Chapter 14
Ultrasound in Trauma Critical Care

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Introduction

Some of the earliest descriptions of ultrasound as a rapid and noninvasive tool in the evaluation of the trauma patient date back to the early 1970s [1]. By 1976, Asher and colleagues had published data describing reliable use of ultrasound in the diagnosis of splenic injury [2]. Widespread adoption of ultrasound in the American medical and surgical communities progressed quickly in the 1990s [3, 4]. An earlier example of the role of ultrasound in triage and patient management occurred in 1988 during a major earthquake in Armenia, highlighting the utility and significance of this evolving diagnostic tool. During this mass casualty event, death toll estimates reached 25,000 with an additional 150,000 injured. Medical centers left standing were overwhelmed. In an attempt to triage those needing immediate surgical intervention, screening ultrasounds were performed in the reception area of one hospital on 400 patients within the first 72 h after the quake. The average time spent on each patient was 4 min. Trauma-related pathology of the abdomen and/or retroperitoneal space was identified, correctly, in 12.8 % of patients, with only 1 % false negatives and no false positives [5]. False negative cases included solid organ hematomas and retroperitoneal injury, highlighting important limitations that must be considered when using ultrasound as an examination or diagnostic tool.

In current practice, point of care ultrasound training is recommended for residents by both the American College of Surgeons and the American College of Emergency Physicians [6]. The Focused Assessment with Sonography in Trauma exam, or FAST exam, has existed in the curriculum for the advanced trauma life

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support (ATLS) course since 1997 [7], and has become standard of care for evaluating the unstable trauma patient. In the transition from the trauma bay to the medical, surgical, or trauma critical care unit, trauma patients continue to remain ideal candidates for this portable, noninvasive, and rapid technology. Patients in the intensive care unit (ICU) frequently require ventilatory support, may be hemodynamically unstable, and are difficult to transport. The ability to perform serial ultrasound exams provides valuable clinical information without adding additional radiation risk to the patient. Furthermore, ultrasound assists in the monitoring of patients for whom nonoperative management of traumatic abdominal injuries is preferred, e.g., splenic lacerations.

In this chapter, we will examine the use of ultrasound in the setting of trauma, both in the initial patient evaluation and the critical care setting. We will illustrate and discuss both normal and abnormal images of the abdomen, heart, and lung. We will also explain standard techniques of image acquisition and comment briefly on evolving uses of ultrasound in trauma. The extended FAST (eFAST) exam asks the additional questions of whether fluid is visible above the diaphragm, or if a pneumothorax is present. At the chapter's conclusion, we will illustrate a sample clinical protocol for integrating the FAST and eFAST exams into the management of the trauma critical care patient.

Technical and Patient Considerations

Successful diagnostic ultrasonography results from a combination of operator skill and the right equipment. Similar to computers and smartphones, companies producing ultrasound machines have responded to increased consumer demand for miniaturization and have created handheld ultrasound machines which may to be carried in the pocket of a white coat. While these devices are attractive in their advanced design and portability, their diminutive size makes theft or misplacement a costly possibility in the busy environments of trauma and critical care. Additionally, the small screen size can make image interpretation difficult for other team members, decreasing its utility as a teaching tool for early learners. In contrast, older ultrasound machines of significantly larger size may be difficult to maneuver in the crowded trauma bay and limited space of the ICU. A compromise of size, durability, and quality will ultimately guide an appropriate machine selection. For probe selection, a phased array or curvilinear probe ranging in frequency from 2 to 5 MHz (Fig. 14.1) is most commonly used to acquire images in the FAST exam. The lower frequency sacrifices some resolution but improves penetrance, a critical component in the search for deeper visceral injury.

The target patient population for the eFAST exam is any patient with a history of blunt or penetrating thoracoabdominal trauma and/or any patient with unexplained hypotension or shortness of breath in a known or suspected trauma. Other accurate modalities exist for detecting pathologic thoracoabdominal free fluid, such as computed tomography, but ultrasound is ideal in that it may be performed at the bedside

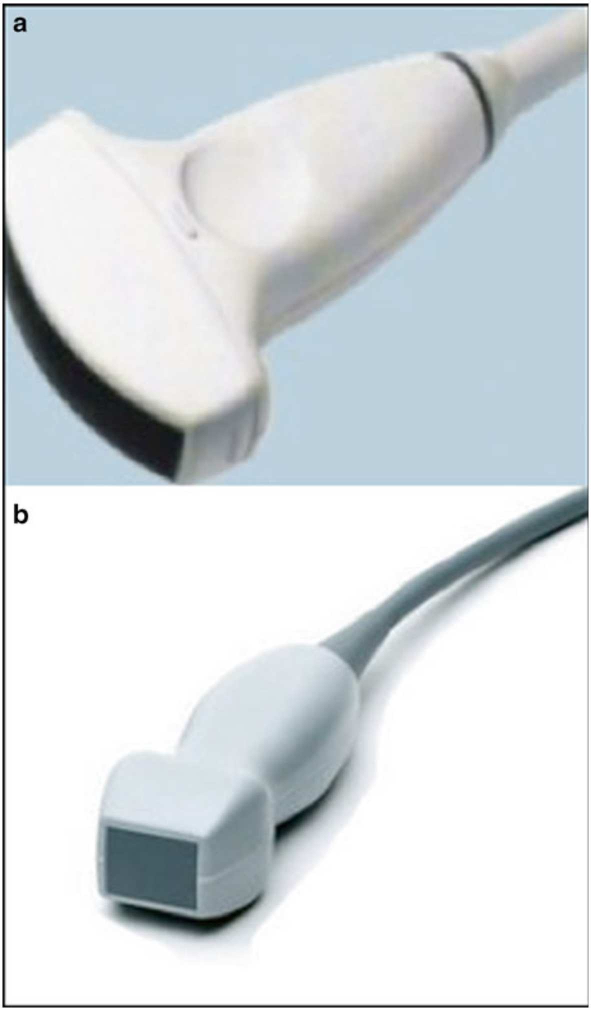

Fig. 14.1 (**a**) Curvilinear probe, (**b**) phased array probe

of the unstable patient for whom transport to radiology poses too great a risk. Previous gold standard diagnostic methods, such as peritoneal lavage, have an extremely high sensitivity for detecting abdominal free fluid (98 %) [8], but pose the risk of exposing the patient to a nontherapeutic laparotomy [9]. For this reason, their use in practice has waned in favor of less invasive methods [10]. Both morbid obesity and the presence of subcutaneous air dramatically reduce the sensitivity of the FAST exam. Patients with these conditions should be approached with caution when the suspicion for the presence of abdominal or pericardial free fluid is high. One method of increasing the sensitivity of the FAST exam is placing the patient in the Trendelenburg position, a feasible maneuver as most trauma patients arrive supine with cervical spine immobilization [11]. Further limitations of the FAST exam will be discussed later in the chapter.

Image Acquisition and Interpretation

The traditional FAST exam is performed with a goal of obtaining three views of the abdomen and a single view of the pericardial space, or four views in total:

1. Right upper quadrant (RUQ) or Morison's pouch/hepatorenal space
2. Left upper quadrant (LUQ) or splenorenal space
3. Pelvic view
4. Subxiphoid or other pericardial view

The exam addresses the focused question of whether free fluid is present in the abdomen and/or pericardium. Some authors have traditionally taught that the first view acquired is the subxiphoid or other pericardial view, with a goal of allowing the operator to adjust the gain based on the appearance of intracardiac fluid. Our current discussion will focus on the patient with blunt or penetrating abdominal trauma, for whom the first view obtained should be that of the most dependent space in the peritoneum, known as Morison's pouch.

A discussion of orientation is important, as this component of ultrasonography may be difficult for the novice and is crucial for accurate image interpretation. Figure 14.2 illustrates the relationship between the probe marker, the orientation mark on the screen, and the operator. Understanding that the probe uses a credit card thin beam to create a two-dimensional image from three-dimensional structures takes some practice; one analogy used is that of "shining a flashlight in a dark room." What is visible on the screen is only that which is present in the probe beam's path; once the beam moves beyond the object, the image is no longer visible, but it does not mean that the object does not exist.

Fig. 14.2 The *yellow star* denotes the corresponding direction between the screen, the probe, and the operator

Varying clinical circumstances and space availability hinder the practice of performing the FAST exam on a dedicated side of the patient and require flexibility on the part of the operator. Therefore, while the exam may be performed from either side of the patient and with either hand, depending on the operator's comfort, the image planes should remain consistent. Images will then be dutifully replicated with attention to marker consistency and operator orientation to patient. We recommend one-handed scanning, whether right or left, with the operator's other hand free to adjust the gain, depth, and other components of the image. All images should be obtained by the operator from the same side of the patient, with skilled ultrasonographers dividing their attention among the screen, the probe, and the patient as needed.

Due to its higher specificity than sensitivity the FAST exam is suited for use only as a screening tool for thoracoabdominal free fluid, and should be interpreted accordingly – negative exams should be regarded with caution. Trauma patients with abdominal pain and an absence of abdominal free fluid on ultrasound should be observed with serial exams and undergo a repeat ultrasound or be further evaluated with an additional imaging modality such as CT scan [12].

RUQ View

Each patient will bring unique anatomic characteristics to the clinical scenario; thus, accurate images will be obtained using slightly different movements each time. A starting point for the RUQ view begins at the intersection of the anterior- to mid-axillary line and the horizontal subxiphoid line or at the seventh to tenth intercostal rib spaces on most patients (Fig. 14.3). The probe marker is oriented toward

Fig. 14.3 Probe position for RUQ view. The marker is oriented toward the patient's head

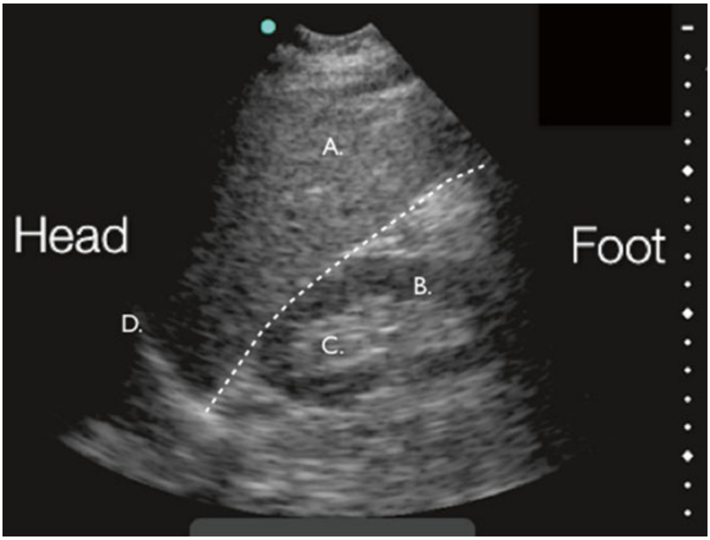

Fig. 14.4 A normal RUQ view. *A* liver, *B* renal cortex, *C* renal medulla, *D* diaphragm. Note the *dashed line* indicating the potential space between the echogenic liver and hypoechoic renal cortex, or Morison's pouch

the patient's head, and the image created is a coronal plane. The lateral aspect of the body correlates with the near field of the image, while the far field of the image demonstrates medial structures. In other words, Images at the top of the screen represent structures closest to the skin's surface, and images at the bottom of the screen represent structures deeper in the body. Recognizing that the ribs run obliquely across the body, the probe may be rotated slightly so that the thin ultrasound beam is able to penetrate through the narrow rib space. Figure 14.4 demonstrates the normal RUQ FAST view. Visible here is the normal homogenous, echogenic liver, the hyperechoic (compared to liver, which serves as the reference for echogenicity) renal medulla, the hypoechoic renal cortex, and the hyperechoic diaphragm. Morison's pouch, the most dependent space in the peritoneum and the potential space between the liver and the right kidney, is the visual zone on which the operator should focus, searching for a hypo- or anechoic area between the two organs which represents free fluid (Fig. 14.5). Vigilance must be maintained to ensure that the entirety of Morison's pouch is evaluated, lest a small amount of free fluid "hide" near the inferior portion of the liver. Visualization of the inferior pole of the right kidney is an effective way to do this. After the liver, the superior pole of the right kidney, and the bright respirophasic diaphragm are visualized, the probe may be slid caudally to reveal the kidney's inferior pole. Figure 14.6 demonstrates how free fluid may be missed in absence of attention to this fact.

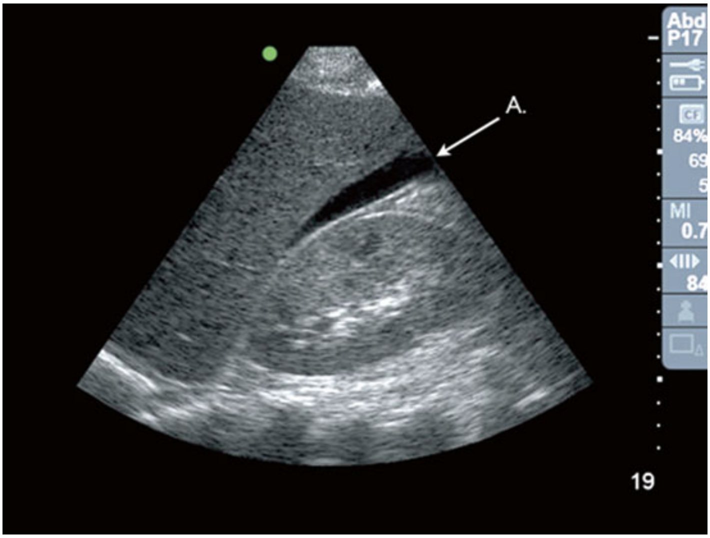

Fig. 14.5 *A* Free fluid in Morison's pouch, indicated by the *black*, or anechoic stripe of fluid in the hepatorenal space

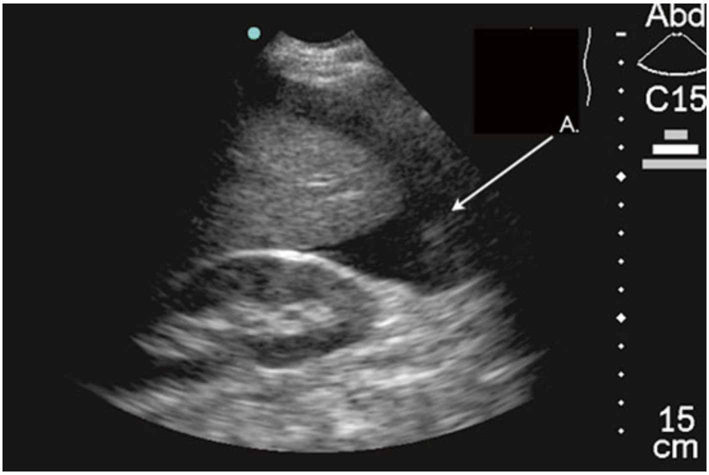

Fig. 14.6 *A* Free fluid in the RUQ at the inferior kidney pole, which may be missed without a complete survey of the right kidney

LUQ View

The splenorenal space is visualized in similar fashion to Morison's pouch, with the probe marker toward the patient's head and the probe placed in the horizontal subxiphoid line, with the corresponding intersecting line as the middle to posterior

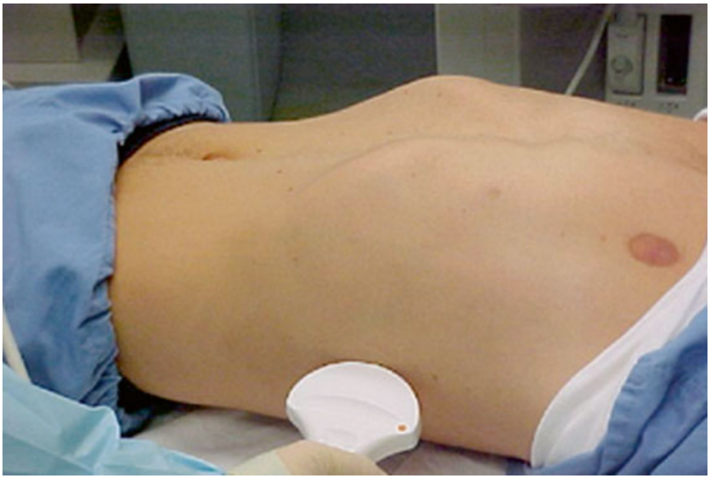

Fig. 14.7 Probe position for the LUQ view. The probe marker is oriented toward the patient’s head

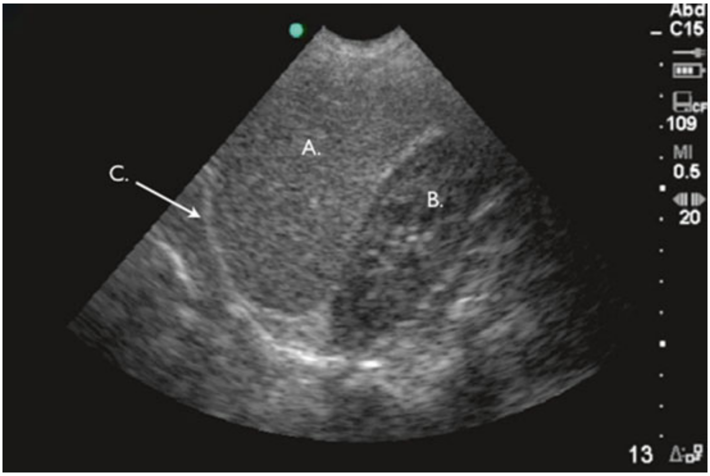

Fig. 14.8 Normal LUQ view. *A* spleen, *B* left kidney, *C* diaphragm

axillary line (Fig. 14.7). The smaller size of the spleen provides less of an acoustic window than the liver, and the more posterior position of the left kidney requires positioning adjustment. A direction frequently given to trainees standing on the right side of the patient performing this component of the FAST exam is to put their “knuckles on the stretcher,” extending the probe-holding hand posteriorly enough to orient the probe beam in a retroperitoneal direction, which will adequately visualize the splenorenal space. Figure 14.8 demonstrates the normal LUQ view; note the echogenic spleen, left kidney, and diaphragm. Because the phrenicocolic ligament creates a barrier to the splenorenal space, fluid generally accumulates in the subphrenic space prior to the splenorenal space. For this reason, attention should be paid to adequately visualize the border of the spleen and diaphragm, where free fluid may be missed (Fig. 14.9). After this, the search for free fluid continues to the splenorenal space (Fig. 14.10).

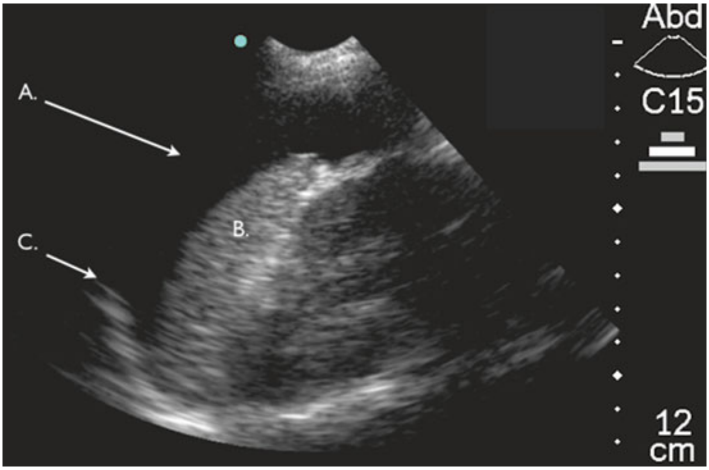

Fig. 14.9 *A* Free fluid in LUQ in subdiaphragmatic space, *B* spleen, *C* diaphragm. Fluid accumulates here before the splenorenal recess due to the phrenicocolic ligament

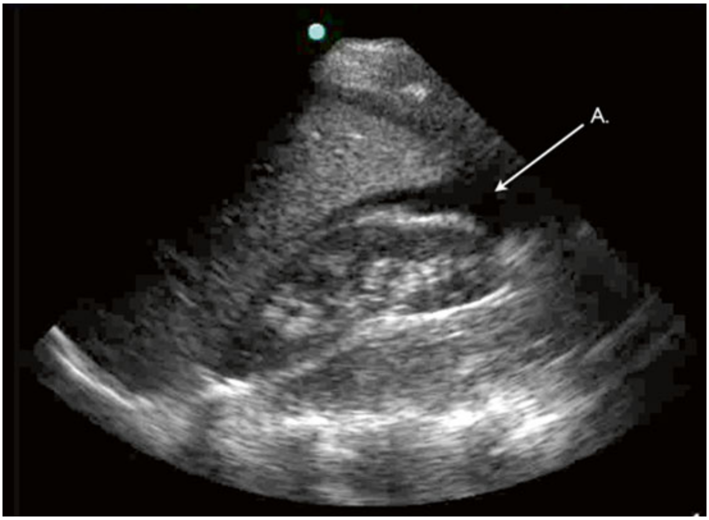

Fig. 14.10 *A* Free fluid in splenorenal recess

Pericardial View

Due to the anatomic position of the heart, penetrating trauma to the chest wall often injures the right ventricle. The classic pericardial image obtained in a FAST exam is that of a subxiphoid image. On initial positioning, the probe marker is on the patient's right, and the probe itself is aimed toward the patient's head or slightly toward the patient's left shoulder (Fig. 14.11). An overhand grip of the probe is encouraged here, as the probe must be angled closely to the body to provide an adequate view into the thoracic space, and an underhand grip may inhibit this. The normal subxiphoid view of the heart uses the liver as an acoustic window and demonstrates the hyperechoic pericardium and cardiac septum and the four anechoic chambers of the heart (Fig. 14.12). The border of the liver and the right side of the heart, found in the near field of the image, is the focal zone in the search for anechoic fluid (Fig. 14.13). In some cases, the subxiphoid view may not be attainable either due to cutaneous abdominal or chest trauma or patient anatomy (e.g., those with a long thoracic cage or narrow subxiphoid space). An alternative view in the search for pericardial free fluid is the parasternal long view. Teaching varies in regard to screen and probe marker orientation, but probe placement is consistent in that it is placed in the left mid-clavicular line at the second through fourth intercostal space, in plane with a sagittal cut through the heart. Care should be taken to decrease the depth of the image, as the parasternal long heart is much more shallow than the subxiphoid image previously described. Obtained is the image seen in Fig. 14.14; visible is the left atrium and ventricle, the aortic outflow tract, the right ventricle, and the descending thoracic aorta in cross section. This last structure is crucial, as

Fig. 14.11 Probe position for the subxiphoid view. The probe marker is toward the patient's *right side*. An overhand grip is used to flatten the probe against the xiphoid process

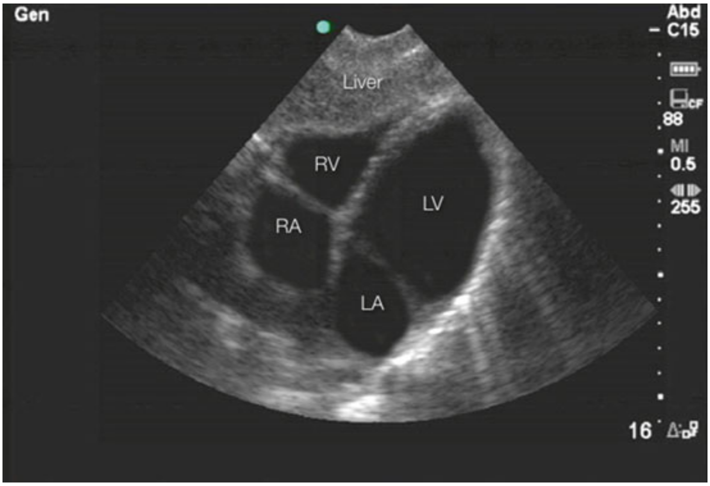

Fig. 14.12 Normal subxiphoid view of the heart. *RA* right atrium, *RV* right ventricle, *LA* left atrium, *LV* left ventricle

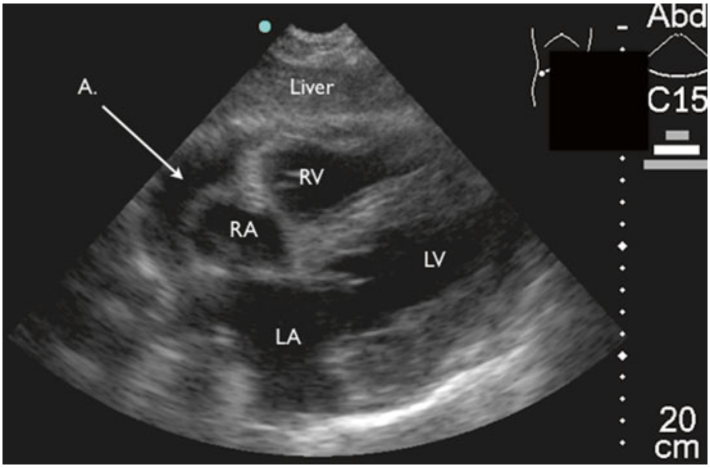
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Fig. 14.13 Subxiphoid view of fluid in pericardium. The liver is used as an acoustic window to visualize the echo-free stripe of fluid (*A*) shown between the liver and right side of the heart

the anechoic stripe seen in Fig. 14.15 between the descending thoracic aorta and the posterior pericardium represents pericardial fluid, whereas Fig. 14.16 also shows an anechoic stripe of fluid, but its location behind the descending thoracic aorta indicates that this is a pleural effusion or hemothorax. Further discussion of echocardiography is available in Chaps. 5, 6, and 7. We will discuss the search for fluid above the diaphragm in the description of the eFAST exam in the "advanced competencies" section of this chapter.

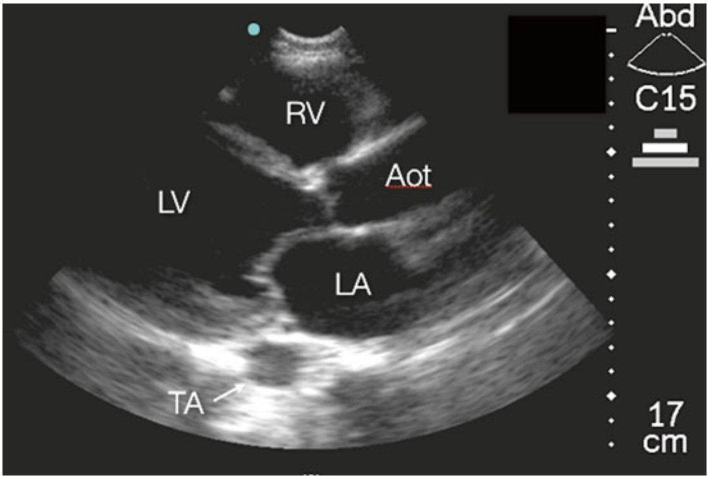


Fig. 14.14 Normal parasternal long view. *LA* left atrium, *LV* right ventricle, *RV* right ventricle, *Aot* aortic outflow tract, *TA* descending thoracic aorta in cross section

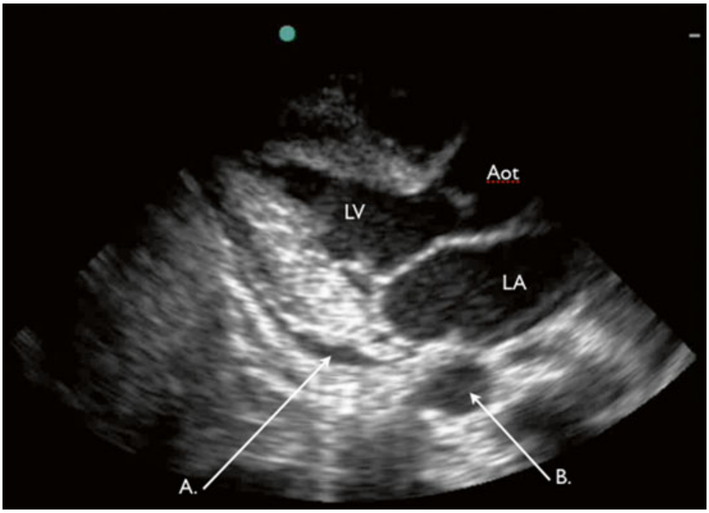


Fig. 14.15 Parasternal long view with pericardial fluid. Note the location of fluid (*A*) between the descending thoracic aorta (*B*) and the posterior pericardium, indicating that the effusion is pericardial

Pelvic View

The pelvic view is obtained by placing the probe in the midline just superior to the symphysis pubis, angled 30° caudal with the probe marker toward the patient's right side; this provides an axial view of the bladder. An additional view is obtained by

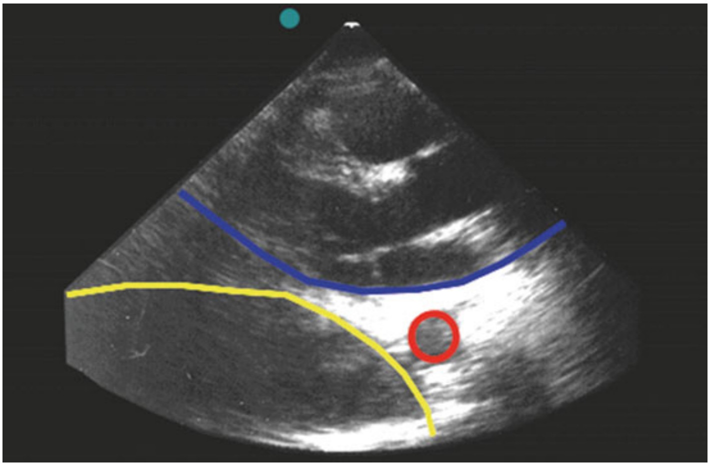


Fig. 14.16 Parasternal long view with pleural fluid. Note the location of fluid (*yellow*) behind the descending thoracic aorta (*red*), rather than the pericardium (*blue*), indicating that the effusion is pleural

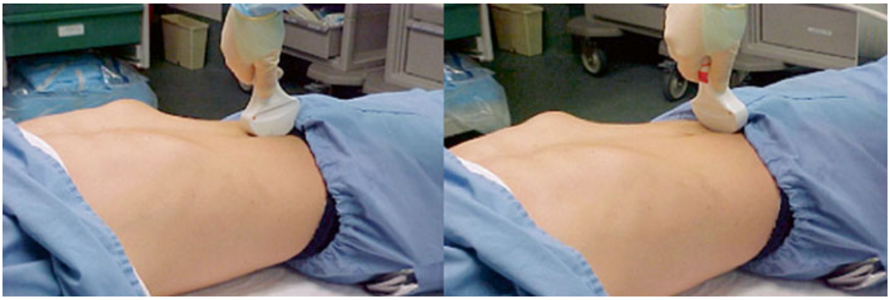


Fig. 14.17 Probe position for pelvic view. The *left* image shows the probe marker oriented toward the patient's head, producing a sagittal pelvic view. The *right* image shows the probe marker oriented toward the patient's right side, producing an axial pelvic view

placing the probe in the same location and position with the probe marker oriented toward the patient's head; this provides a sagittal view (Fig. 14.17). In the axial view, the probe is fanned cranially and caudally, visualizing the superior and inferior portions of the bladder and, in women, the uterus in cross section (Fig. 14.18). In the sagittal view, the bladder and uterus are visualized in sagittal or long-view (Fig. 14.19). In women, the search for fluid should include the space posterior to the bladder and uterus, and among loops of bowel. In men, views should include the posterior bladder and anterior rectal space. The paired, hypoechoic seminal vesicles may be noted posteriorly to the bladder. In contrast to the pericardial view just obtained, adjustments of both gain and depth are often necessary to obtain a

Fig. 14.18 Normal transverse view of the female pelvis with the anechoic bladder in the near field (*A*) and the uterus in the far field (*B*). The probe is oriented so that the marker is pointed toward the patient's *right*

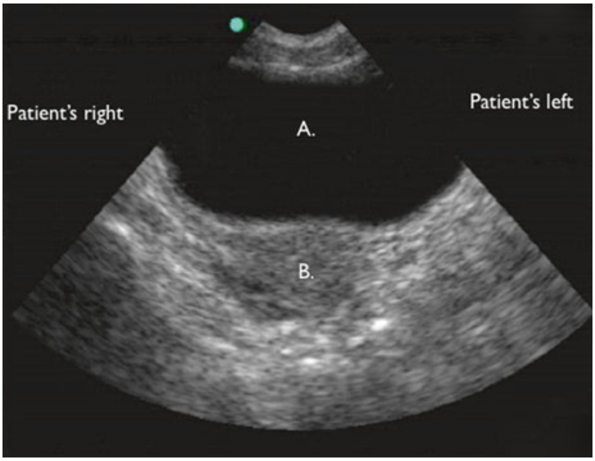
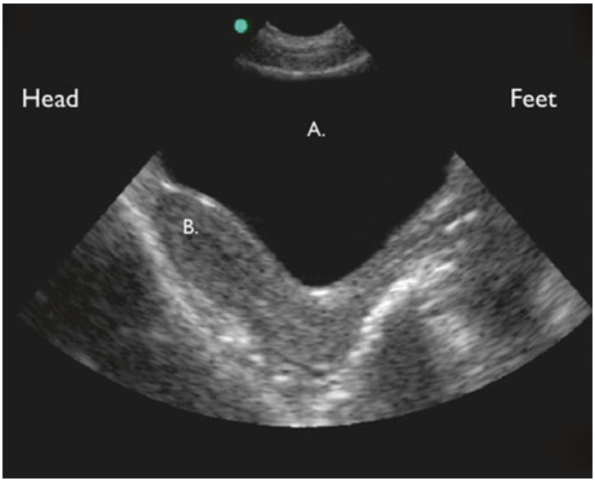


Fig. 14.19 Normal sagittal view of the female pelvis. Again seen is the anechoic bladder in the near field (*A*) and the uterus in the far field (*B*). The probe is oriented so that the marker is toward the patient's head



satisfactory search for pelvic free fluid. If the preceding view obtained was of the subxiphoid heart, minimal depth increase may be needed. However, if the image obtained was that of the parasternal long heart, a depth increase will likely be required to properly search for pelvic free fluid. A full urinary bladder provides an excellent acoustic window through which pelvic free fluid may be visible (Fig. 14.20). Posterior enhancement, an artifactual phenomenon which causes structures deep to an area of anechogenicity to appear bright, may result in a need for gain adjustment. A greater challenge is the patient with an empty bladder who lacks an acoustic window through which free fluid may be visible. Gain adjustment may be necessary in this scenario to find small pockets of anechogenicity among the surrounding structures. Free fluid located adjacent to the bladder may also be indicative of traumatic bladder rupture, especially in the patient with gross hematuria and suprapubic abdominal trauma or a high clinical likelihood of pelvic fractures [13].

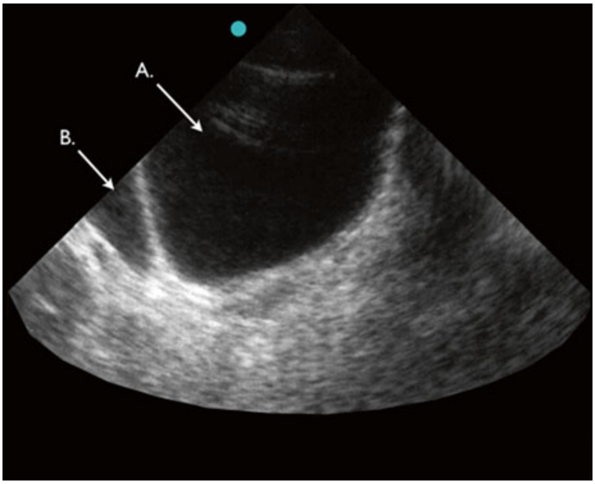


Fig. 14.20 This transverse view of the bladder (*A*) shows a small area of free fluid (*B*) on the *left* side of this image, which is the patient's *right* side

Basic Competencies

The FAST exam is approached from the standpoint of whether or not free fluid is present in the peritoneal or pericardial space. As described above, while free fluid in Morison's pouch may be easily noted by an experienced sonographer, free fluid in other locations such as the pelvis or LUQ may be more difficult to visualize and will require careful technique. Once the exam is performed, the appropriate use of the information gained is crucial. Figure 14.21 illustrates an algorithm for use of the FAST exam in the setting of blunt abdominal trauma, with the hinge point for action resting on hemodynamic stability. In the hemodynamically unstable patient with a history of trauma and free fluid visible on FAST exam, operative management is indicated. A notable and complex exception here is the patient with a past medical history significant for ascites (e.g., patients with a history of liver disease, cancer, or dialysis). These patients may also have a baseline low blood pressure, and this clinical information must be integrated into their management. One solution is a brief and small volume diagnostic paracentesis, using ultrasound in real time or for marking the fluid's location. If straw-colored fluid is retrieved, clinical management may be redirected accordingly; if blood is obtained, the pathway described above stands [14].

In the hemodynamically stable patient, some trauma and critical care providers may elect to perform a FAST exam; others may not. However, as systemic hypotension has been validated as a late marker of shock [15], we recommend the FAST exam for all patients with a history of blunt abdominal trauma as long as it does not interfere with the primary/secondary survey. The stable patient with a positive FAST exam may be directed for expedited CT; the stable patient with a negative FAST exam may be managed with serial exams, CT as indicated, or observation.

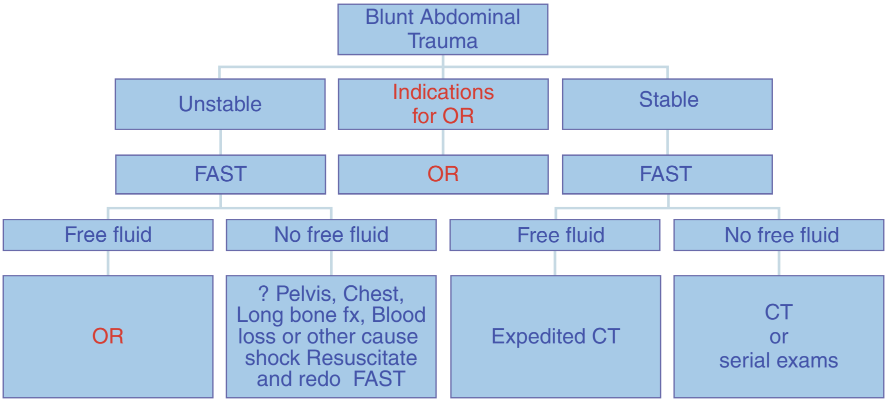


Fig. 14.21 Blunt abdominal trauma algorithm

The unstable patient with a negative FAST exam and a history of blunt abdominal trauma is one who requires clinical problem solving on the part of the providers. Has the patient suffered a long bone injury and lost blood into an extremity? Was blood loss significant enough on the scene of the event that tachycardia and/or hypotension has resulted? Is there another cause of shock that must be considered given the patient's medical history? In these cases, resuscitation is continued and the FAST exam may be repeated as needed. A trauma patient for whom immediate operative management is indicated based on primary/secondary survey alone is a patient for whom management should never be delayed for purposes of ultrasound examination. In such cases, the FAST exam does not add any information that will help guide patient management further, and therefore should not be performed.

Recommendations for teaching and establishment of competency vary by specialty, but a combination of didactic and hands-on instruction has been demonstrated to be an effective teaching tool for the clinician sonographer [16]. While no established competency exam exists, the use of an objective structured clinical examination (OSCE) is one effective method of evaluating knowledge base and ultrasound interpretation skills [17], while others direct competency assessments and clinical privileges to the institution's designated ultrasound or medical director [6]. For a further discussion of educational issues, see Chap. 2.

Advanced Competencies

The extended FAST, or eFAST exam, expands the purpose of the FAST exam in its search for intra-abdominal injury to ask the questions "is there fluid above the diaphragm?" and "is there a pneumothorax?" These advanced competencies add minimal time to that required to complete the FAST exam and may aid the clinician in the diagnostic evaluation of a patient, as well as enhance understanding of the patient's risk for morbidity/mortality.

Evaluation of the thoracic cavity for fluid above the diaphragm may be seamlessly incorporated into the FAST exam, and is a reliable method of diagnosing traumatic hemothorax [18]. In obtaining the first two FAST views, the RUQ and LUQ views, respectively, the operator identifies the hyperechoic, respirophasic line of the diaphragm, slides the probe cephalad, and looks for an anechoic stripe of fluid. An absence of fluid above the diaphragm will not reveal lung tissue in the image, but rather the echogenic appearance of liver or spleen above the diaphragm. This is because of the phenomenon of mirror image artifact. In the absence of fluid, the bright reflective surface of the diaphragm causes the ultrasound beam to produce a mirror image of the solid organ on the opposite side (Fig. 14.22). Thus, in the normal FAST exam, mirror image artifact will be present in both the upper quadrant views, and absent in the presence of thoracic free fluid (Fig. 14.23).

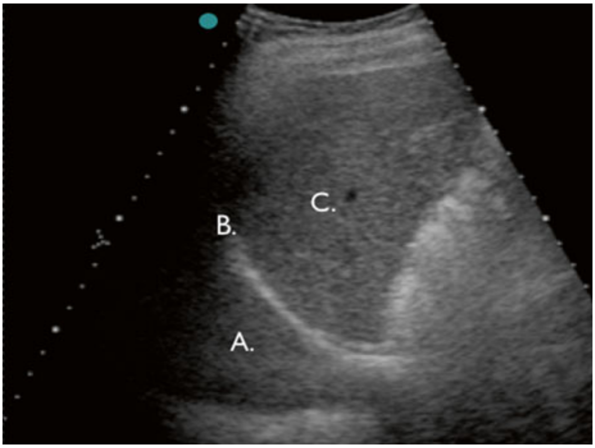


Fig. 14.22 Normal RUQ image with mirror image artifact. *A* mirror image, *B* diaphragm, *C* liver

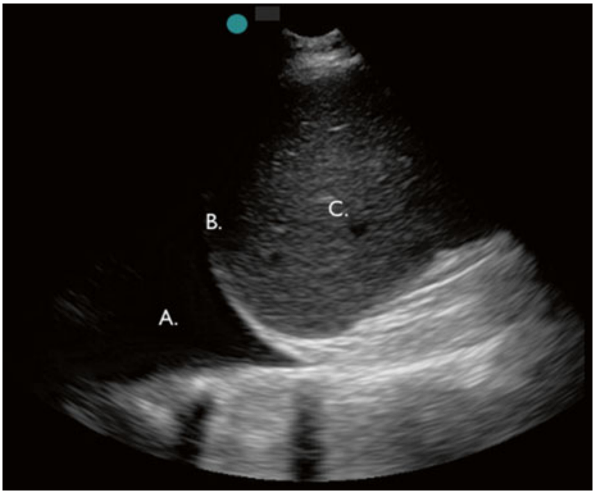


Fig. 14.23 Traumatic pleural effusion. Note the echo-free fluid (*A*) above the diaphragm (*B*) and liver (*C*), with absence of mirror image artifact

Fig. 14.24 Probe placement for pneumothorax (PTX) at 2nd/3rd intercostal space. The probe marker is oriented toward the patient's head. *Black lines* denote additional locations for probe placement during a complete evaluation for PTX

A component of the eFAST exam performed separately from the abdominal/diaphragmatic evaluation is the search for a pneumothorax (see Chap. 10 for a complete discussion of ultrasound for pneumothorax). Portable chest x-ray is traditionally used for this purpose, but due to the supine position of most trauma patients and variability of air location in the setting of pneumothorax, the sensitivity of supine chest x-ray is exceeded by lung ultrasound when performed correctly [19]. A higher frequency, lower penetration probe (a probe used for vascular access is typical) is optimal for this exam, although a curvilinear or phased array probe will also work. The exam is begun with the probe placed anteriorly in the mid-clavicular line, at the second or third intercostal space (Fig. 14.24), the probe marker oriented toward the patient's head. Note that this location is toward the lung's apex. The goal is identification of the intercostal pleura. The probe may be rotated 10–20° clockwise when evaluating the right lung, or counterclockwise when evaluating the left lung, to assume a position perpendicular to the rib/pleural complex. Once the intercostal space is identified, the image produced is that of the bright, hyperechoic pleura mid-screen, with the two rib shadows on either side. In the normal lung, the movement of the visceral and parietal pleura creates the appearance of "sliding" or movement of the hyperechoic pleural lines on the screen. At times, the normal sliding pleura will produce several bright, vertical, artifactual lines extending from the pleura, referred to as "comet tails" or "B-lines" (Fig. 14.25). These lines are reverberation artifacts produced by the ultrasound beam moving rapidly between two fixed structures and, while not always seen, are a marker of normalcy if present. The presence of a pneumothorax will reveal the hyperechoic pleura in the intercostal space, with no sliding evident, as air has separated the visceral and parietal pleura (Fig. 14.26). While the absence of pleural sliding is highly suggestive of a pneumothorax, an additional technique to confirm this finding is the use of motion mode (M)-mode. In this technique, the M-mode cursor is placed through the pleura in question and either detects pleural motion (Fig. 14.27, commonly referred to as a "sandy seashore" sign) or not (Fig. 14.28, commonly referred to as a "barcode" sign). The anterior

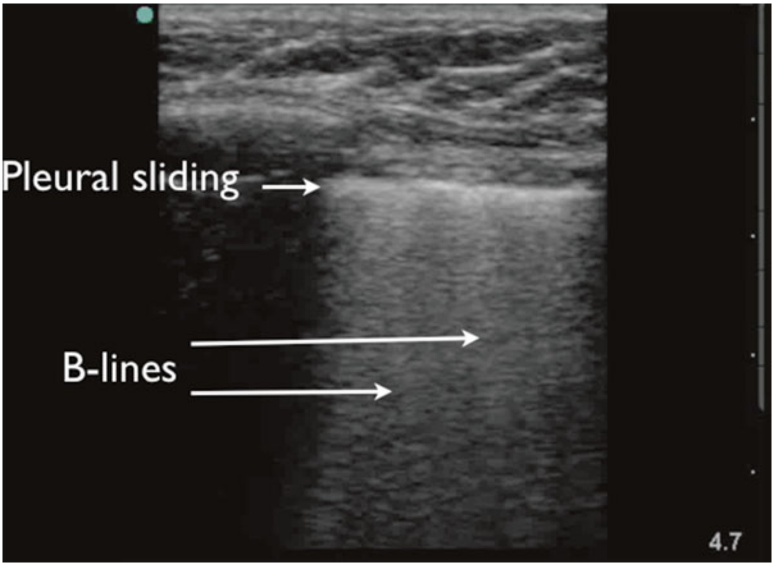


Fig. 14.25 Normal pleural sliding next to rib shadow with comet tails or B-lines

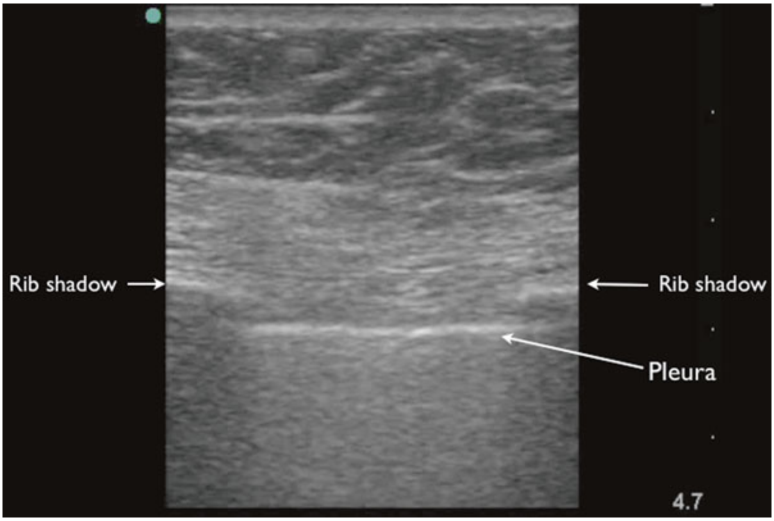


Fig. 14.26 Pneumothorax. Note the two rib shadows and the absence of lung sliding and B-lines seen beneath the bright pleural line. This finding is seen best during a clip or real-time scanning

chest wall must be evaluated at two to four additional intercostal spaces bilaterally, as a pneumothorax may not be present at the apex of the lung in the supine patient. Additional views also increase the likelihood of identifying the junction of pneumothorax and normal lung, known as the “lung point,” where the sliding pleura abuts a

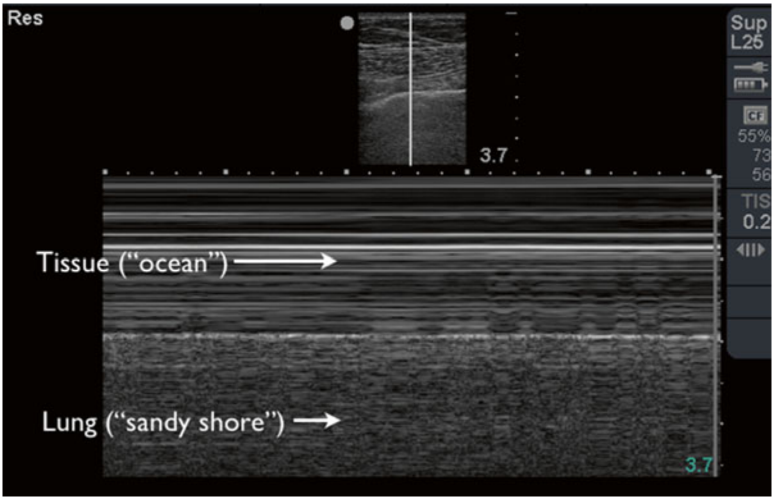


Fig. 14.27 M-mode image of normal lung ("sandy shore") with tissue in the near field ("ocean")

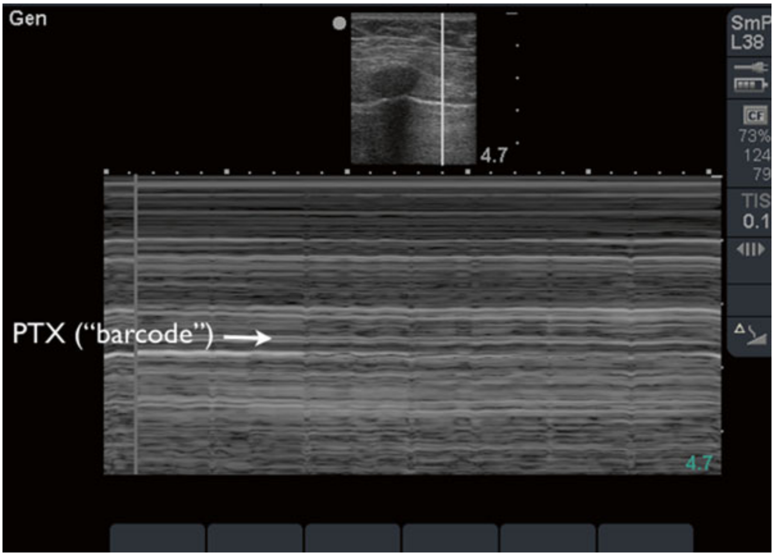


Fig. 14.28 M-mode image of a pneumothorax. The absence of pleural sliding creates a continuous "barcode" sign

non-sliding region (the pneumothorax) in the intercostal space. M-mode may also be used to confirm the finding, producing an image with both the "sandy shore" and the "barcode" present, meeting at the "lung point" (Fig. 14.29). The absence of the lung point increases the sensitivity of the exam, and its presence has been found to be 100 % specific for pneumothorax in the supine patient [20]. Potential limitations of ultrasound for pneumothorax are discussed in Chap. 10.

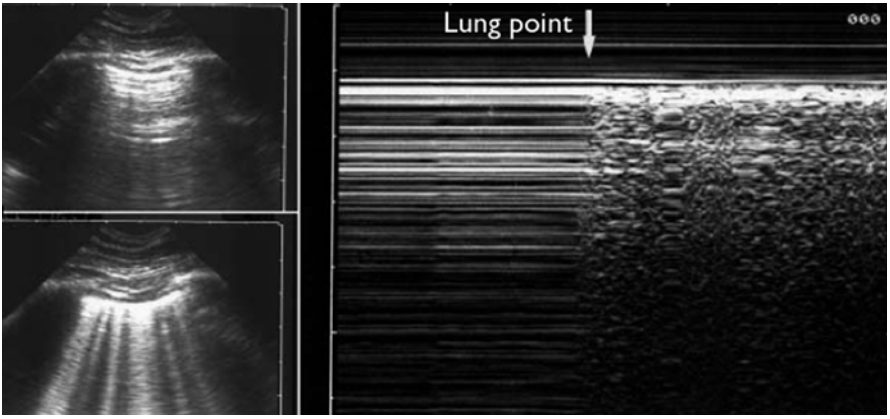


Fig. 14.29 M-mode image of lung point

Diaphragmatic rupture from blunt abdominal trauma, while relatively infrequent, is difficult to diagnose via the conventional methods of chest radiography or computed tomography (CT). Magnetic resonance imaging is more sensitive and specific but may not be obtainable in a timely fashion. One case series describes three cases of diaphragmatic rupture diagnosed on initial evaluation with FAST exam, using the M-mode cursor directed through the diaphragmatic line [21]. In all three cases, when diaphragmatic excursion was noted to be minimal or absent on FAST exam, the M-mode cursor confirmed lack of movement and correctly identified diaphragmatic rupture. Of these three cases, one was unstable on initial evaluation and unable to receive imaging outside the trauma bay, and one had a normal CT scan. The third's diagnosis was confirmed via abnormal appearance of NG tube on post-placement chest x-ray. This report represents a small number of cases, and further studies with a greater number of patients are required to validate this technique.

The pregnant trauma patient represents a unique challenge to providers. In cases where viability is confirmed or suspected, the number of patients requiring treatment has now become two. Assessment of the fetus, legally considered viable between 24 and 28 weeks [22] is beyond the scope of this discussion, but the mother remains a valid candidate for FAST evaluation due to the limitations of imaging in pregnancy. Accurate images are often obtained by probe adjustment with allowances made for the space-occupying uterus; at 28 weeks fundal height is found approximately 3 fingerbreadths above the umbilicus. Both RUQ and LUQ views should therefore be obtained with probe adjustment superiorly and posteriorly, and the pelvic view just above the symphysis pubis and angled caudal. Often the subxiphoid cardiac view will be impossible due to the gravid abdomen, and a parasternal long view is recommended. Limited data is available validating the accuracy of the FAST exam in the pregnant trauma patient, but initial reports suggest that as a test it performs less well on the pregnant than the nonpregnant trauma patient [23].

Evidence Review and Evidence-Based Use

Lessons learned from early success in European centers of the utility of bedside ultrasound in management of the trauma patient began populating the North American literature in the 1990s. In a large early study, Tiling et al. found a sensitivity of 89 % and a specificity of 99 % with an accuracy of 99 % for the detection of free intraperitoneal fluid in a prospective study of 808 blunt trauma patients [24]. With these results validated in future studies [25–27], ultrasound quickly became a viable and widespread tool used in the trauma evaluation, with the term "FAST" cemented as the accepted term describing the exam by Rozycki and colleagues in 1996 [28]. With a growing body of data supporting the use of ultrasound in the setting of blunt abdominal trauma, the utility of ultrasound in the setting of the patient with penetrating abdominal trauma remained less quantified. Udobi and colleagues prospectively evaluated 75 patients presenting with either stab or gunshot wounds to the abdomen, flank, or back, comparing results of the FAST exam with diagnostic peritoneal lavage (DPL), triple-contrast CT, or laparotomy. The sensitivity of FAST was 46 % and the specificity was 94 %, concluding that while ultrasound exam plays a role in the evaluation of penetrating abdominal trauma, negative results should be interpreted with caution [29].

On average, a FAST exam of the abdominal and thoracic cavities can be performed with the accuracy described above in an average of 4 min [30]. While identification of free fluid has been demonstrated with a single RUQ view in less than 20 s [31], the standard four-view FAST exam has retained higher sensitivity and accuracy for detection of free fluid when compared to a single-view technique [32] and remains the currently recommended method. In 2006, Melniker and colleagues performed a randomized controlled trial to assess the use of a protocol which included point of care ultrasound to evaluate patients with suspected torso trauma. The study was conducted during a 6-month period at two Level I trauma centers. The primary outcome measure was time from emergency department arrival to transfer to operative care; secondary outcomes included CT use, length of stay, complications, and charges. For patients whose trauma evaluation included bedside ultrasound, time to operative care was 64 % less, days spent in the hospital were reduced by 27 %, and hospital charges were reduced by 35 %. Those patients also underwent fewer CTs and had fewer complications when compared to control patients who did not receive an ultrasound inclusive protocol [33].

Patients presenting with penetrating cardiac trauma are at a distinct disadvantage in that the physical diagnosis of effusion or tamponade can be difficult and unreliable. The use of ultrasound in the diagnosis of serious cardiac injury resulting in acute hemopericardium has been shown to be effective, with a sensitivity approaching 100 % and a specificity of 97 % [34, 35]. Plummer and colleagues retrospectively evaluated patients with penetrating cardiac injury who received a cardiac ultrasound compared to controls who were not evaluated with ultrasound. Time to operative management and survival was compared between the two groups. Patients with penetrating cardiac injury who received an ultrasound arrived in the operating room in 15 min and had a 100 % survival rate, compared to 57 % survival in control patients who did not receive an ultrasound, who arrived in the operating room in 42 min [36].

To assess the utility of ultrasound in the diagnosis of hemothorax, Ma and colleagues compared clinician-performed trauma ultrasound with the results of the initial plain chest radiograph in 245 patients at a level I trauma center. Findings indicated that both modalities were comparably sensitive and specific in the diagnosis of hemothorax but that ultrasound may provide the diagnosis faster [37]. Sisley and colleagues addressed this question in their evaluation of 360 patients with blunt and penetrating torso injuries. All patients had a surgeon-performed thoracic ultrasound in addition to supine portable chest radiography. Sensitivity and specificity of x-ray versus ultrasound were comparable, but the standout data point was performance time: an average of 1.3 min for ultrasound versus 14.2 min for x-ray for the detection of traumatic effusion [38]. Further comparisons of ultrasound to traditional chest imaging were made when Rowan and colleagues prospectively compared the accuracy of ultrasonography with that of supine chest x-ray in the detection of traumatic pneumothoraces. Using CT as the reference standard, ultrasound was more sensitive than supine chest x-ray and as sensitive as CT, in the detection of traumatic pneumothoraces [39].

The use of ultrasound in the triage and assessment of trauma lies not only in the identification of injury but also in the incorporation of that knowledge into the clinical picture of the patient. Free fluid may be identified on the initial trauma evaluation but may not warrant immediate surgical intervention, as seen by the increasing prevalence of nonoperative management of intra-abdominal injuries [40]. Two scoring systems have been developed and prospectively evaluated in an attempt to correlate ultrasound findings with need for surgical intervention. The first assigned a score based on presence (one point), depth of fluid (two points for fluid > 2 mm in either upper quadrant), and floating bowel loops (one point). Scores ranged from zero to 8. Investigators found that 96 % of patients with a score greater than or equal to three required therapeutic laparotomy, while only 38 % of those with a score of less than three received operative management [41]. A later study also assigned a score based on presence and depth of fluid but compared that score with initial systolic blood pressure and base deficit to assess the ability of sonography to predict the need for a therapeutic laparotomy. McKenney and colleagues concluded that sonography was 83 % sensitive in determining the need for therapeutic laparotomy, compared to 28 % for systolic blood pressure and 49 % for base deficit [42].

As future studies continue to work toward investigating and validating known data regarding the utility of ultrasound in the management of the acutely ill trauma patient, current consensus guidelines and expert opinions have remained consistent. In the hemodynamically unstable patient with abdominal, thoracic, or pericardial free fluid noted on ultrasound, procedural/operative management is usually indicated. The stable patient with free fluid is directed toward further imaging studies, such as CT, while the unstable patient without abdominal or pericardial free fluid requires further clinical problem solving. The stable patient who receives a FAST exam without significant findings, but remains symptomatic, may undergo varying routes of management, including serial exams and observation, repeat ultrasound, or CT [12].

Pitfalls and Precautions

- Obesity and subcutaneous air greatly decrease both the sensitivity and specificity of the exam.
- Findings that may mimic free fluid in the RUQ due to their anechogenicity include the gallbladder, duodenum, inferior vena cava, and hepatic vessels.
- Failure to visualize the inferior pole of the right kidney may cause small pockets of free fluid to be missed.
- In the LUQ, knowledge of movement patterns of free intraperitoneal fluid will prevent inadequate visualization of the subphrenic space, which is more dependent than the splenorenal recess.
- The slightly superior and posterior position of the left kidney requires concomitant probe adjustment; directing the probe cephalad and posterior usually solves this issue.
- An accessory splenic lobule or more commonly a fluid-filled stomach may be mistaken for free fluid as well. Figure 14.30 depicts the LUQ view of a 30-year-old woman presenting with a history of pregnancy, vaginal bleeding, and hemorrhagic shock. On initial evaluation the picture may suggest subphrenic free fluid, but closer inspection reveals the well-circumscribed nature of the fluid collection, which was indeed a fluid-filled stomach. The presumptive diagnosis of ruptured ectopic pregnancy was avoided with knowledge of this ultrasonographic pitfall; rather than receiving a subtherapeutic laparotomy, she was resuscitated and underwent successful dilation and curettage for an incomplete abortion.
- Both ascites and bladder rupture can mimic hemoperitoneum and can fool the unaware clinician. In the case of the former, we discussed bedside paracentesis as a branch point in diagnostic decision making [14]. In the latter, the finding should be correlated clinically and operative management directed accordingly, as most extraperitoneal ruptures can be safely managed with simple catheter drainage [43], while most intraperitoneal bladder injuries require surgical exploration [44].

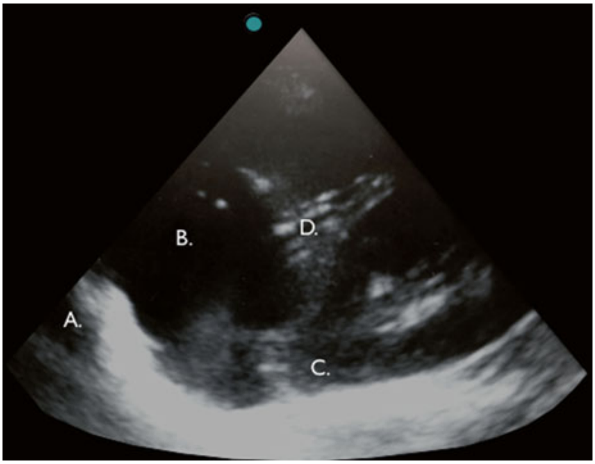


Fig. 14.30 Fluid-filled stomach mimicking free fluid in the LUQ. *A* diaphragm, *B* stomach, *C* superior pole of the left kidney, *D* spleen

- Fluid-filled loops of bowel, the seminal vesicles, and ovarian cysts can also mimic the anechogenicity of free fluid; adjusting the gain and depth may help.
- A full bladder is a significant aid in improving acoustic throughput. If empty, improved results may be obtained by instilling 250 mL of normal saline through an inserted Foley catheter and repeating the exam if pelvic free fluid is suspected. This is contraindicated in patients for whom urethral injury may be present.
- In a prior section we discussed the evaluation of a pericardial versus pleural effusion. A large left hemothorax can either prevent visualization of a pericardial effusion due to displacement of the pericardial sac or be confused with a pericardial effusion due to its proximity. The parasternal long view is especially helpful in this scenario, as visualization of the descending thoracic aorta and subsequent identification of fluid anterior (pericardial) or posterior (pleural) to this structure can help differentiate the two findings.
- Another common pitfall is incorrectly labeling an epicardial fat pad as a pericardial effusion [45]. This common anatomic variant, which will not be visualized posteriorly, is an accumulation of fat between the parietal pericardium and the parietal pleura. The ability to differentiate a fat pad versus a potential effusion in multiple views will aid an operator's diagnostic abilities.

Like any diagnostic tool, ultrasonography in the setting of trauma and critical care must be used and interpreted correctly to add successfully to the trauma evaluation. While the FAST exam has been shown to reliably identify as little as 250 mL of free fluid in Morison's pouch [46], it has not been shown to be a reliable indicator of solid organ injury [47]. Additionally, in patients with penetrating torso trauma, the specificity for the FAST exam remains high, but the sensitivity drops significantly [48]. Clinicians are cautioned to avoid overreliance on an initially negative FAST exam and to perform repeat exams on patients with evolving symptoms or a changing hemodynamic profile. Bearing these principles in mind, skilled clinician sonographers can use the FAST and e-FAST exam(s) to greatly improve diagnostic accuracy and thereby improve patient care.

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