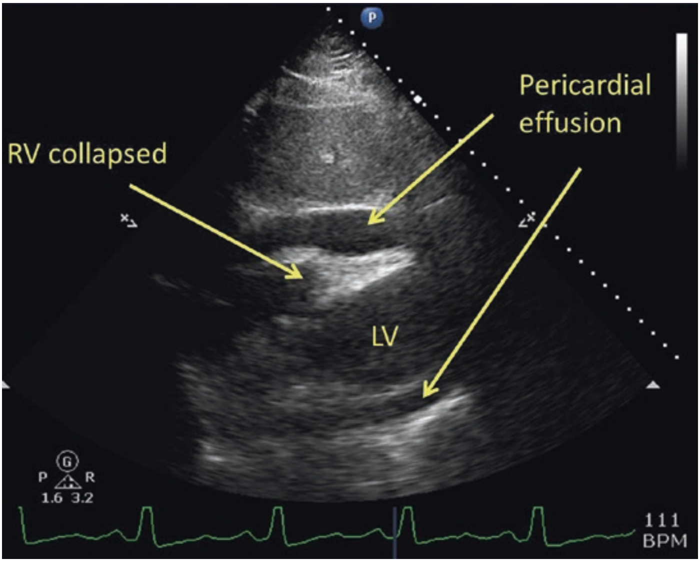

Figure 7.20 In the space between the right ventricle and the liver, blood will appear as a black stripe below the pericardial bright white strip

may be obtained by placing the phased array transducer just left of the sternum at the patient's 3rd–4th intercostal space with the indicator pointed toward the patient's left shoulder. Fluid will appear black and should accumulate posteriorly between the left ventricle and pericardium. In older, more obese patients, epicardial fat may appear dark gray and is typically only anterior. Do not confuse epicardial fat with pericardial fluid. See Fig. 7.21.

Critical Image PSL view with posterior pericardial effusion anterior to descending thoracic aorta (Fig. 7.22). PSL with pleural effusion that is posterior to descending thoracic aorta (Fig. 7.23).

Figure 7.21 PSL view with phased array transducer

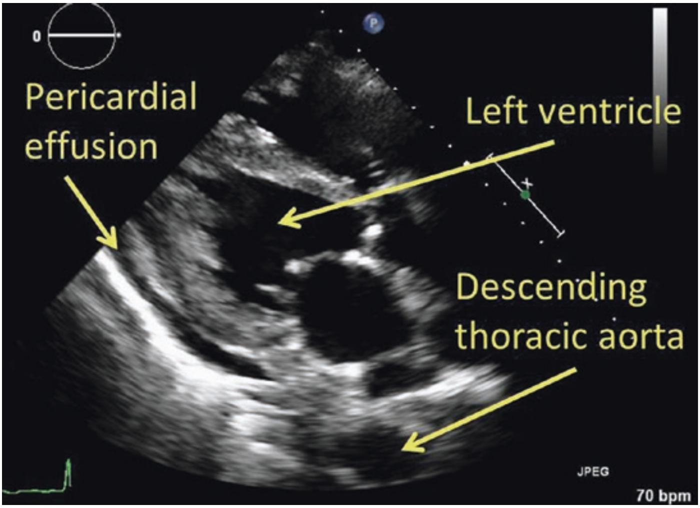

Figure 7.22 PSL view with posterior pericardial effusion anterior to descending thoracic aorta

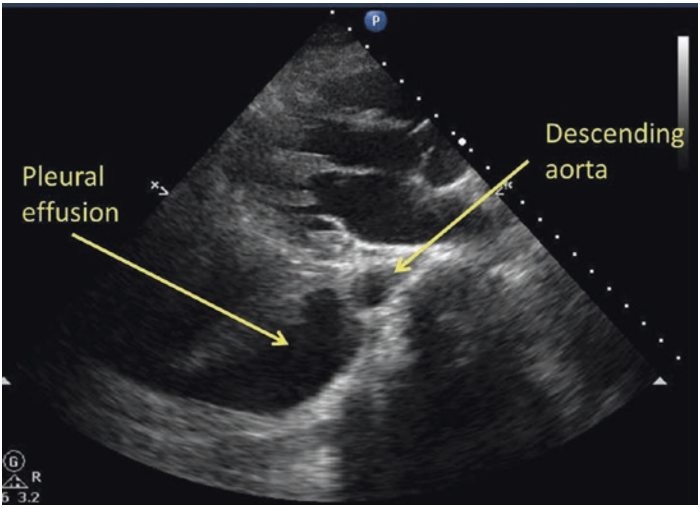

Figure 7.23 PSL with pleural effusion that is posterior to descending thoracic aorta

Pitfall In the case of penetrating cardiac trauma, blood can decompress into the chest rendering the pericardial window negative. In this case, thoracic ultrasound (or chest X-ray) will show a hemothorax. Suspicion of a cardiac injury must remain high.

Right and Left Anterior Thorax

The transducer is moved to the least dependent area of the left and right chest. In a supine patient, this is usually the midclavicular line of the second or third rib. A HF probe can be used, but it is not a requirement. The probe is oriented transversely across the rib. An acoustic shadow artifact makes the rib easy to see. Just below the rib, a shiny horizontal line representing the interface of the parietal and visceral pleura can be seen. M-mode can be applied to confirm 2D imaging if available.

Critical Image The pleural line of the most anterior aspect of both chests (Figs. 7.2 and 7.3).

What Is the Appropriate Order of the eFAST Exam?

When evaluating patients with blunt trauma, the clinical situation dictates whether to start with chest or abdominal imaging. In patients with hypoxia or significant chest pain or shortness of breath, whether hemodynamically stable or unstable, we recommend starting with PTX assessment because chest tube insertion can be performed immediately in the ED and while the sonographer proceeds to abdominal imaging. Otherwise, in patients without significant chest complaints or findings, we prefer the following series of imaging:

$$\text{RUQ} \rightarrow \text{LUQ} \rightarrow \text{Pelvis} \rightarrow \text{Pericardium} \rightarrow \text{R Thorax} \rightarrow \text{L Thorax}$$

Again, we recommend that the sonographer assess the posterior diaphragmatic recess for hemothorax while imaging the hepatorenal and splenorenal spaces in the abdomen.

In general, we recommend a systematic approach to abdominal imaging (RUQ → LUQ → Pelvis), starting with the RUQ because it is the most commonly "positive" area in the abdomen and is most sensitive for hemoperitoneum [30].

For penetrating thoracoabdominal trauma, we recommend starting with pericardial imaging (subxiphoid and/or parasternal long axis) to assess for cardiac tamponade and effusion. We then recommend proceeding to PTX assessment with the HF transducer on both sides of the thorax. The sonographer should then proceed to the abdominal views.

$$\text{Pericardium} \rightarrow \text{R Thorax} \rightarrow \text{L Thorax} \rightarrow \text{RUQ} \rightarrow \text{LUQ} \rightarrow \text{Pelvis}$$

Pearls and Pitfalls of the FAST

- Should be able to be performed in 3–4 minutes
- Low-frequency probe (3–5 MHz), curvilinear probe (C), or phased array (PA)
- High-frequency probe for PTX detection (pleural line imaging) is preferred.
- Ultrasound should be performed during the primary survey in an unstable patient and the secondary survey in a stable patient. It should never interfere with resuscitation. The patient is more important than the eFAST.
- A negative abdominal FAST does not rule out clinically significant injury. It may frequently miss mesenteric, bowel, retroperitoneal, or diaphragmatic injury.
- The abdominal FAST is poor at detecting fluid volumes less than 400 mL.
- The eFAST is more sensitive and specific than CXR in the diagnosis of PTX.
- Repeated eFAST exams improve sensitivity and should be repeated with clinical changes.

IVC Ultrasound in the FAST

The IVC can be easily visualized from the SX window, by simply fanning over the liver and finding the IVC/RA junction. The probe is then rotated so the IVC is in long axis. Both the diameter of the IVC (< 1 cm, 1–2 cm, and >2 cm or FLAT vs. FAT) and its respiratory variations are reflective of volume status. M-mode can be used to better quantify both measures. The measurement is relatively easy and has utility in initial fluid management. If the patient is on positive pressure ventilation, it is unreliable.

Cardiac Ultrasound

Background

The assessment of volume status, responsiveness to fluids, and cardiac function is difficult, especially in the intubated patient. Focused cardiac ultrasound (FOCUS), like the FAST, is performed by the treating physician to answer specific questions. With a 1-day course and a limited number of proctored exams, practitioners can become competent in diagnosing severe LV and RV cardiac dysfunction [6, 31].

The focused rapid echocardiographic evaluation (FREE) is a hybrid between a formal echo and a bedside cardiac ultrasound. The FREE incorporates measurements of cardiac function and volume status, with clinical information, and characterizes hemodynamics [5]. The majority of the time, one can place left ventricular function into "depressed," "normal," or "hyperdynamic" categories. The right ventricle can occasionally be assessed as well as "full" or "empty" [6, 32].

Cardiac Views

There are four standard windows: the parasternal long axis (PSL), parasternal short axis (PSS), apical four chamber (A4C), and SX. Echo-based presets will generally orient the groove on the right, which is the opposite of the abdominal presets. Familiarity with all windows is important, as each window provides different information. If performing the exam in abdominal or FAST presets, the probe would need to be turned 180°. Here are the standard cardiac views:

1. *PSL*: The transducer is placed to the left of the sternum from the second to the fourth interspace in non-intubated patients and fourth to sixth interspace in mechanically ventilated patients (Fig. 7.21). The groove is oriented to the patient's right shoulder, and the transducer is gently rocked under the sternum. The LV can be seen in long axis (Fig. 7.24).

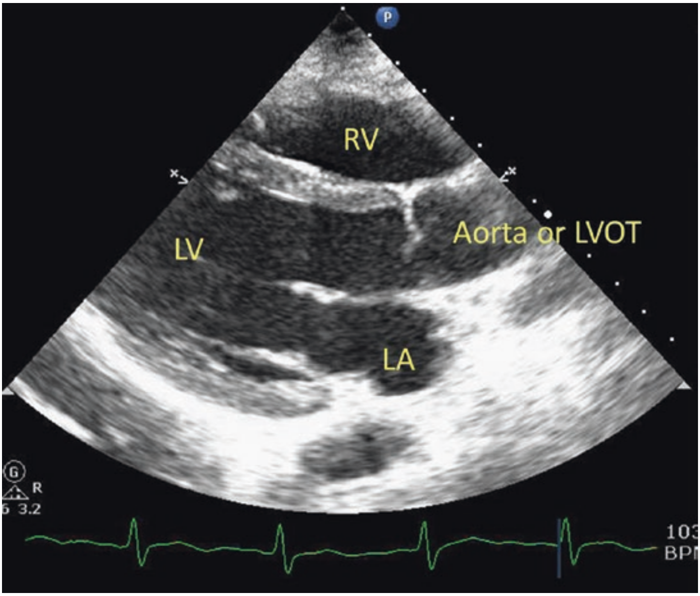

Figure 7.24 Parasternal long axis (PSL) cardiac view: LV can be seen in long axis

2. *PSS*: The transducer is rotated 90° so that the indicator points toward the left shoulder (Fig. 7.25). The LV and RV are seen in cross section. The transducer is rocked up to visualize the aortic valve and then down to see the LV at the mitral, papillary muscles, and the apex (Fig. 7.26).
3. *A4C*: The transducer is moved to the apex of the heart. This is usually located between the sixth and eighth interspace of the left chest (Fig. 7.27). It is generally lateral (at anterior axillary line) in non-intubated patients and more medial and inferior in intubated patients. The groove is oriented to the patient's left. Propping the right side of the patient up can improve the view. The LV and RV are visualized. If the transducer is rocked up, the aortic valve can be seen. This view is the best view for comparing the LV and RV (Fig. 7.28).

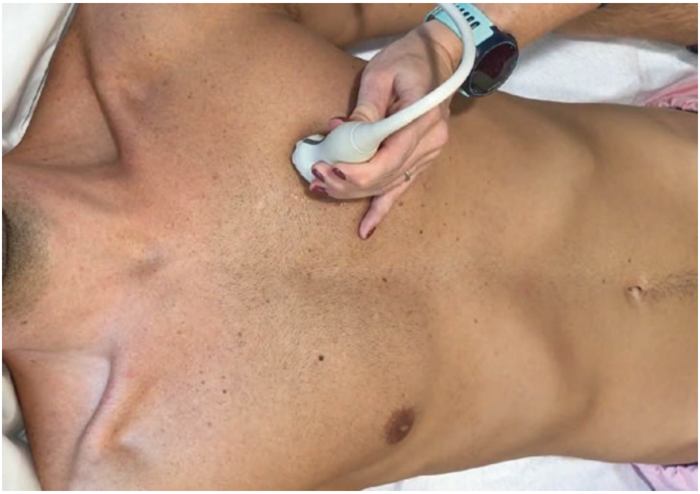

FIGURE 7.25 Parasternal short axis (PSS) cardiac view: The transducer is rotated 90° so that the indicator points toward the left shoulder

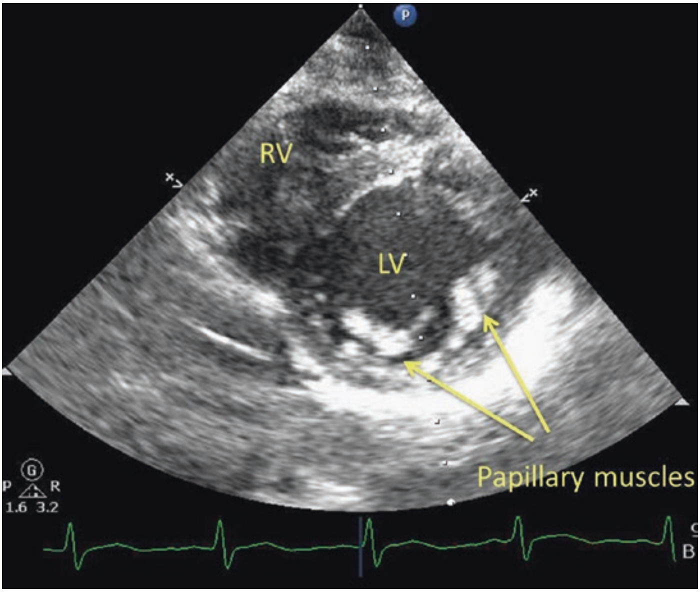

Figure 7.27 Apical four-chamber (A4C) cardiac view: The transducer is moved to the apex of the heart. This is usually located between the sixth and eighth interspace of the left chest. It is generally lateral (at anterior axillary line) in non-intubated patients and more medial and inferior in intubated patients. The groove is oriented to the patient's left. Propping the right side of the patient up can improve the view

4. *SX*: The transducer is moved 2–4 cm below the xiphoid, and the groove is oriented to the left. The transducer is rocked up and looking under the xiphoid (Fig. 7.18). The RV and LV can be seen (Fig. 7.29). The ventricles are often foreshortened and can appear globular. If this is the case, the transducer should be flattened more against the abdomen. Pericardial fluid can be seen superficial to the RV. The groove is then rotated toward the head and angled slightly toward the liver to see the IVC in long axis (Fig. 7.30a, b).

Figure 7.26 Parasternal short axis (PSS) cardiac view: The LV and RV are seen in cross section. The transducer is rocked up to visualize the aortic valve and then down to see the LV at the mitral, papillary muscles, and the apex

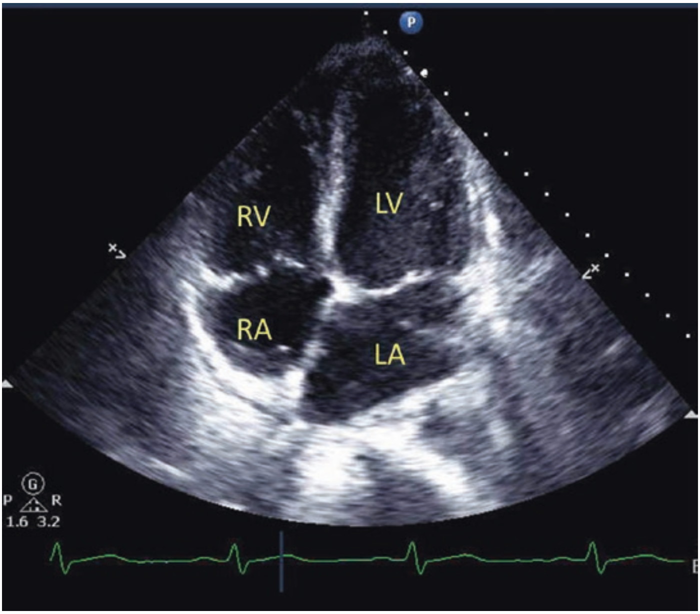

Figure 7.28 Apical four-chamber (A4C) cardiac view: The LV and RV are visualized. If the transducer is rocked up, the aortic valve can be seen. This view is the best view for comparing the LV and RV

Future Directions

There may soon be a role for the US in the bedside evaluation of solid organ injury (especially with the use of IV contrast), in the initial workup of traumatic brain injury (optic nerve sheath diameter may predict ICP), diagnosis of pelvic fracture, diagnosis and treatment of pneumothorax, confirmation of endotracheal tube placement, and assessment of long bone fractures. Ultrasound has been studied as a tool for

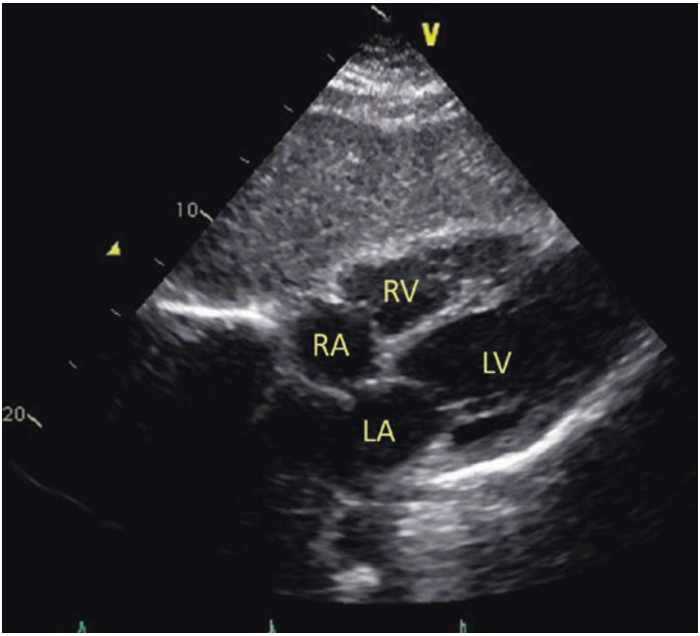

Figure 7.29 Pericardial space or subxiphoid cardiac view. The RV and LV can be seen. The ventricles are often foreshortened and can appear globular. If this is the case, the transducer should be flattened more against the abdomen. Pericardial fluid can be seen superficial to the RV

mass casualty triage, as a triage tool in the prehospital environment, and for providing portable diagnostics in the battlefield or humanitarian environments. US is the only diagnostic modality available on the international space station. With cost pressures, convenience, and risk of ionizing radiation, it seems that US is poised to change the face of diagnostic imaging.

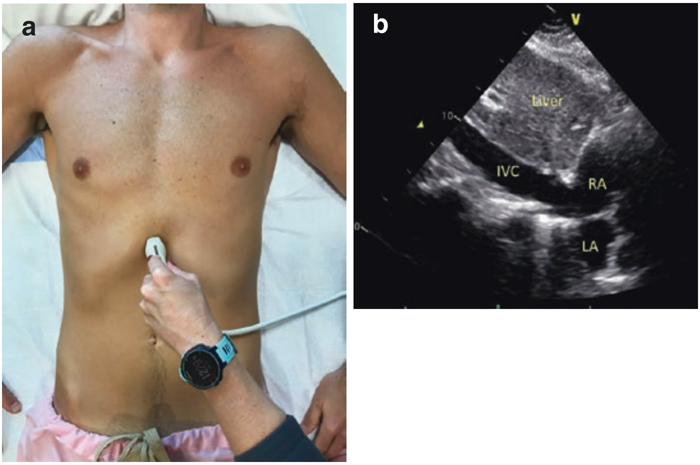

Figure 7.30 (**a**, **b**) Pericardial space or subxiphoid cardiac view: The groove is then rotated toward the head and angled slightly toward the liver (**a**) to see the IVC in long axis (**b**)

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