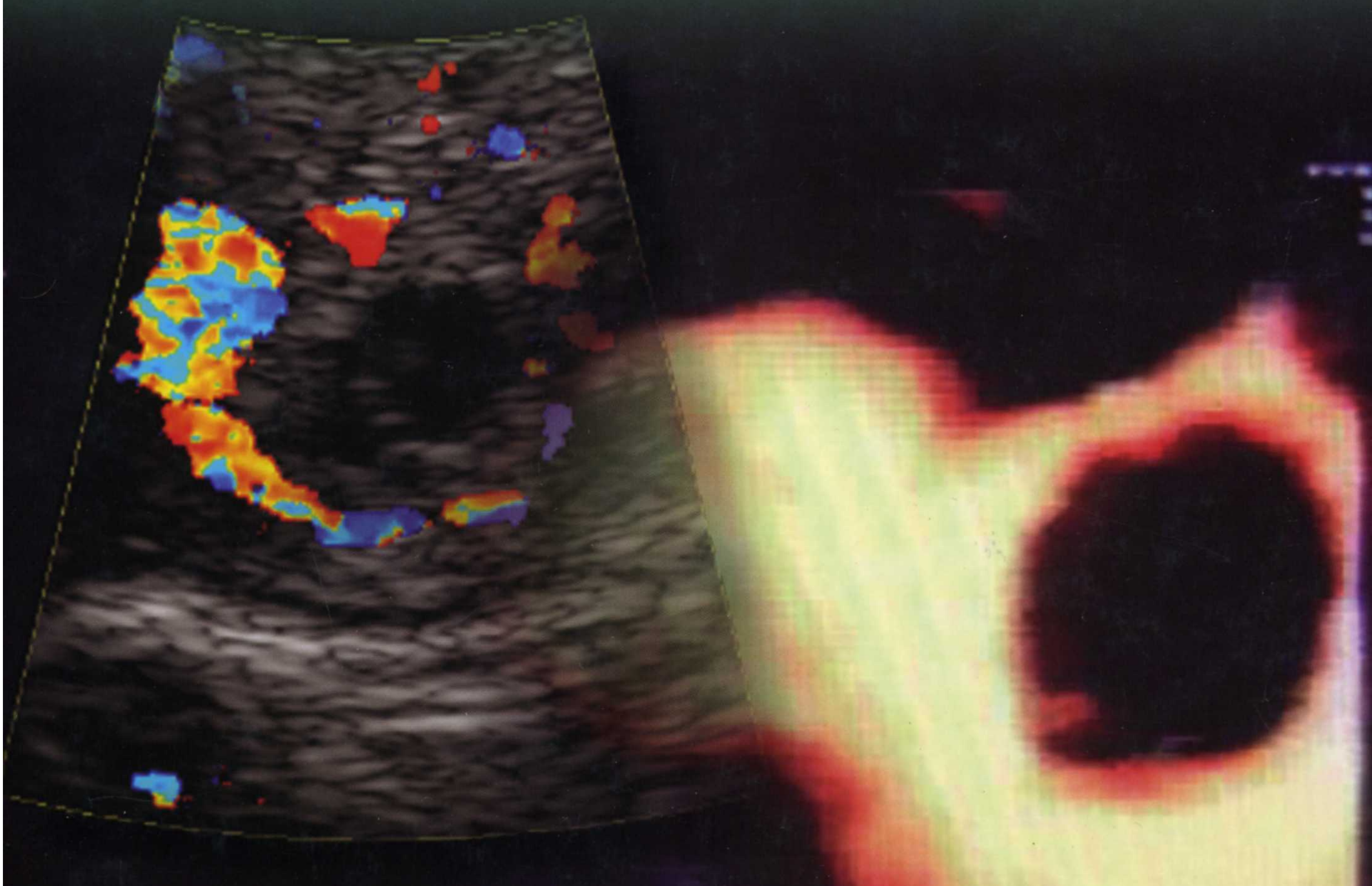
Practical Guide to EMERGENCY ULTRASOUND



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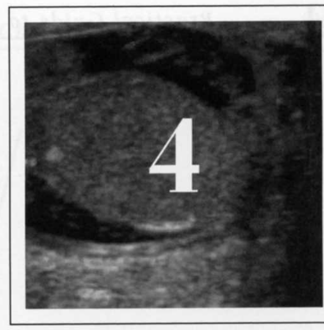

TRAUMA

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INTRODUCTION

For many, "trauma ultrasound" is synonymous with "emergency ultrasound." The use of ultrasound in the evaluation of the traumatically injured patient originated in the 1970s when trauma surgeons in Europe and Japan first described sonography for rapid detection of life-threatening hemorrhage. While the original studies set conservative goals of determining whether ultrasound could in fact detect peritoneal fluid (1–3), they shortly evolved to a point where ultrasound was lauded as a replacement for diagnostic peritoneal lavage (DPL) (4–8). This rapid ascension was fueled by evidence that ultrasound could not only accurately detect free fluid in body cavities, but also do it quickly, noninvasively, at the bedside, and without exposing the patient to radiation. The experience of physicians in the United States with ultrasound in the setting of trauma came to publication in the early 1990s as a number of papers reported similar results to those out of Europe and Japan (9). From these studies came the first description of the exam being performed as the "Focused Abdominal Sonography for Trauma," or the FAST exam (10). Later this terminology was changed to "Focused Assessment with Sonography for Trauma" (11), but the goal remained the same: the evaluation of trauma patients with the aid of ultrasound.

Beyond a purely historical perspective, trauma ultrasound is also equated with emergency ultrasound due to its widespread acceptance in Emergency Departments (ED). Ultrasound proved to be such a practical and valuable bedside resource for trauma that it received approval by the American College of Surgeons and was incorporated into standard teaching of the Advanced Trauma Life Support curriculum. With this endorsement, the use of ultrasound became a new standard for trauma centers throughout the world. In fact in many trauma centers bedside ultrasound has become the initial imaging modality used to evaluate the abdomen and chest in patients who present with blunt and penetrating trauma to the torso. As emergency physicians gained basic ultrasound skills for trauma, it became only natural to expand those skills to other applications. For many, ultrasound introduced a resource that greatly expanded the ability to assess and treat all patients.

CLINICAL APPLICATIONS

The primary goal of the FAST exam in its original description was the noninvasive detection of fluid (blood) within the peritoneal and pericardial spaces. Ultrasound provides a method to detect quantities of fluid within certain spaces that are either undetectable by the physical exam or without the use of other invasive (DPL), expensive [computed tomography (CT)], or potentially delayed (clinical observation) methods. As experience has been gained, trauma ultrasound has been expanded to include assessment for specific solid organ injury and the detection of pleural effusions (hemothorax) and pneumothorax. The clinical scenarios where this information becomes exceedingly useful are in the evaluation of patients presenting with blunt or penetrating trauma to the chest or abdomen. This chapter will discuss the clinical applications, techniques, and use of the standard FAST exam, as well as expanded applications for those with more advanced skills.

Image Acquisition

Equipment

Most trauma ultrasound is performed with compact or cart-based systems using a 3.5 MHz transducer. While the exam can be done with a curvilinear abdominal transducer, the tighter the radius of the probe and the smaller the footprint, the easier it is to perform the upper quadrant, cardiac, and thoracic views of trauma ultrasound. A smaller footprint can facilitate imaging between and around the ribs.

A single general-purpose transducer used for most abdominal scanning is sufficient for the FAST exam. Most machines sold today have multifrequency transducers with frequency and depth controls that allow adjustment for a variety of applications and body habitus. Adjustments can optimize imaging. For instance, in larger adults, a lower frequency (2 MHz) may be optimal, whereas in children and smaller statured adults, a higher frequency (5 MHz) may provide better imaging (12). Some physicians prefer a phased array transducer for cardiac imaging and a linear probe (with better near field resolution), if available, for the detection of pneumothorax and for sonographic procedural guidance.

Timing and Speed

The acronym "FAST" suggests a quick survey of the peritoneal and pericardial spaces. Usually the exam can be completed in 3 to 5 minutes and is done simultaneously with resuscitation, or as part of the secondary survey in the stable patient. Though the study should be done relatively quickly, this does not mean that the ultrasound exam should be done haphazardly (13). Biplanar views of each window with angling of the transducer, rotation to a 90 degree angle, and further manipulation should be done to survey the entirety of the potential space. Usually a static image of a representative window is frozen, and printed to paper, disc, or even film. Serial sonographic examinations have been proposed but very few studies have shown the utility of such an approach (14).

Basic Exam

The basic FAST exam includes 4 views (Fig 4.1) (11):

1. Perihepatic (right upper quadrant)
2. Perisplenic (left upper quadrant)
3. Pelvic (Pouch of Douglas or retrovesicular)
4. Pericardial (cardiac)

Perihepatic

The right upper quadrant view, also known as the Morison's pouch or perihepatic view, is commonly viewed as the classic image of trauma ultrasound. It allows for visualization of free fluid in the potential space between the liver and right kidney. In addition, fluid above

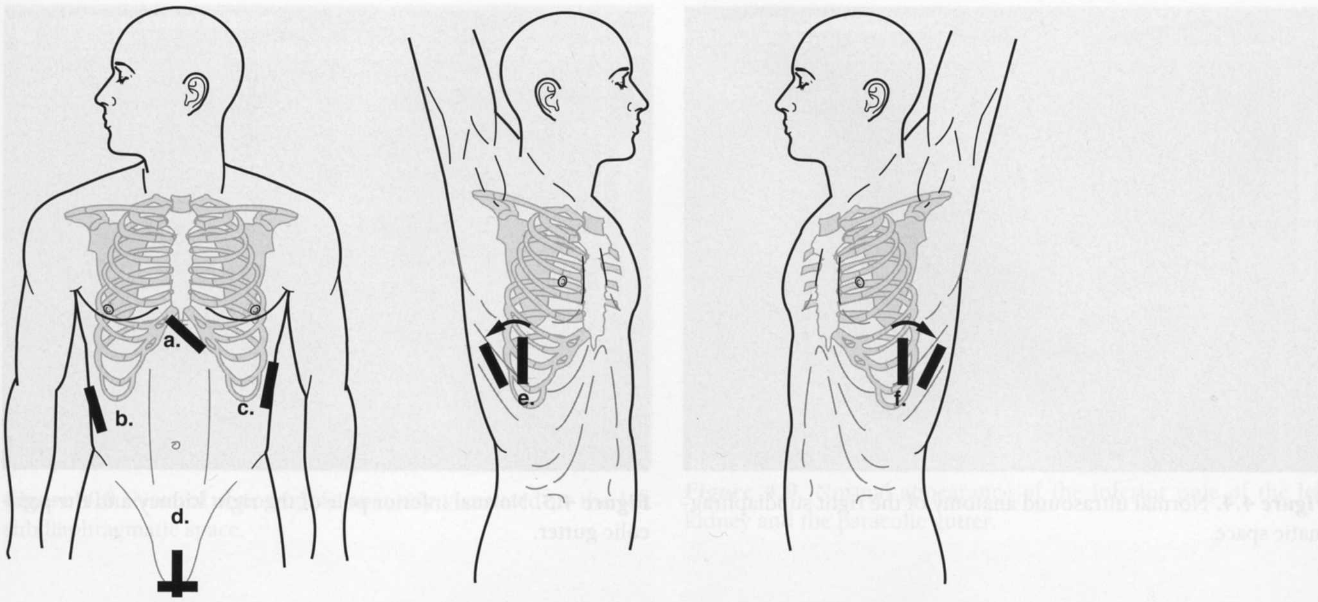


Figure 4.1. Transducer placement for views of the FAST exam. (a) subxihoid; (b) perihepatic; (c) perisplenic; (d) pelvic; (e and f) extended thoracic views.

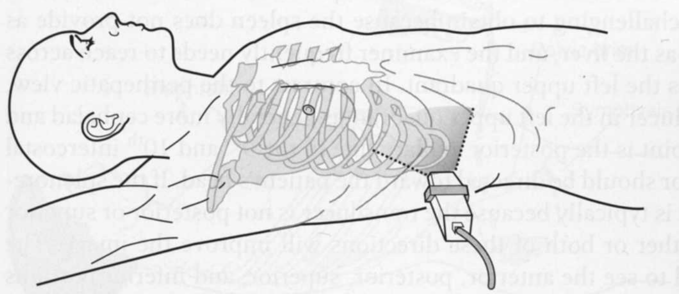


Figure 4.2. Right upper quadrant transducer positioning for the FAST exam.

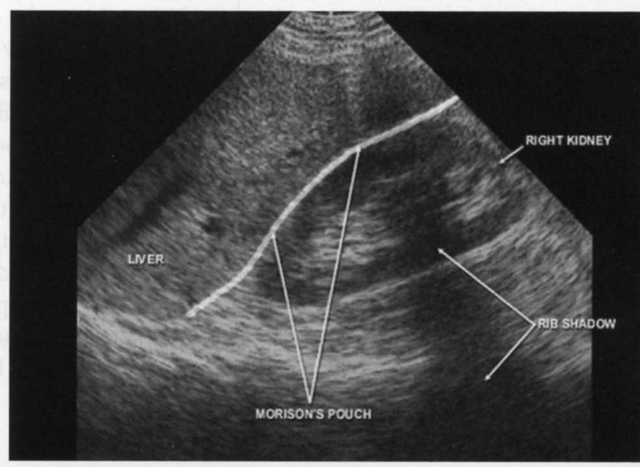


Figure 4.3. Ultrasound image demonstrating normal appearance of Morison's pouch.

and below the diaphragm in the costophrenic angle or subdiaphragmatic space can be seen. The transducer is initially placed in a coronal orientation in the midaxillary line over an intercostal space of one of the lower ribs (Fig. 4.2). The indicator on the transducer should be directed toward the patient's head. Once Morison's pouch is visualized (Fig. 4.3), the transducer should be angled in all directions to fully visualize the potential spaces of the right upper quadrant. Angling anteriorly and posteriorly will allow for the complete interrogation of Morison's pouch. The sonographer will need to manipulate the transducer to minimize artifact from the ribs. The real-time image can be optimized by gently rocking the transducer to create a mental three-dimensional view of the space. In addition, the transducer can be directed cephalad to visualize the pleural and subdiaphragmatic space (Fig. 4.4). Moving the transducer caudad brings the inferior pole of the kidney and the superior aspect of the right paracolic gutter into view (Fig. 4.5).

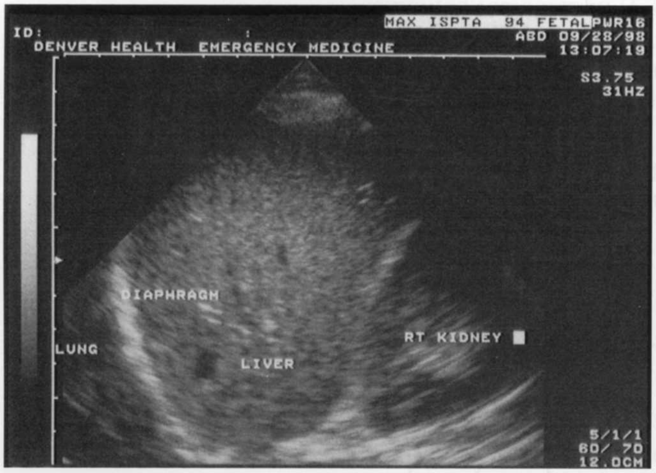


Figure 4.4. Normal ultrasound anatomy of the right subdiaphragmatic space.

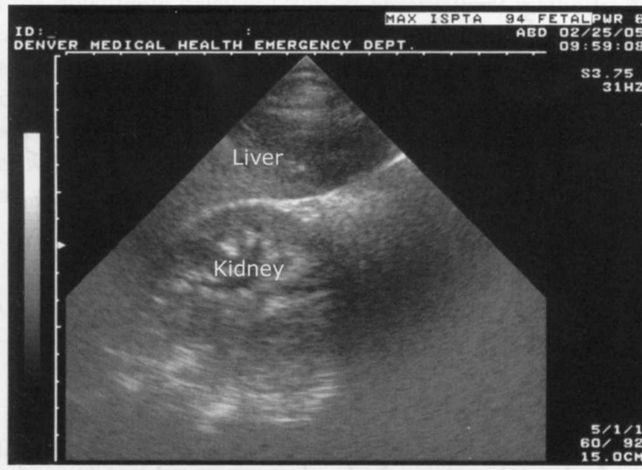


Figure 4.5. Normal inferior pole of the right kidney and the paracolic gutter.

Perisplenic

The left upper quadrant view is also known as the perisplenic or, less accurately, the splenorenal view. It can be challenging to obtain because the spleen does not provide as large a sonographic window as the liver, and the examiner frequently needs to reach across the patient in order to access the left upper quadrant. In contrast to the perihepatic view, ideal placement of the transducer in the left upper quadrant is generally more cephalad and posterior. A good starting point is the posterior axillary line in the 9th and 10th intercostal space (Fig. 4.6). The indicator should be directed toward the patient's head. If the splenorenal space is not visualized, it is typically because the transducer is not posterior or superior enough, so movement in either or both of these directions will improve the image. The transducer should be angled to see the anterior, posterior, superior, and inferior portions of the perisplenic space. Important landmarks to visualize include the spleen-kidney space (Fig. 4.7), the spleen-diaphragm interface (Fig. 4.8), and the inferior pole of the kidney-paracolic gutter transition (Fig. 4.9).

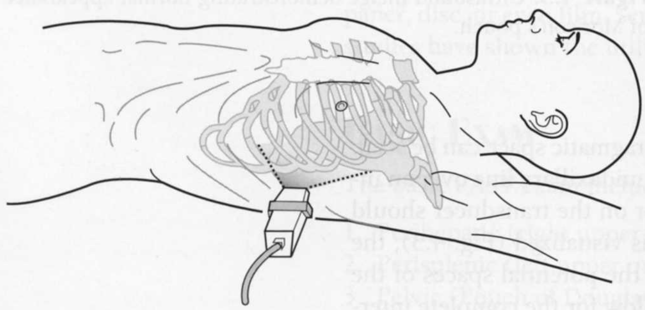


Figure 4.6. Left upper quadrant transducer positioning for the FAST exam.

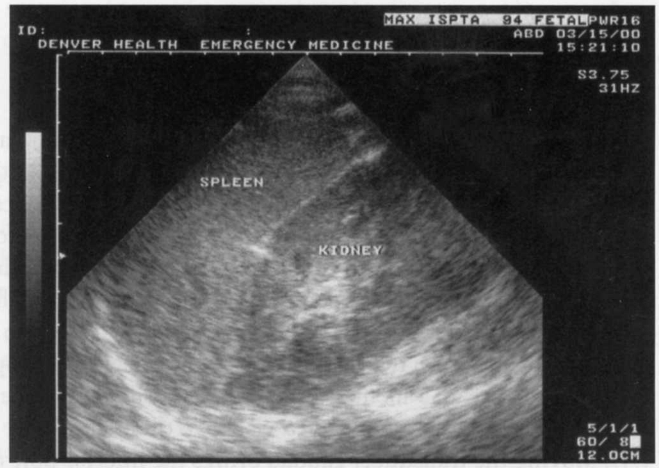


Figure 4.7. Normal ultrasound image of the spleen and left kidney.

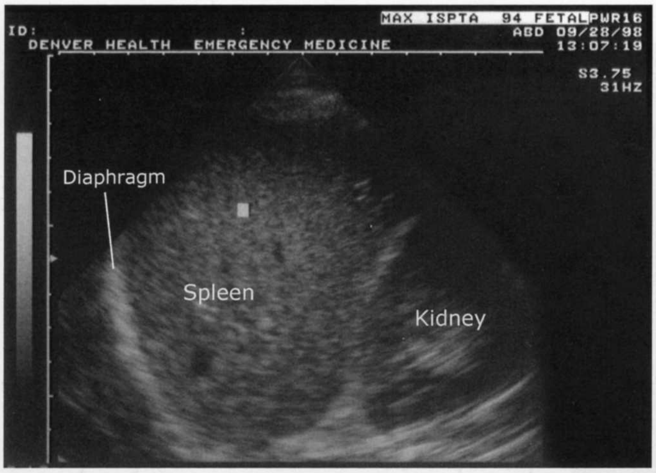


Figure 4.8. Normal sonographic anatomy visualized in the left subdiaphragmatic space.

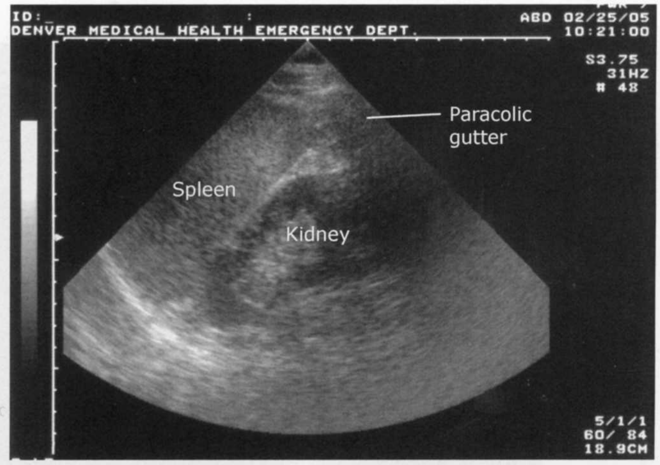


Figure 4.9. Normal appearance of the inferior pole of the left kidney and the paracolic gutter.

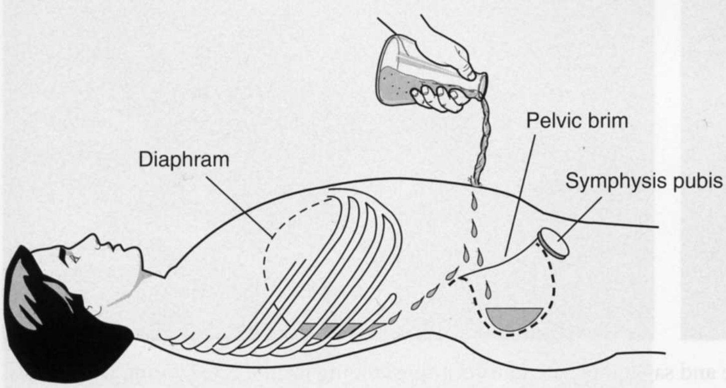


Figure 4.10. Locations of the dependent areas of the peritoneal cavity.

Pelvic

The pelvic view is an important and potentially underappreciated window for detecting free peritoneal fluid. Since it is one of the most dependent and easily visualized portions of the peritoneal cavity, fluid collections may be seen here before being detected in other areas (Fig. 4.10). As well, it is away from the chest and upper abdomen, so images can be obtained simultaneously with the evaluation and resuscitation of the trauma patient. The key to the pelvic view is scanning through a moderately full bladder to facilitate visualization of the underlying and adjacent structures, so imaging should be done before placement of a Foley catheter or spontaneous voiding. The transducer is initially placed just superior to the symphysis pubis in a transverse orientation with the indicator directed to the patient's right (Fig. 4.11 **a**, **b**). From here the transducer can be angled cephalad, caudad, and side to side to fully visualize the perivesicular area. It is also important to image the bladder in a sagittal orientation. To obtain this view, the transducer should be rotated clockwise so that the indicator is directed towards the patient's head (Fig. 4.11). The transducer can then be angled side to side, superiorly, and inferiorly to gain a full appreciation of the retrovesicular space (Fig. 4.11 **c**).

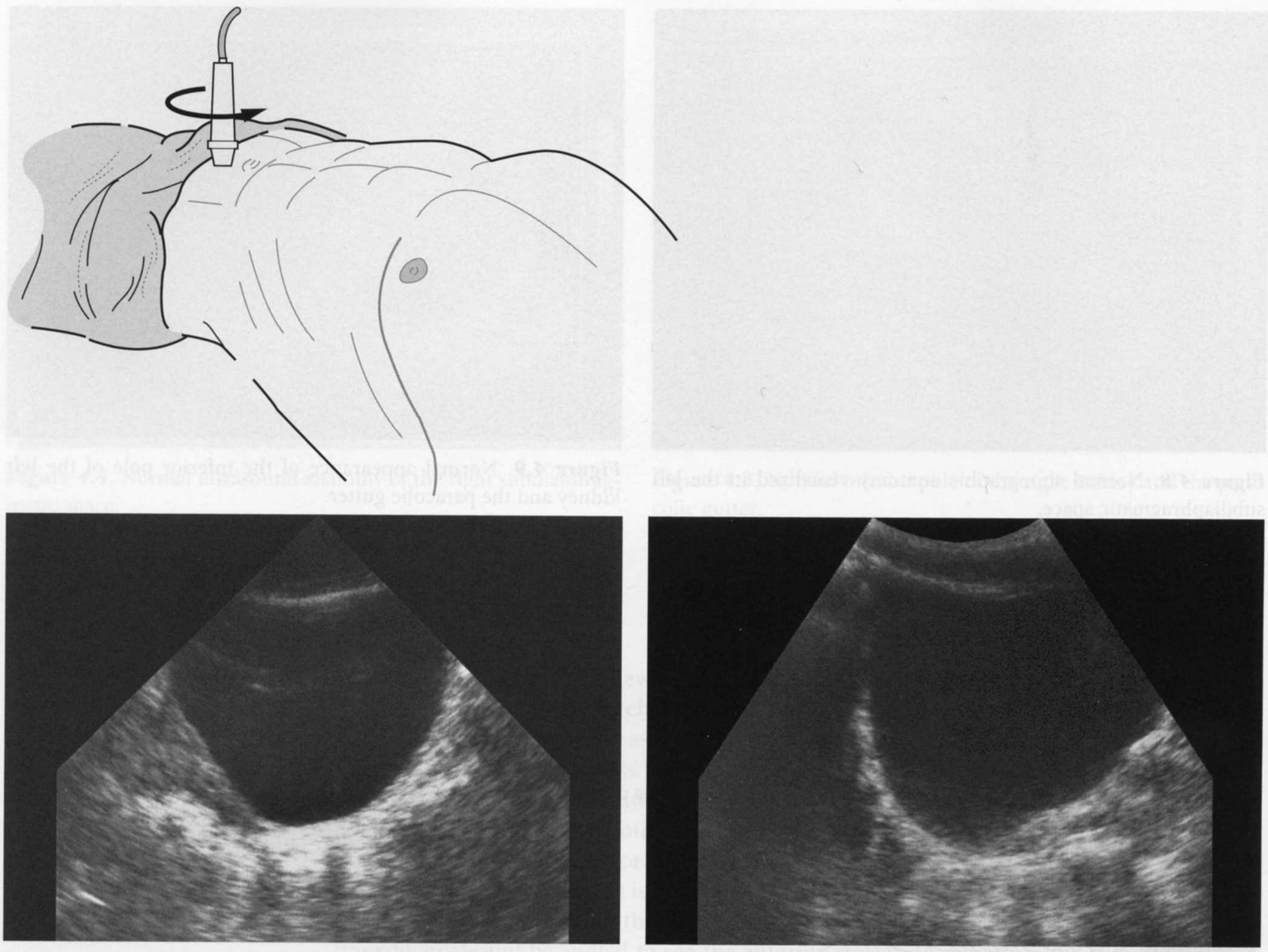


Figure 4.11 (***a***) Transverse and sagittal pelvic transducer positioning for the FAST exam. (***b***) Normal transverse transabdominal anatomy of a male bladder. (***c***) Normal sagittal transabdominal anatomy of a male bladder.

Pericardial

The subxiphoid approach is the most commonly used and convenient way to visualize cardiac structures and the pericardial space. The four-chamber subxiphoid view is performed with the transducer oriented transversely in the subcostal region and the indicator directed to the patient's right. The transducer should be held almost parallel to the skin of the anterior torso as it is pointed to a location just to the left of the sternum toward the patient's head (Fig. 4.12 **a**, **b**). Gas in the stomach frequently obscures views of the heart, but this can be minimized by using the left lobe of the liver as an acoustic window. This is accomplished by moving the transducer further to the patient's right. The liver should come into view as well as the interface between the liver and the right side of the heart (Fig. 4.13). The subxiphoid view may not be obtainable in all patients, so other cardiac views should be obtained to rule out traumatic pericardial effusion, especially in those with anterior pericardial fat pads (15). The approach to obtaining alternative cardiac views can be found in the echocardiography chapter (Chapter 5).

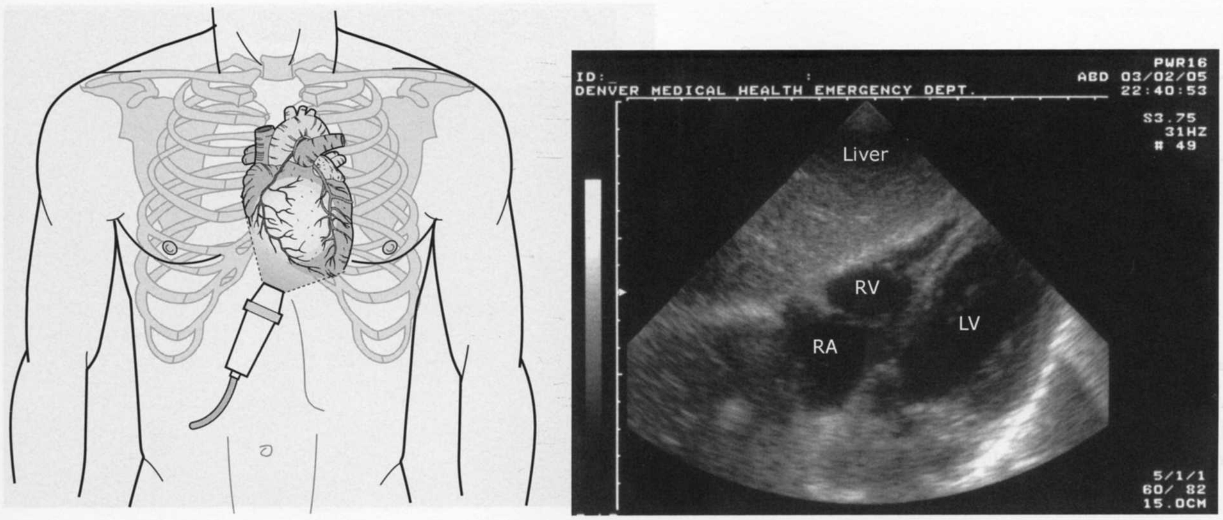


Figure 4.12 (*a*) Subxiphoid transducer position for the FAST exam. (*b*) Normal ultrasound anatomy visualized from the subxiphoid transducer position (RV, right ventricle; RA, right atrium; LV, left ventricle).

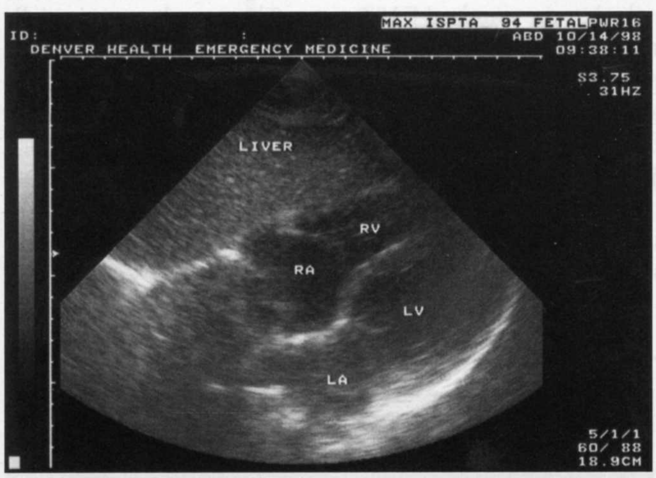
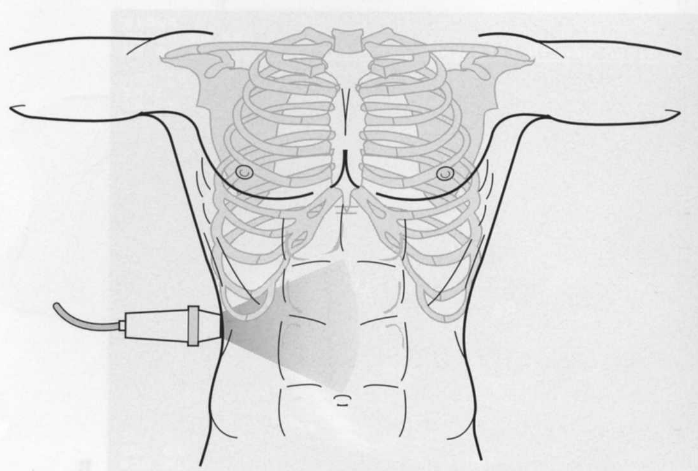


Figure 4.13. Ultrasound image demonstrating the liver as an acoustic window to the heart from the subxiphoid transducer position (RV, right ventricle; RA, right atrium; LV, left ventricle; LA, left atrium).

Extended Views

Paracolic gutters

The paracolic gutters are additional sonographic views that may increase the sensitivity of the standard FAST exam for the detection of peritoneal fluid. They are obtained by placing the transducer in either upper quadrant in a coronal plane and then sliding it caudally from the inferior pole of the kidney (Fig. 4.14 a, b). Alternatively, the transducer can be placed in a transverse orientation medial to the iliac crests. It can be angled inferiorly and superiorly to assess for the presence of loops of bowel outlined by peritoneal fluid.



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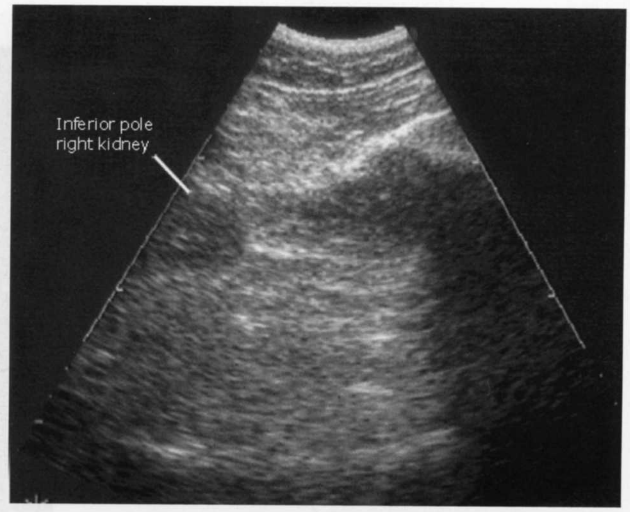
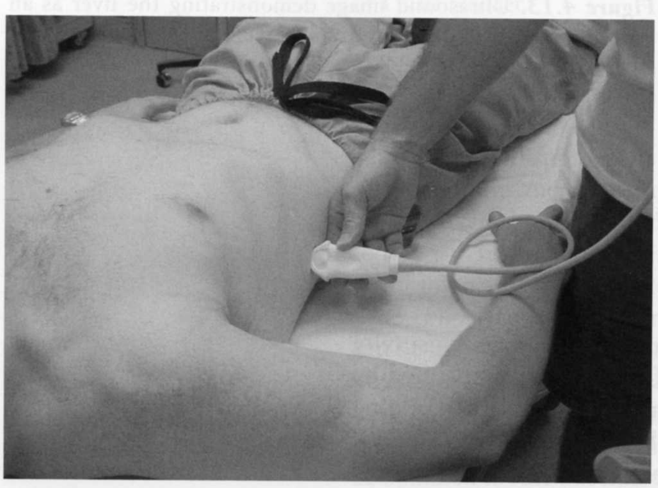


B

Figure 4.14 (***a***) Right paracolic gutter transducer position for the FAST exam. (***b***) Typical ultrasound appearance of the paracolic gutter.

Costrophrenic angle or pleural base

The sonographic evaluation of the pleural space for fluid is an adaptation of the right and left upper quadrant views described in the standard FAST exam. The transducer is initially placed in position to obtain a right or left upper quadrant view. It is then angled or moved superiorly to visualize the diaphragm and pleural space (Fig. 4.15 **a**, **b**). The region immediately above the diaphragm should be imaged to detect fluid. In the normal patient, air from lung tissue will scatter the signal and create shadowing and artifact. When pleural fluid is present, an anechoic space appears above the diaphragm. Visualization can be improved if the liver or spleen is used as an acoustic window to the pleural space (Fig. 4.16), but even with optimal transducer placement, only a small portion of the pleural space is typically accessible in patients without pathology.



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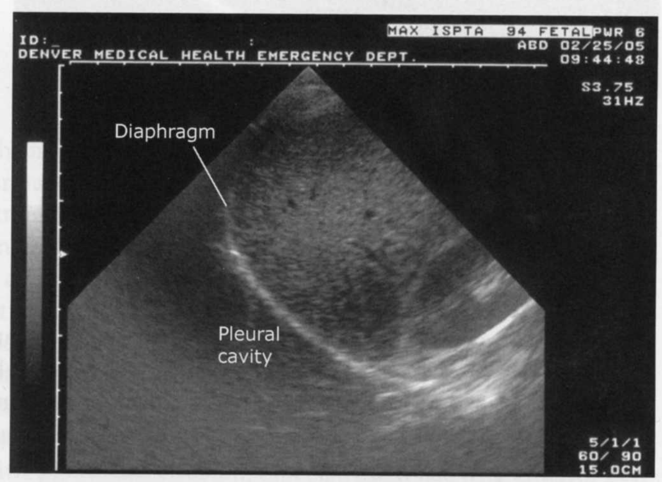

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Figure 4.15 (***a***) Pleural base transducer position for the FAST exam. (***b***) Sonographic appearance of the inferior aspect of a normal pleural cavity.

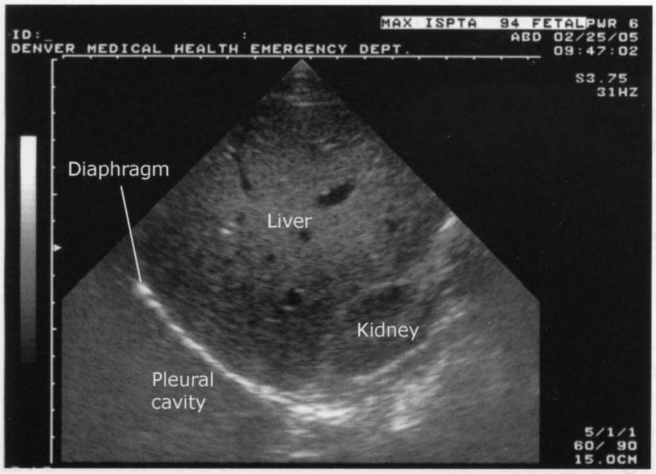


Figure 4.16. Ultrasound image of the liver acting as an acoustic window to the costophrenic angle. Note how the scan plane uses as much of the liver tissue as possible to view the pleural base.

Anterior thorax (pneumothorax)

Interrogation of the anterior pleura for the presence of pneumothorax can be done with a number of transducers, although it is preferable to use a high-frequency, linear model that is set to a shallow depth of penetration (4 to 6 cm). The transducer is placed longitudinally in the midclavicular line over the third or fourth intercostal space (Fig. 4.17).

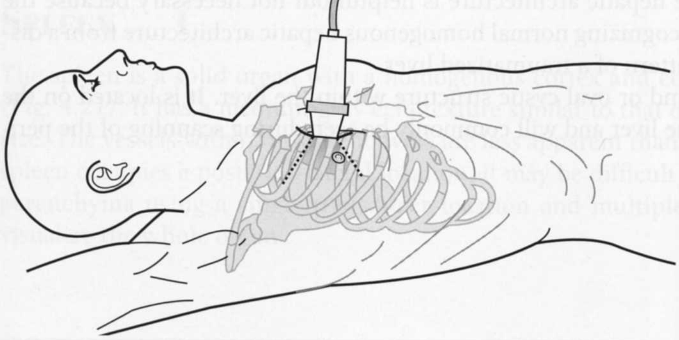


Figure 4.17. Anterior thorax transducer placement for the evaluation of pneumothorax.

ORDER

While there is no current standard for the order in which the views of the FAST exam are obtained, arguments have been made for starting with certain windows. For instance, the right upper quadrant view is a common starting point because it is one of the most sensitive and specific locations for detecting hemoperitoneum and many physicians routinely scan from the patient's right side (16–18). Alternatively the pelvic view may be the first view obtained, as it is one of the most dependent portions of the peritoneal cavity so smaller fluid collections may detected here before other locations (16). As well, placement of a urinary catheter to decompress the bladder essentially eliminates the sonographic window to the pelvis, so there is a priority in obtaining this window before the Foley is placed. Another approach is to scan the left upper quadrant first, but this is usually advocated by institutions that have a protocol of scanning from the patient's left side. Finally, the subxiphoid approach is often proposed as a starting point for the FAST exam so that potentially life-threatening cardiac injuries can be quickly identified. As well, intracardiac blood can be used as a reference point of an anechoic fluid collection to facilitate adjustment of the overall gain and time gain compensation (TGC). All in all, there is no standard order for performing the FAST exam and in many instances the order will be dictated by the patient's clinical presentation and institutional preferences.

Normal Ultrasound Anatomy

Peritoneal Space

The basic FAST exam requires the sonographer to be familiar with the sonographic appearance of the major abdominal solid viscera (liver, spleen, uterus), to have the ability to recognize fluid collections in potential spaces, and to have the technical ability to acquire 4 to 6 standard FAST exam views. The most important skill for trauma ultrasound is the ability to detect free fluid in the potential recesses within the peritoneal cavity (Fig. 4.18). These include Morison's pouch, the perisplenic space, and views of the pelvis and the pericardium. Free intraperitoneal fluid appears as anechoic signals that outline other structures or fills potential spaces.

Liver and Gallbladder

The normal liver has a homogeneous, medium-level echogenicity (Fig. 4.19). Glissen's capsule outlines the liver with an echogenic, defined border. The liver parenchyma is punctuated by a variety of vascular and biliary vessels that appear as anechoic linear structures. A detailed knowledge of the hepatic architecture is helpful but not necessary because the FAST exam relies only on recognizing normal homogenous hepatic architecture from a disrupted or inhomogenous pattern of a traumatized liver.

The gallbladder is a round or oval cystic structure within the liver. It is located on the medial, inferior surface of the liver and will commonly be seen during scanning of the peri-

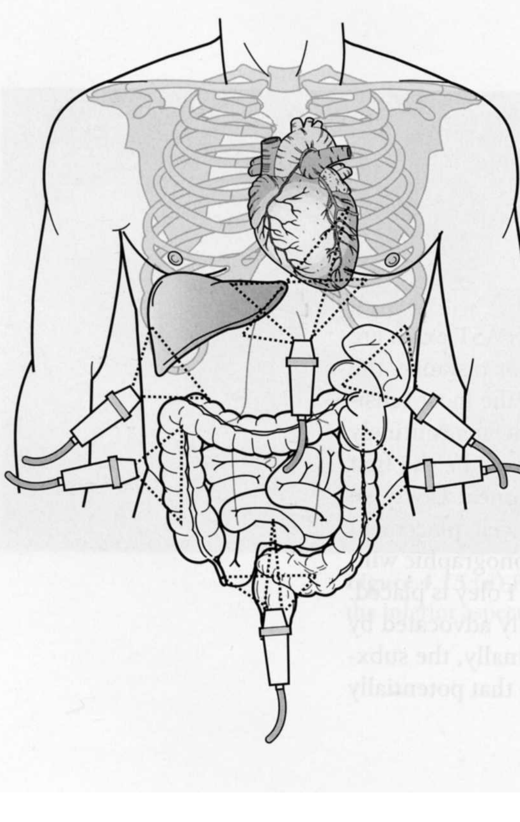


Figure 4.18. Typical transducer positions used to evaluate potential spaces within the peritoneal cavity.

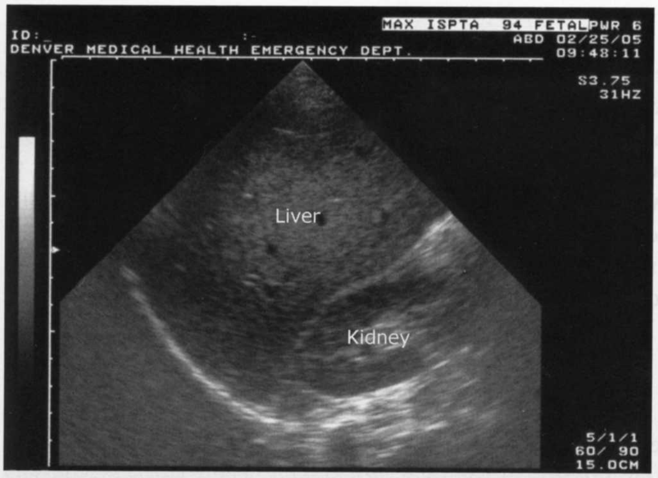


Figure 4.19. Ultrasound image demonstrating the appearance of normal liver tissue.

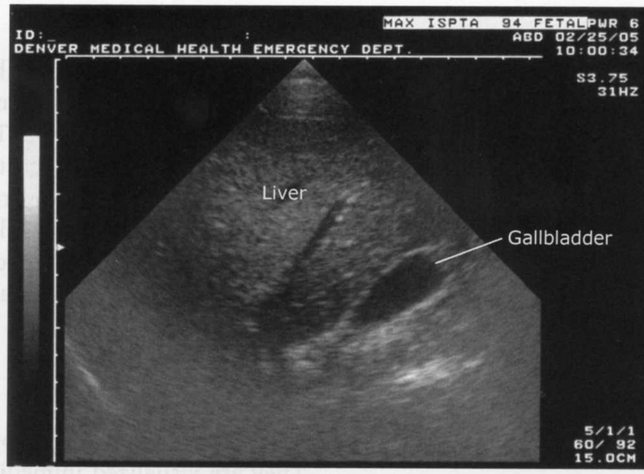


Figure 4.20. Sonographic appearance of the gallbladder while scanning in the perihepatic region.

hepatic area if the transducer is angled anteriorly from Morison's pouch (Fig. 4.20). It is not necessary to identify the gallbladder during the FAST exam, although the gallbladder may be seen to float or bob around in the face of free fluid and may be sonographically enhanced by surrounding fluid.

Spleen

The spleen is a solid organ with a homogenous cortex and echogenic capsule and hilum (Fig. 4.21). It has a medium-gray echotexture similar to that of the liver, but is smaller in size. The vessels within the parenchyma are less apparent than those in the liver. Since the spleen occupies a posterior-lateral location, it may be difficult to assess the entirety of the parenchyma using a single transducer location and multiple planes may be needed to visualize the whole organ.

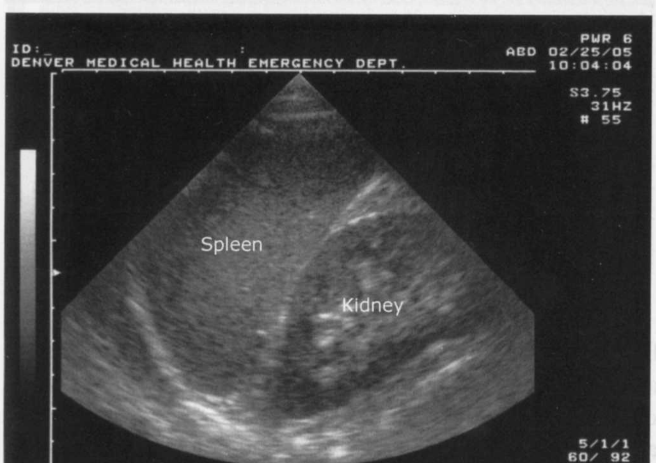


Figure 4.21. Ultrasound image demonstrating the appearance of normal splenic parenchyma.

Bowel

The bowel can have a number of different sonographic appearances depending upon its contents. Air within the lumen of the bowel creates gray shadows that distort the view of surrounding structures. This distortion often makes it difficult to achieve a fine resolution of the image. When the bowel is filled with fluid or solid matter, it can appear to be cystic or solid. However, with simple and brief observation, the image will typically change with visible peristaltic waves. When free fluid is present, anechoic spaces may separate loops of bowel and mesentery, creating a confusing pattern to the novice eye. Loops of bowel may bob about with percussion of the abdomen or movement of the ultrasound transducer.

Kidneys

The kidneys are paired retroperitoneal organs that have a distinct sonographic appearance. They are visualized immediately inferior to the liver and spleen. Their surface (Gerota's fascia) is characterized by a bright echogenic line that outlines the renal cortex. The cortex itself has a medium-gray echotexture that is slightly hypoechoic compared to the hepatic and splenic parenchyma (Fig. 4.22). The central renal sinus is typically echogenic, unless there is a component of hydronephrosis, which, depending on the degree of obstruction, will appear anechoic (Fig. 4.23).

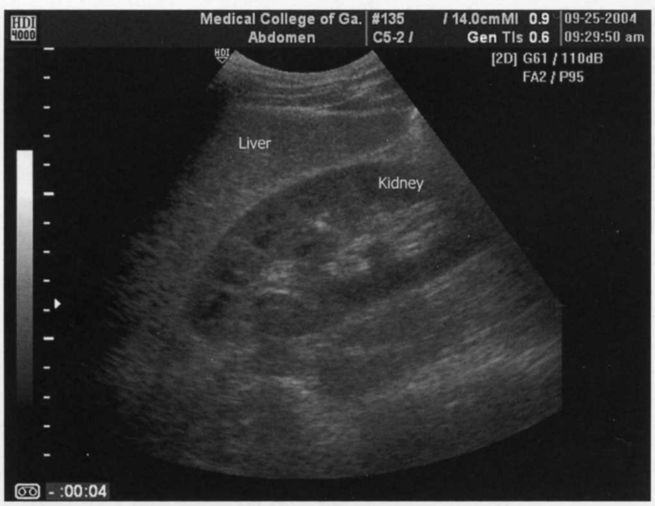


Figure 4.22. Ultrasound image demonstrating the appearance of normal renal parenchyma. (Courtesy of Mike Blaivas.)

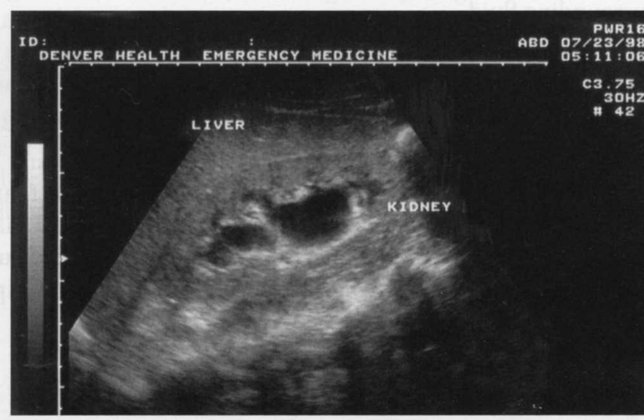


Figure 4.23. Ultrasound taken from a patient with moderate hydronephrosis.

Uterus

The uterus is the major identifiable organ within the female pelvis. It is situated just above the bladder and has a pear-shaped appearance when viewed in its long axis in the sagittal orientation (Fig. 4.24). The lower uterine segment and cervix define the cul-de-sac, the most dependent peritoneal space where free fluid is likely to accumulate (Fig. 4.25).

Figure 4.24. Sagittal orientation of the female pelvis showing the relationship of a normal uterus and bladder.

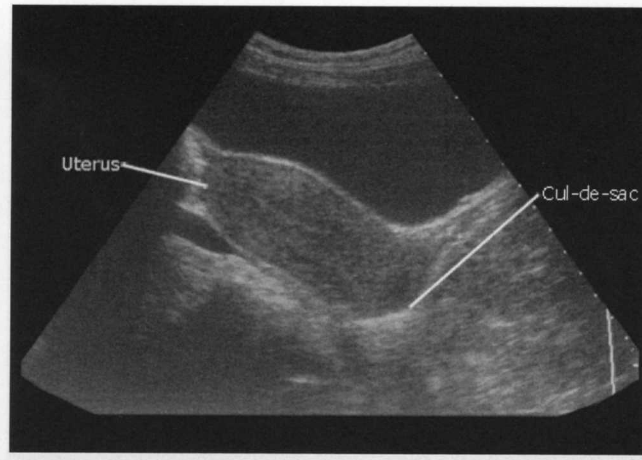


Figure 4.25. Transabdomonal ultrasound image demonstrating the cervix and pelvic cul-de-sac.

Bladder

The bladder is a retroperitoneal organ that is the most sonographically visible portion of the lower urinary tract. It occupies the midline in the lower pelvis, typically at or below the pubic symphysis. When the bladder is empty, the transducer may need to be directly below the pubic ramus to visualize it. When full, the distended bladder provides an excellent acoustic window to pelvic structures (Fig. 4.26). It is important to distinguish between fluid in the bladder and free intraperitoneal fluid.

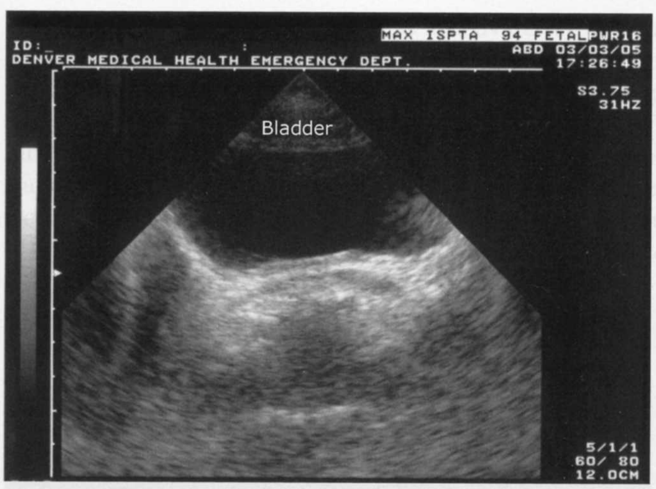


Figure 4.26. Transabdominal pelvic ultrasound of a full bladder in the transverse orientation.

Thorax

Pericardium

The pericardium is usually seen as a white echogenic line surrounding the heart. When pericardial fluid is absent, the parietal pericardium and the visceral pericardium are usually indistinguishable and are seen as a single echogenic line. On occasion the space between the parietal pericardium and visceral pericardium will have a small amount of epicardial fat or may contain up to 10 ml of serous physiologic fluid (Fig. 4.27).

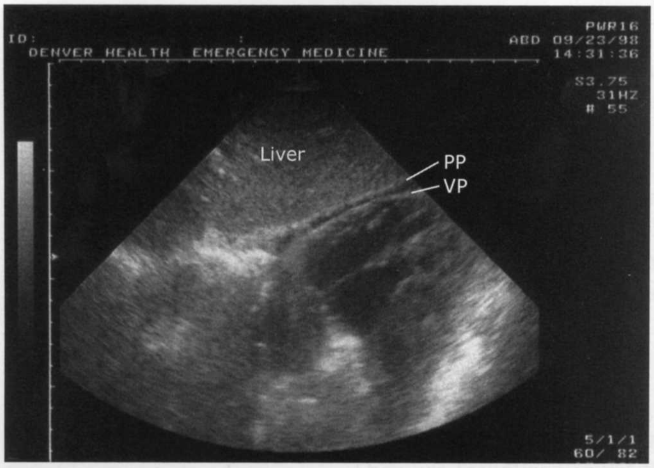


Figure 4.27. Subxiphoid orientation of the heart demonstrating separation of the layers of the pericardium by a small amount of pericardial fluid (VP, visceral pericardium; PP, parietal pericardium).

Cardiac chambers

The chambers of the heart have very distinct locations and appearances. The base of the heart, which includes the atria and major valves, is to the right and slightly posterior, while the apex of the heart points to the left, anteriorly and inferiorly. The right-sided chambers have thin walls that can collapse when pressure within the pericardial space is elevated, as in the case of a pericardial effusion. The left ventricle has a thicker wall and is usually larger than its counterpart on the right (Fig. 4.28). Although a number of approaches can be used to examine the heart and pericardium, the FAST exam typically uses a subxiphoid approach.

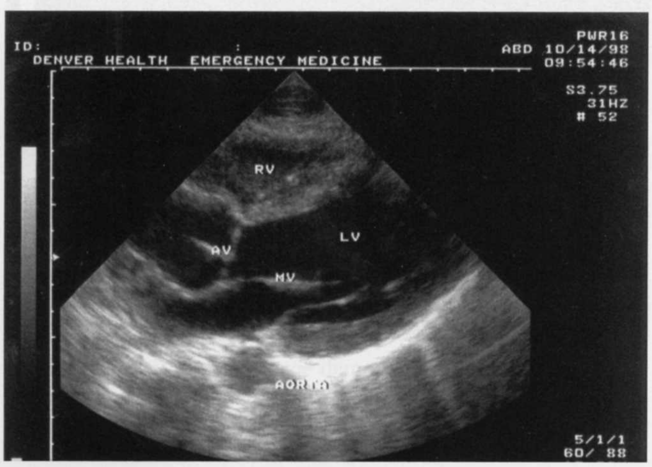


Figure 4.28. The chambers of the heart visualized from the long axis parasternal transducer position. Note that this view uses the emergency medicine orientation; see Chapter 5 (RV, right ventricle; LV, left ventricle; MV, mitral valve; AV, aortic valve).

Pleural cavity

The sonographic assessment of the normal pleural base anatomy is rarely clear, since the scatter and reflection from the lung precludes significant sound penetration. As the transducer is angled or moved to visualize the costophrenic angle, views of the liver, spleen, and diaphragm will give way to scatter artifact that looks like the screen has become dirty: this is the appearance of normal lung. On the other hand, elucidating normal sonographic anatomy of the anterior thorax is extremely useful. The most visible and superficial finding is the acoustic shadowing from the ribs (Fig. 4.29). The pleural space is just deep to the posterior aspect of the ribs. It can be recognized as an echogenic line that has the appearance of to-and-fro sliding (Fig. 4.30). This is termed the "sliding sign," and if it is seen the

Figure 4.29. Anterior thorax transducer position demonstrating the appearance of rib shadow.

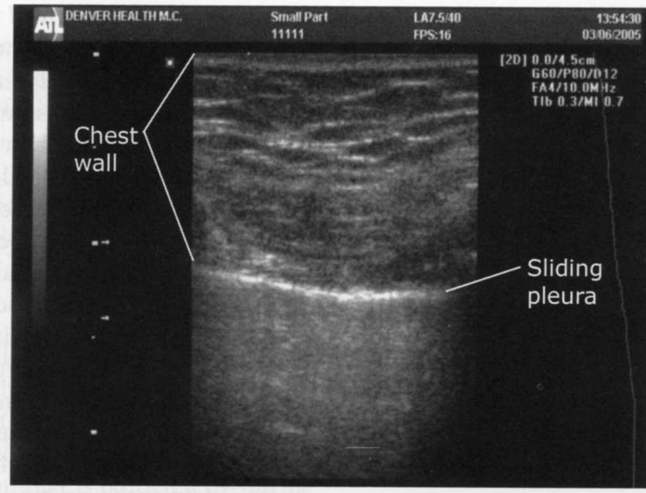


Figure 4.30. Ultrasound anatomy visualized during scanning to assess for the presence of a "sliding sign."

exam is considered negative for a pneumothorax, because the visceral and parietal pleura are in proximity. Additional sensitivity for visualizing these structures may be achieved by using power color Doppler (19). Using the "power slide" technique, normal lung anatomy is easily noted by the presence of color signal enhancement.

Pathology

Free Peritoneal Fluid

Fluid (blood) in the trauma patient is usually detected in the dependent areas of the peritoneal cavity including the hepatorenal space (Morison's pouch), the perisplenic space, the pelvis, and the paracolic gutters. In general, free fluid appears anechoic (black) and is defined by the borders of the potential spaces it occupies (Fig. 4.31). As an example, free fluid in Morison's pouch will be bounded by Glisson's capsule or the liver anterolaterally and Gerota's fascia or the kidney posteromedially. There are a number of variables that affect the appearance and location of fluid within the peritoneal cavity. These include the site of origin of the bleeding, the rate of accumulation, time since the injury, and movement of fluid within the peritoneal cavity.

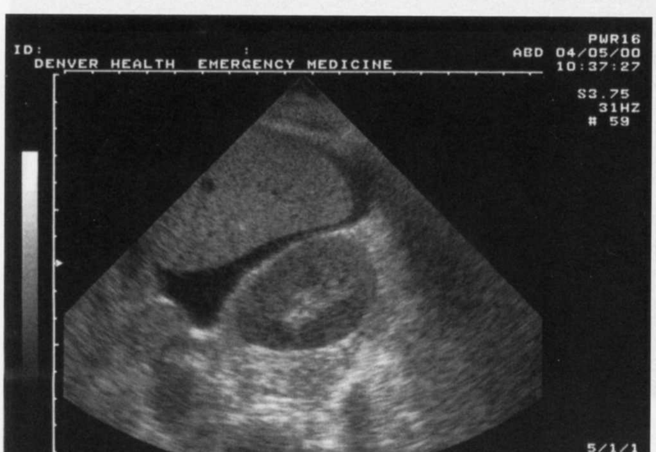


Figure 4.31. Peritoneal fluid visualized in the perihepatic region.

Minimum amount of fluid

The ability to detect free intraperitoneal fluid by ultrasound was first illustrated in a cadaver study in 1970 that demonstrated that as little as 100 cc of instilled peritoneal fluid was detectable by ultrasound when the body was placed in a hand-knee position and scanned from the abdomen (1). Additional studies have been done since, including one finding that as little as 10 mL of fluid could be consistently visualized in the pouch of Douglas (20). The minimal amount of fluid detected by ultrasound depends on a number of factors, most notably, the location of the fluid and the positioning of the patient. Most studies that have assessed the ability of ultrasound to detect minimal volumes of peritoneal fluid have focused on Morison's pouch using a saline infusion model (20–23). In one study using DPL as a model for intraperitoneal fluid, the mean volume detected in Morison's pouch was 619 mL (standard deviation, 173 mL). Only 10% of the sonographers could detect fluid volumes of 400 mL or less (21). Using a similar DPL model, another study assessed the minimum volume detected using the pelvic view (24). They determined that the average minimum detectable volume was 157 mL by one participant and 129 mL by an independent reviewer, thus suggesting that the pelvic view may be more sensitive than Morison's pouch for small volumes of peritoneal fluid.

Patient positioning has also been studied as a factor in detecting peritoneal fluid. For instance one study found that the optimal positions for detecting minimal volumes of fluid in a cadaver model were right lateral decubitus or facing downward while being supported on both hands and knees (1). Since neither of these positions is practical for scanning the trauma patient, other positioning has been investigated. For example, a small amount (5 degrees) of Trendelenburg positioning has been shown to statistically increase the sensitivity for detecting peritoneal fluid in the right upper quadrant (25).

Finally, attempts have been made to correlate the width of the fluid stripe in Morison's pouch with intraperitoneal fluid volumes. In a DPL model, a mean stripe width of 1.1 cm was found after 1 L of saline had been instilled (22). Other studies have proposed that fluid can be seen at similar or even smaller volumes (26,27), but how the authors of these studies derived their results is largely unknown and, therefore, their conclusions are unsubstantiated.

Fluid flow patterns

Fluid in the peritoneal cavity can collect and subsequently spread in a predictable manner, which can aid in its detection. One study found that in the supine position, the

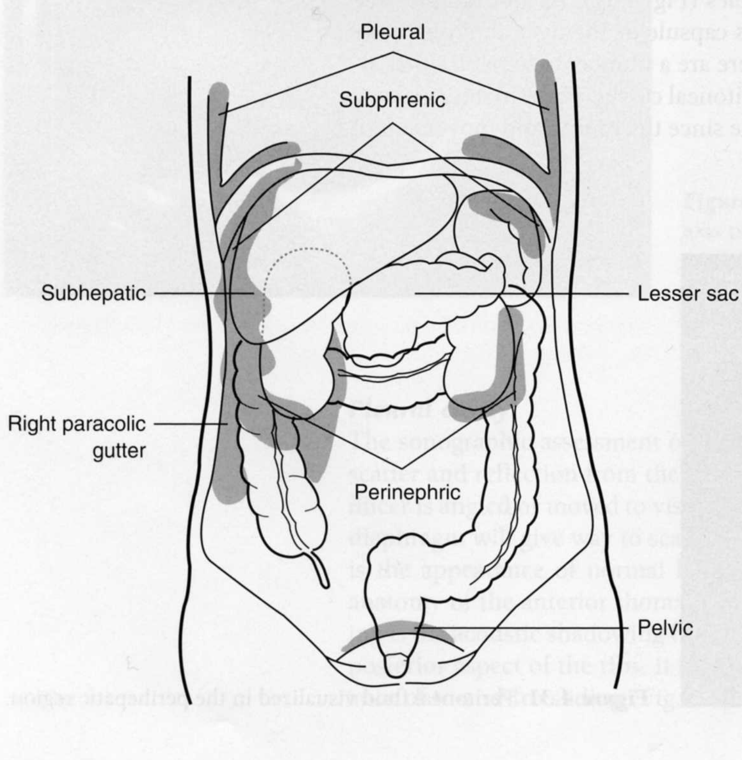


Figure 4.32. Potential spaces within the torso where fluid can collect.

pelvis is the most dependent portion of the peritoneal cavity and the right paracolic gutter is the main communication between the upper and lower abdominal compartments (Fig. 4.32) (28). Measured flow patterns have shown that fluid tracking up the right paracolic gutter preferentially collects in Morison's pouch before progressing to the right subphrenic space. Interestingly, the phrenicocolic ligament restricts similar flow between the left paracolic gutter to the left upper quadrant, so fluid in the supramesocolic space actually spreads across the midline into the right upper quadrant. Clinical studies support these findings as the majority of peritoneal fluid collections are detected in the perihepatic region (16,29).

Perihepatic fluid

Fluid can accumulate and be found in a variety of perihepatic locations. Most commonly it will be detected in the hepatorenal space or Morison's pouch. It appears as an anechoic fluid collection with well-defined edges that are bordered by Glisson's capsule of the liver and Gerota's fascia of the right kidney (Fig. 4.33). Fluid can also collect in the subphrenic space and will appear as a crescent-shaped anechoic collection that is bordered by the diaphragm superiorly and the liver inferiorly (Fig. 4.34). Other less common areas where fluid may be detected are at the superior pole of the kidney in Morison's pouch (Fig. 4.35) or at the tip of the liver (Fig. 4.36).

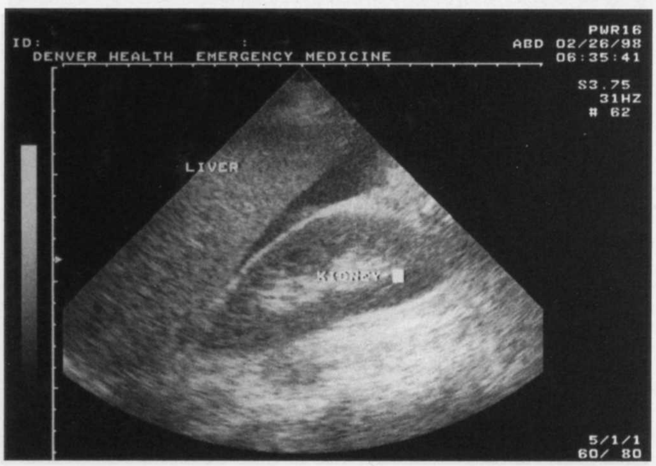
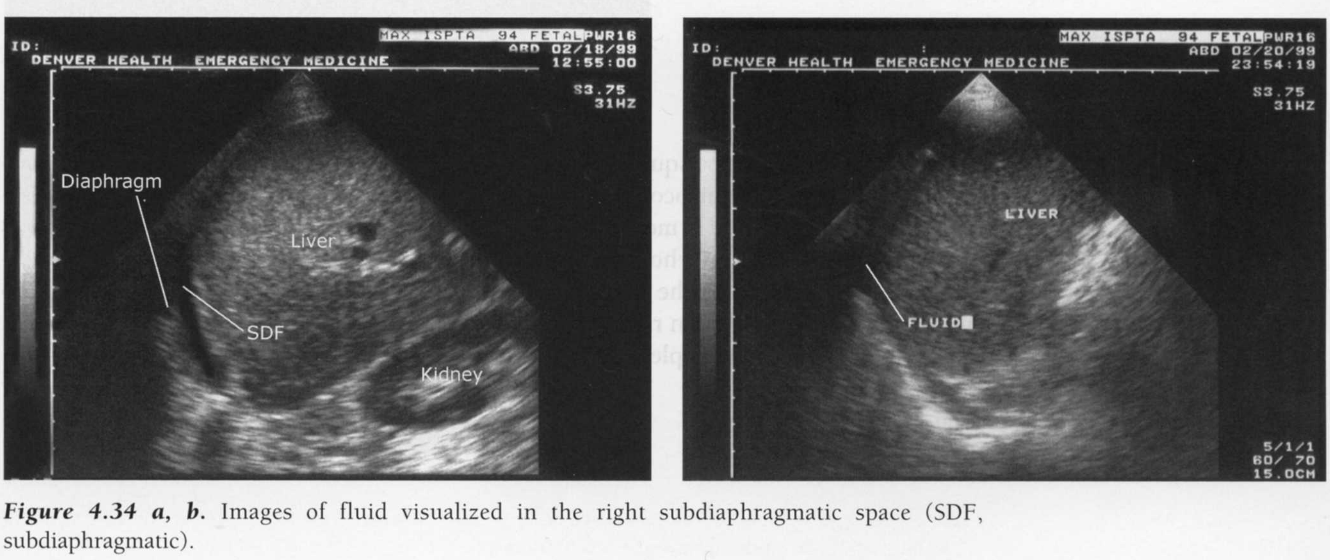


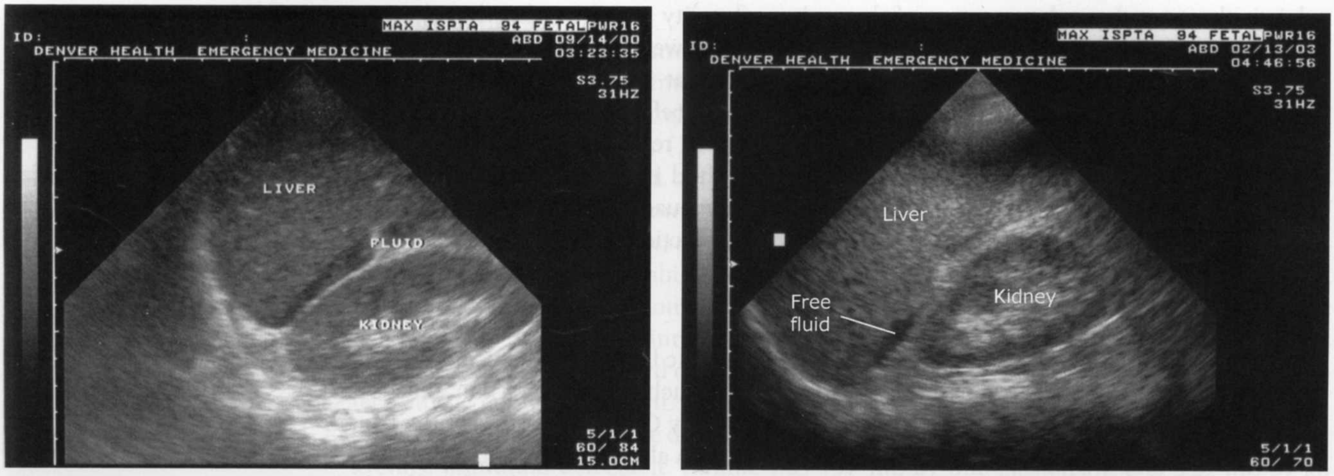
Figure 4.33. Ultrasound appearance of free fluid in Morison's pouch.

A



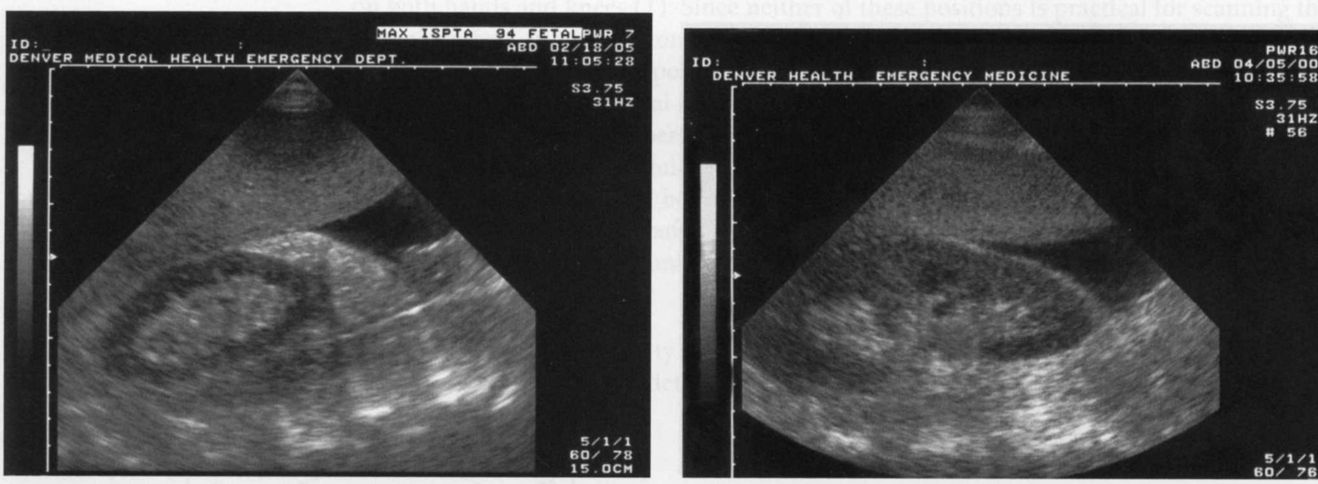
B

Figure 4.34 a, b. Images of fluid visualized in the right subdiaphragmatic space (SDF, subdiaphragmatic).



A B

Figure 4.35 a, b. Examples of the appearance of peritoneal fluid collecting at the superior pole of the right kidney.



A B

Figure 4.36. Examples of peritoneal fluid visualized at the tip of the liver.

Perisplenic fluid

Free fluid in the left upper quadrant collects differently than in the perihepatic area, primarily because the phrenicocolic ligament restricts fluid from filling the splenorenal interface. Consequently, fluid is most commonly detected in the subphrenic space and appears as a crescent-shaped, anechoic fluid collection that is bordered superiorly by the diaphragm and inferiorly by the spleen (Fig. 4.37). Alternatively, fluid may be seen at the tip of the spleen (Fig. 4.38). On rare occasions when large amounts of fluid are present, fluid can be found between the spleen and the kidney (Fig. 4.39).

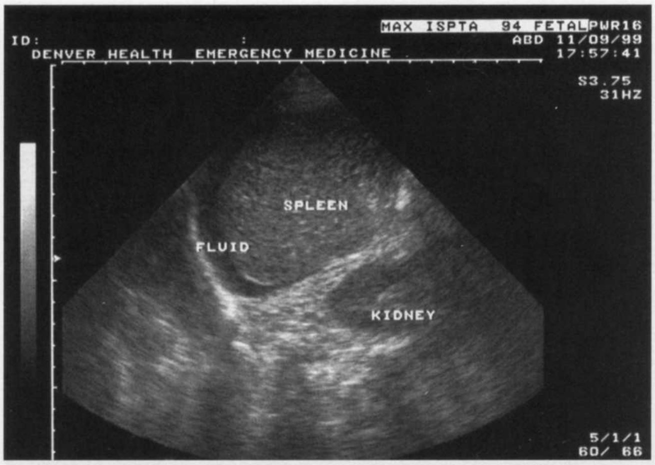
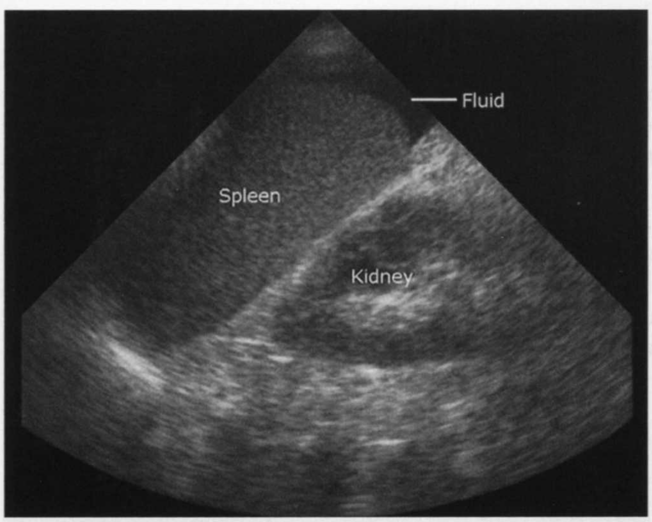
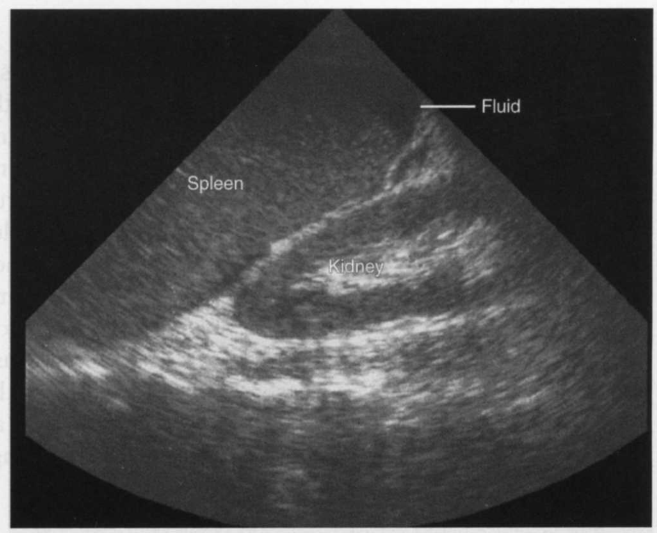


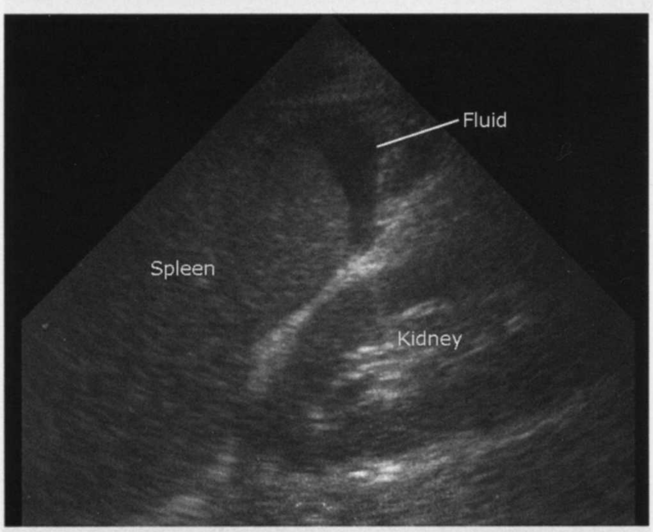
Figure 4.37. Peritoneal fluid detected in the left subdiaphragmatic space.



A



B



C

Figure 4.38 a–c. Images of the perisplenic area with fluid visualized at the tip of the spleen.

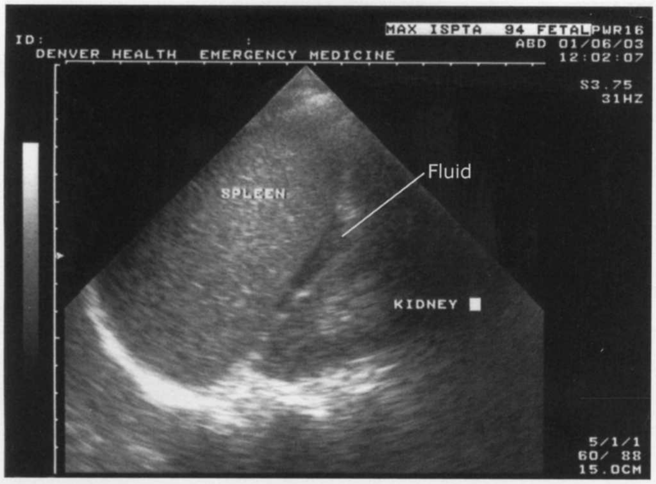
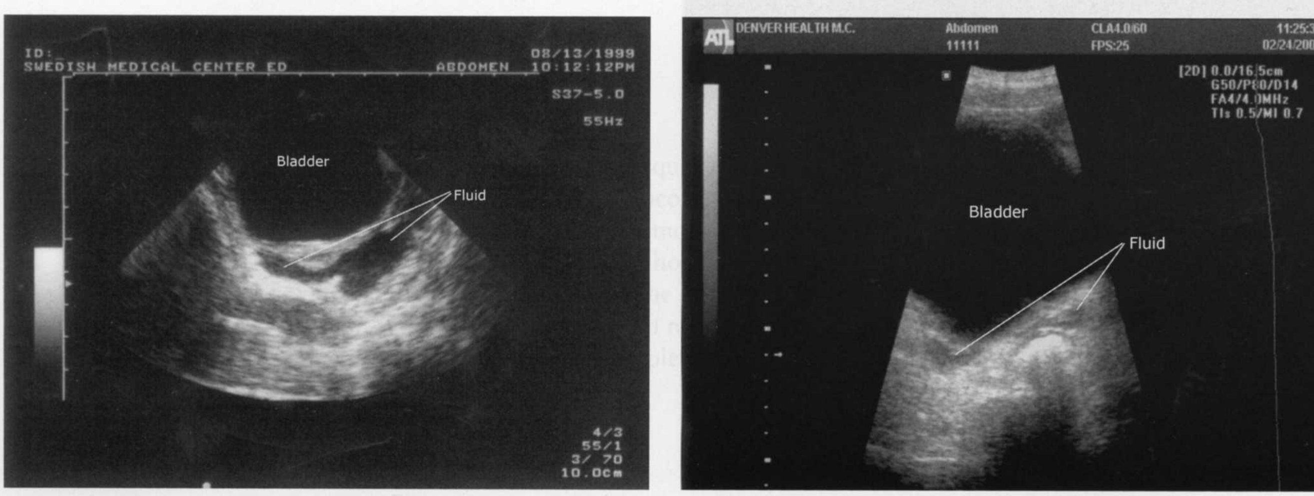


Figure 4.39. Ultrasound image of the left upper quadrant demonstrating fluid in the interface between the spleen and kidney.

Pelvic fluid

Free fluid in the pelvis has a variety of appearances depending on patient gender and transducer orientation. In the transverse plane, fluid in a male pelvis can be seen in the retrovesicular space as an anechoic fluid collection that outlines the posterior wall of the bladder (Fig. 4.40 **a**, **b**). In the transverse orientation of the female pelvis, fluid will collect posterior to the uterus (Fig. 4.41) or, if enough fluid is present, between the body of the uterus and the bladder. When viewing the pelvis in the sagittal orientation, fluid will collect in the same places as in the transverse orientation, but it will appear differently. For instance, in the male pelvis, the fluid will collect posterior to the bladder, but it is represented by an anechoic space between the dome of the bladder and the bowel wall (Fig. 4.42 **a**, **b**, **c**). It has a similar appearance in the female patient except that it collects in the space between the uterus and bowel (Fig. 4.43 **a**, **b**). As with all scanning applications, both transverse and sagittal planes are critical to fully evaluate the pelvis for fluid, as there are many imaging artifacts and confusing structures that can confound the exam.

A



B

Figure 4.40 a, b. Sonographic appearance of fluid collecting posterior to the bladder in male patients with the transducer in the transverse orientation.

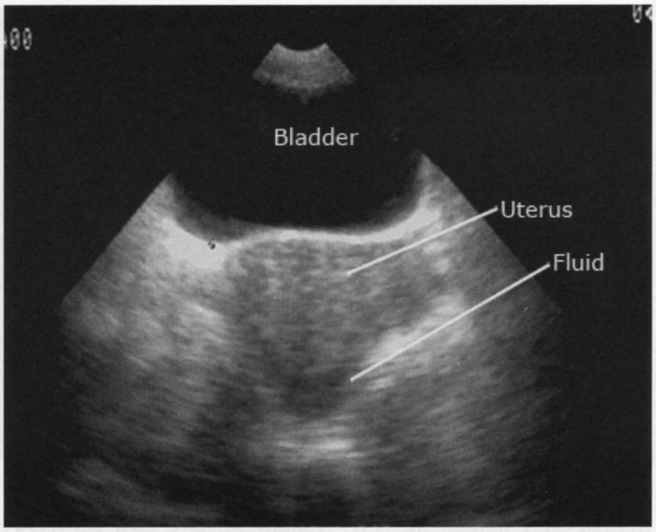
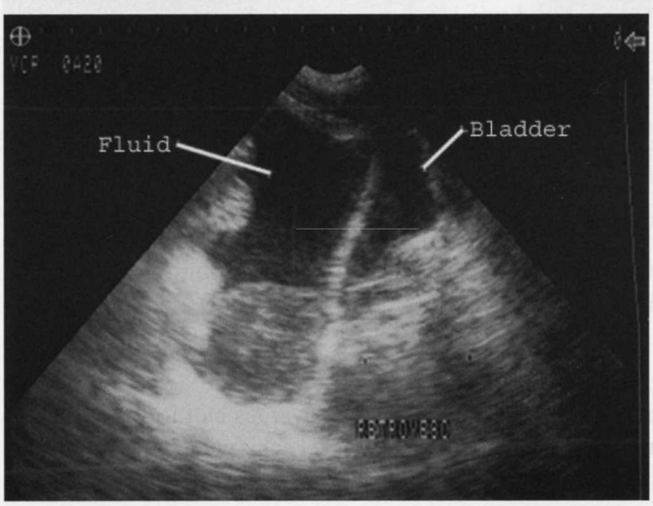


Figure 4.41. Ultrasound image of free fluid located posterior to the uterus with the transducer in the transverse orientation.

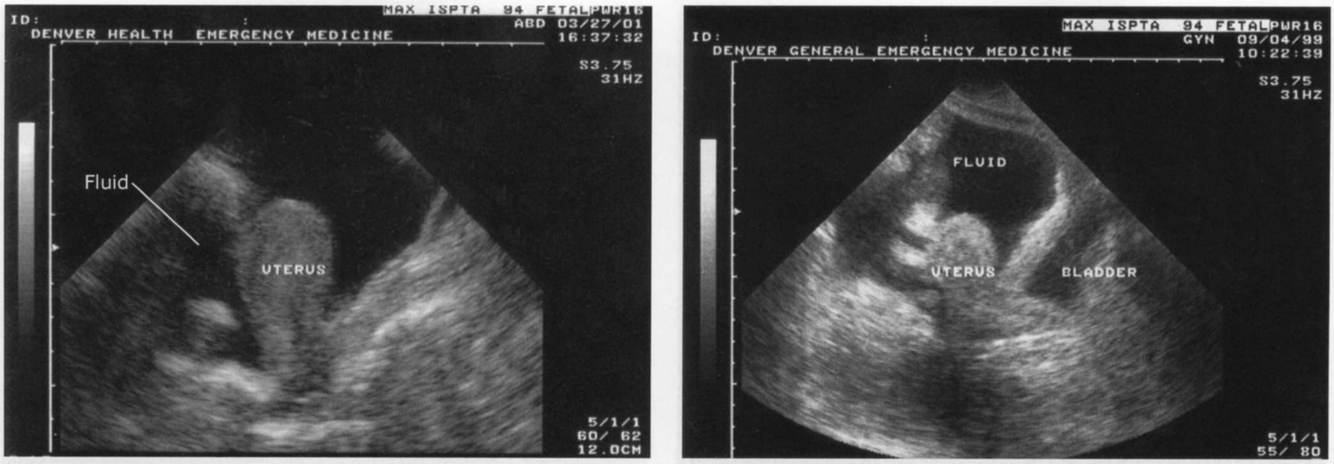
A

B



C

Figures 4.42 a–c. Sagittal orientation of male pelvis demonstrating fluid at the superior aspect of the bladder.



Figures 4.43 a, b. Sagittal orientation of female pelvis demonstrating fluid at the superior aspect of the bladder and uterus.

Paracolic gutter fluid

Fluid in the paracolic gutter has a specific appearance as it forms an anechoic, sharp-edged border to loops of bowel in the area (Fig. 4.44 a, b). The fluid pockets will vary in size and the space between loops of bowel will change with peristalsis.

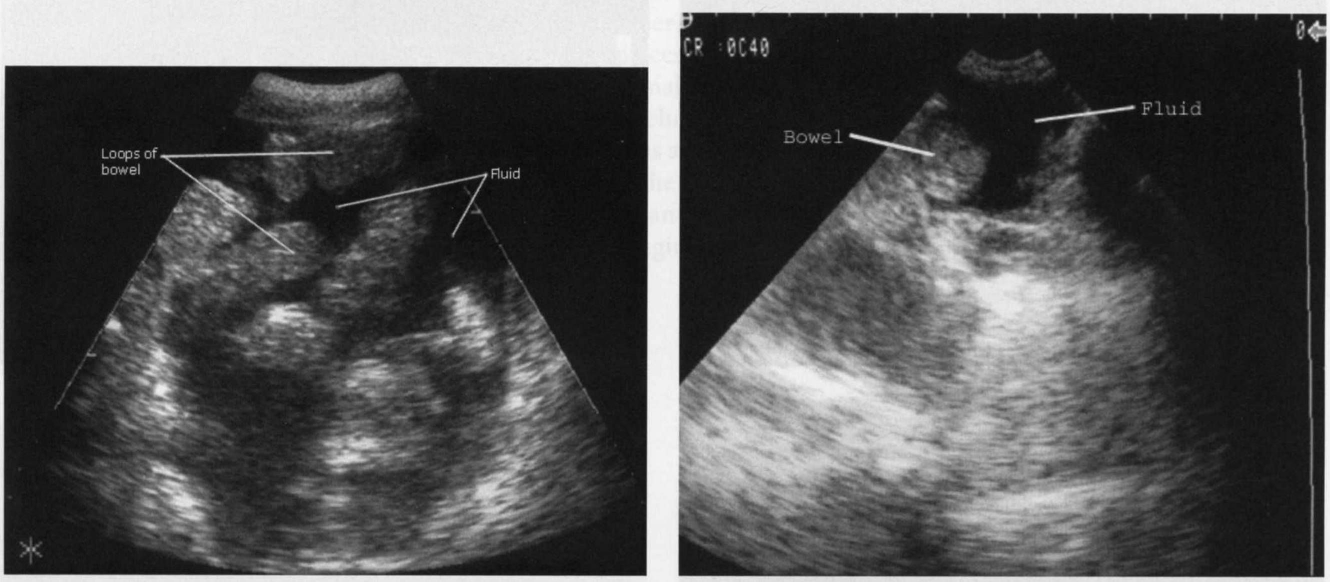


Figure 4.44 a, b. Paracolic gutter ultrasound images with fluid outlining loops of bowel.

Echogenic hemorrhage and clot

Most fresh peritoneal hemorrhage will appear anechoic, however, as clot forms and organizes, it becomes more echogenic. Clotted blood has a midlevel echo pattern that has some sonographic similarities to tissue, such as the spleen or liver parenchyma (Fig. 4.45). Col-

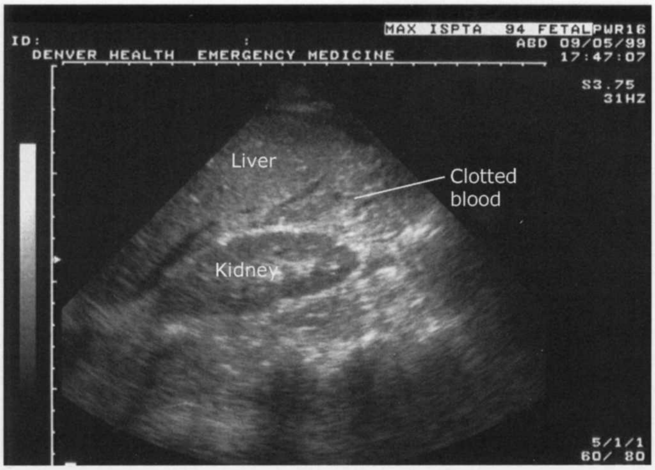


Figure 4.45. Perihepatic view with clotted blood visualized between the liver and the kidney. Note the similar echo pattern between the clotted blood and the liver tissue.

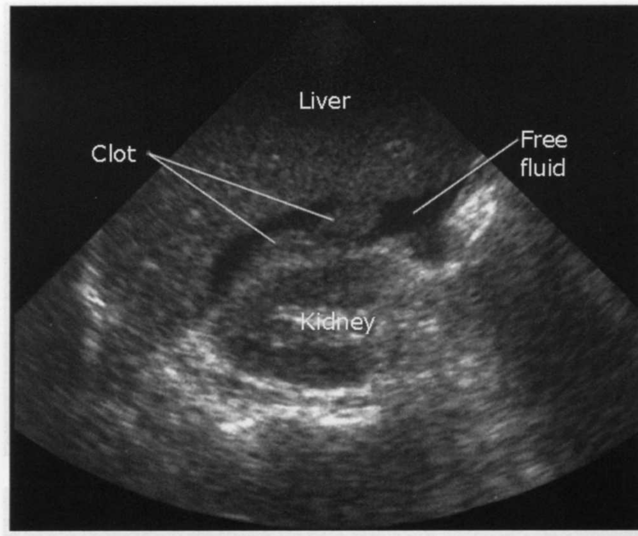


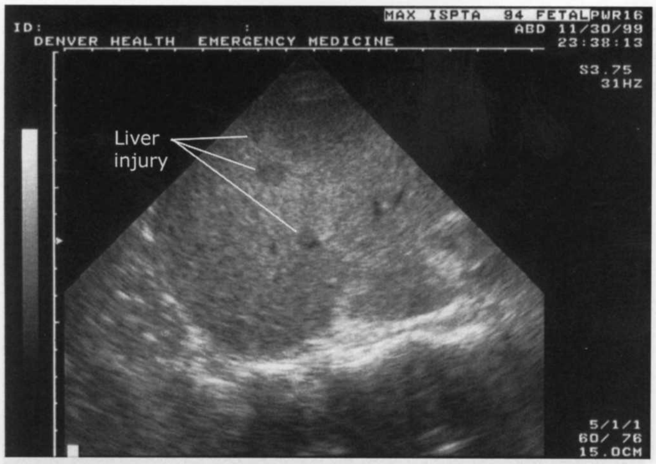
Figure 4.46. A positive Morison's pouch view with free fluid outlining clotted blood.

lections of clotted blood can be found in patients with long transport times or large volumes of peritoneal bleeding. The ability to differentiate clotted peritoneal blood from normal parenchyma can at times be difficult, but in most cases, thorough inspection of the area in question will demonstrate that an anechoic stripe, representing free peritoneal fluid, borders the clotted blood (Fig 4.46).

Solid Organ Injury

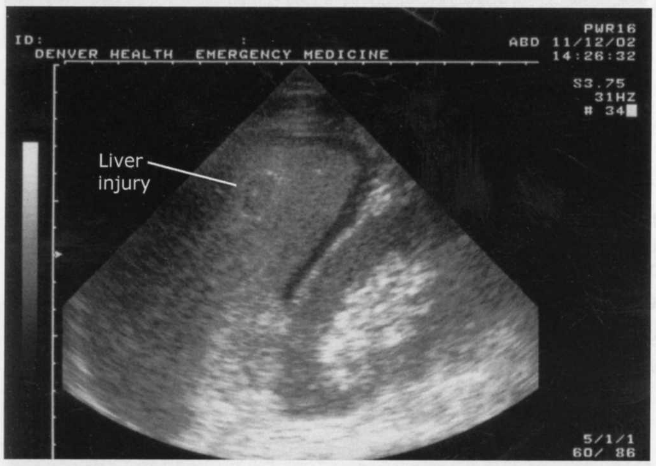
The sonographic appearance of specific organ injury varies. The ultrasound appearance of parenchymal damage in the liver can appear as anechoic or echogenic distortion of the normal architecture (Fig 4.47 a–c), and manifestations of injury can include subcapsular fluid collections and intraperitoneal fluid (30–34). The most common pattern of parenchymal liver injury identified by ultrasonography in patients with blunt abdominal trauma is a discrete region of increased echoes followed by a diffuse hyperechoic pattern (Fig. 4.48 a–c).

Spleen injuries, much like liver injuries, can have a variety of appearances. The most sensitive finding is either hemoperitoneum or a subcapsular fluid collection, whereas the most specific finding is an alteration in the normal homogenous architecture of the parenchyma (35–37). Sonographic patterns of splenic parenchymal injury include (most commonly) a diffuse heterogeneous appearance (Fig. 4.49), hyperechoic and hypoechoic splenic crescents (Fig. 4.50), and discrete hyperechoic or hypoechoic regions within the spleen (Fig. 4.51).



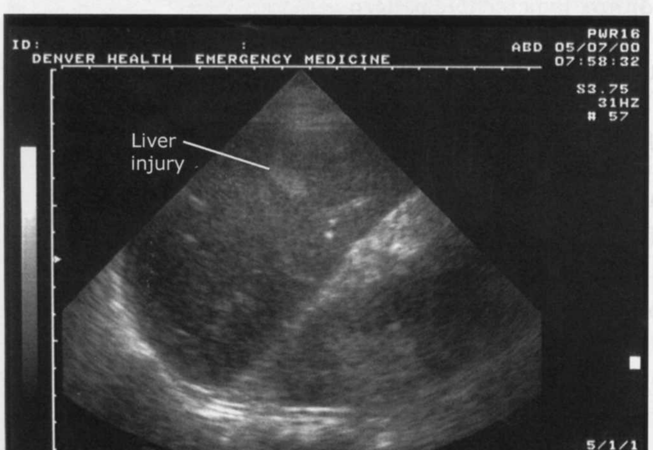
A

B



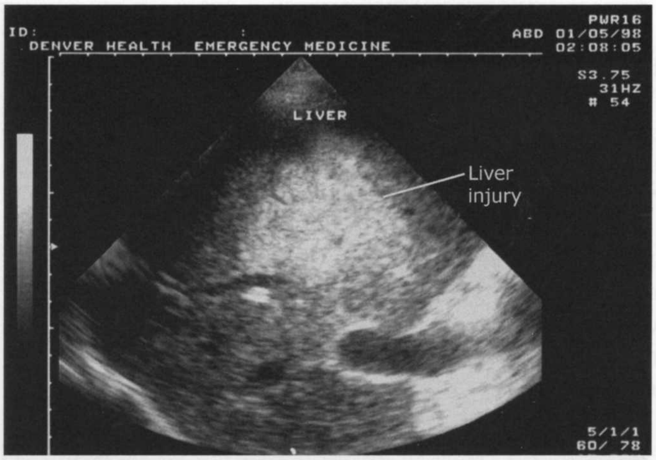
C

Figures 4.47 a–c. Examples of liver injuries visualized as a distortion of the normal tissue anatomy.

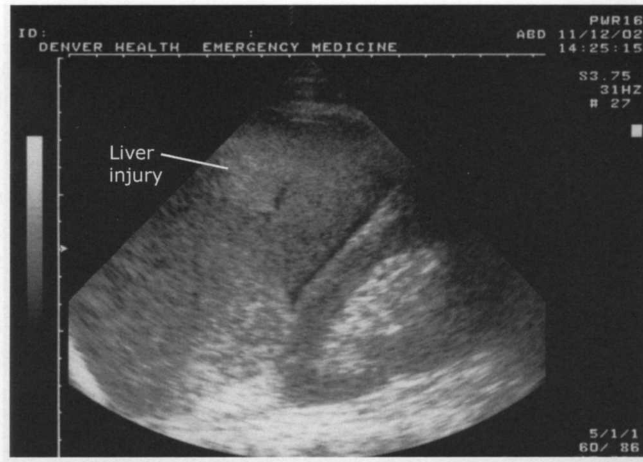


A

Figure 4.48 a–c. Liver injury manifesting sonographically as hyperechoic lesions within the parenchyma.

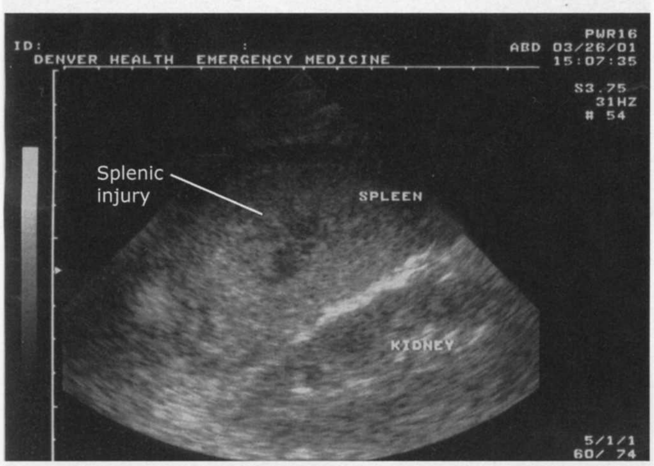


B

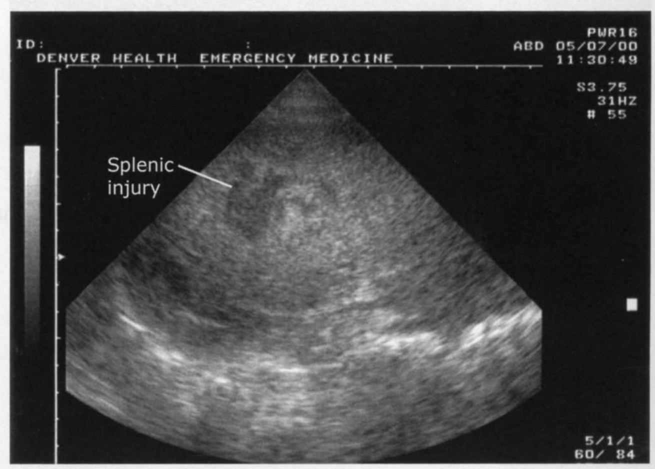


C

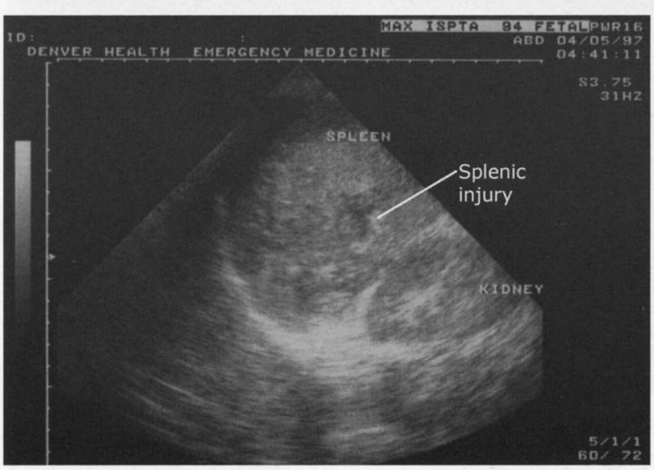
Figure 4.48 (continued)



A



B



C

Figure 4.49 a–c. Injury seen by ultrasound as a heterogeneous appearance to the splenic tissue.

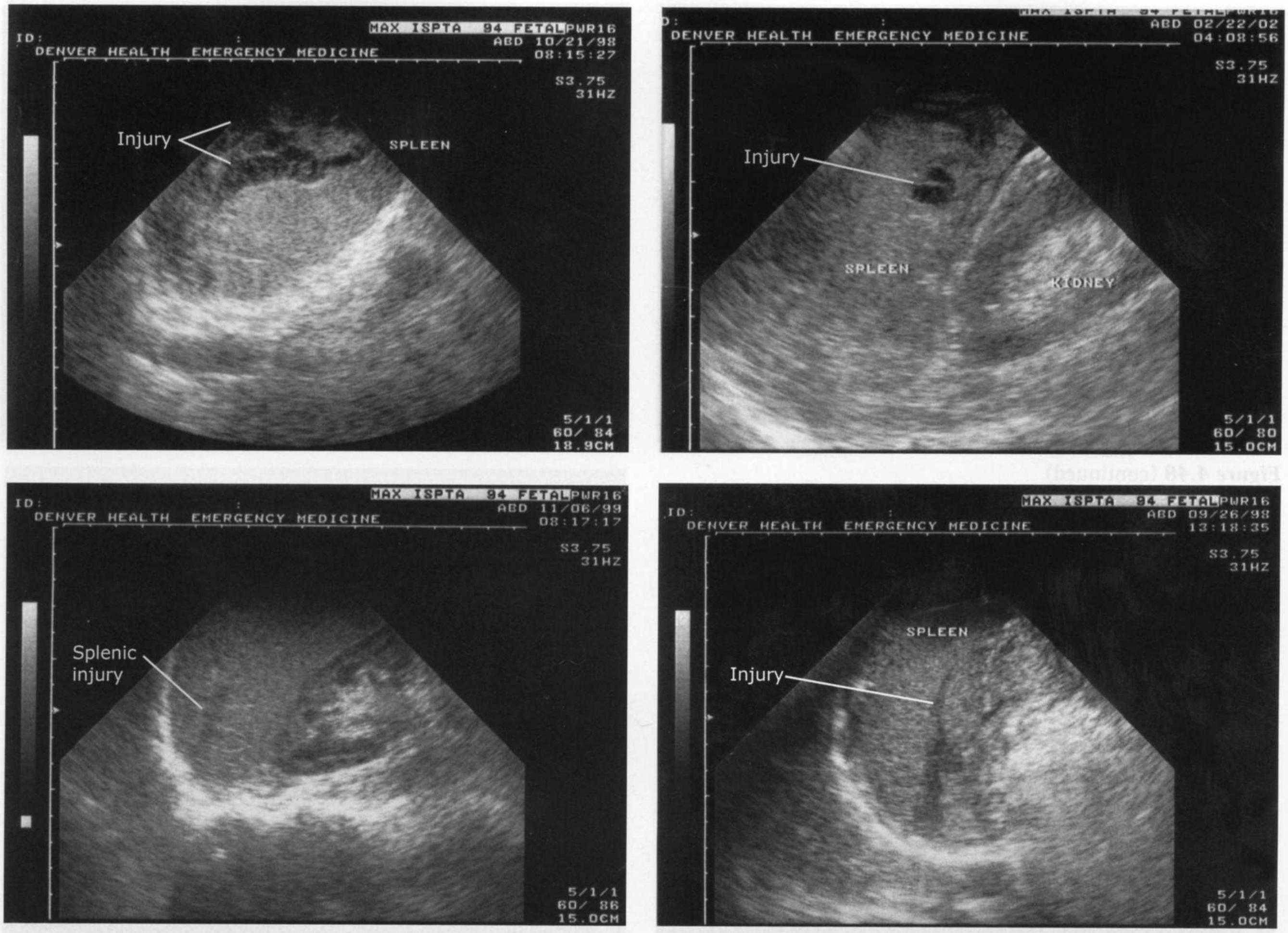


Figure 4.50 a–d. Ultrasound images of splenic injuries seen as hypoechoic cresent-shaped lesions.

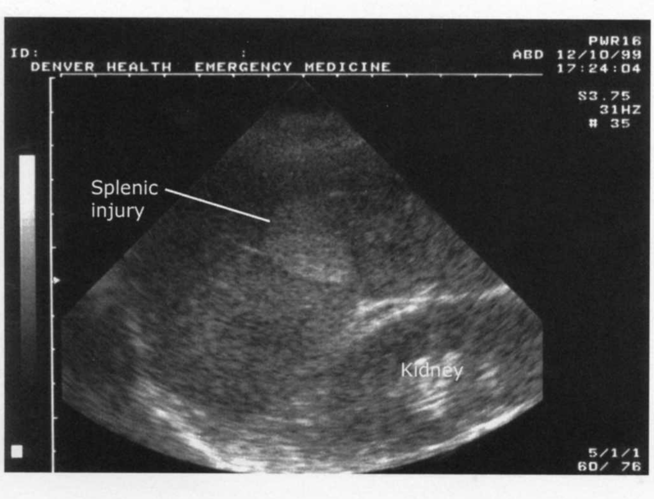


Figure 4.51. Hyperechoic lesion within the spleen representing parenchymal injury.

Pericardial Effusion

Hemorrhage can accumulate quickly in the potential space between the visceral and parietal pericardium and create hypotension due to a cascade of increasing intrapericardial pressure leading to a lack of right heart filling followed by decreased left ventricular stroke volume. Fluid in the pericardial space appears as an anechoic stripe that conforms to the outline of the cardiac structures. In most cases, the fluid should have the same anechoic character as blood within the cardiac chambers. From the subxiphoid orientation, fluid will initially be seen between the right side of the heart and the liver, which is the most dependent area visualized (Fig. 4.52). In the parasternal orientation, fluid may also be seen anteriorly superior to the right ventricle or posteriorly as it outlines the free wall of the left atria and ventricle (Fig. 4.53). The descending aorta is an important landmark for the posterior pericardial sac. Pericardial fluid will often collect just anterior to the descending aorta (Fig. 4.54).

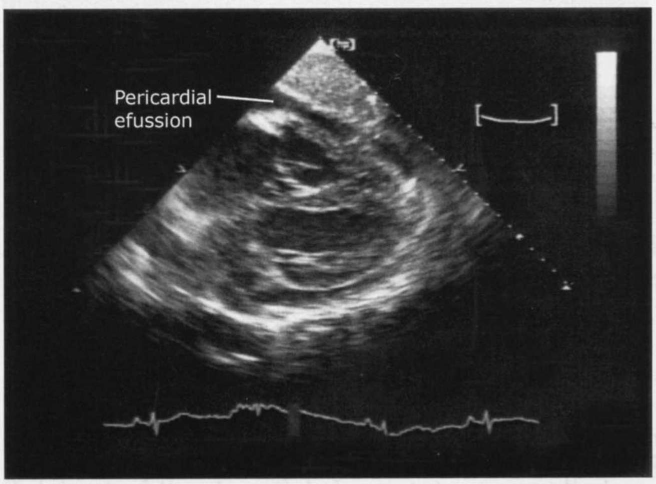


Figure 4.52. Ultrasound image taken from the subxiphoid transducer position demonstrating fluid in the pericardial space.

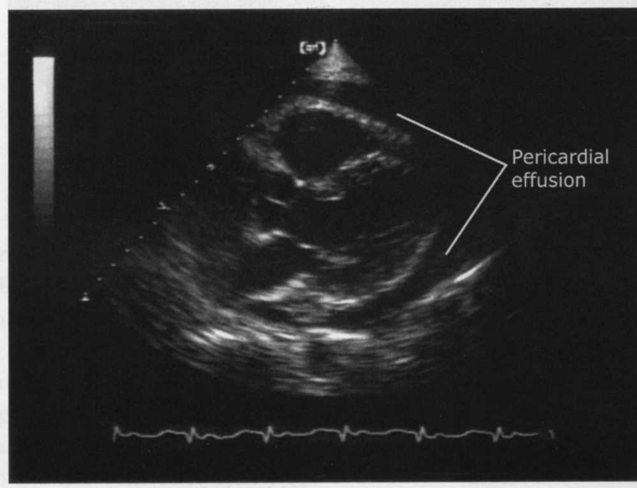
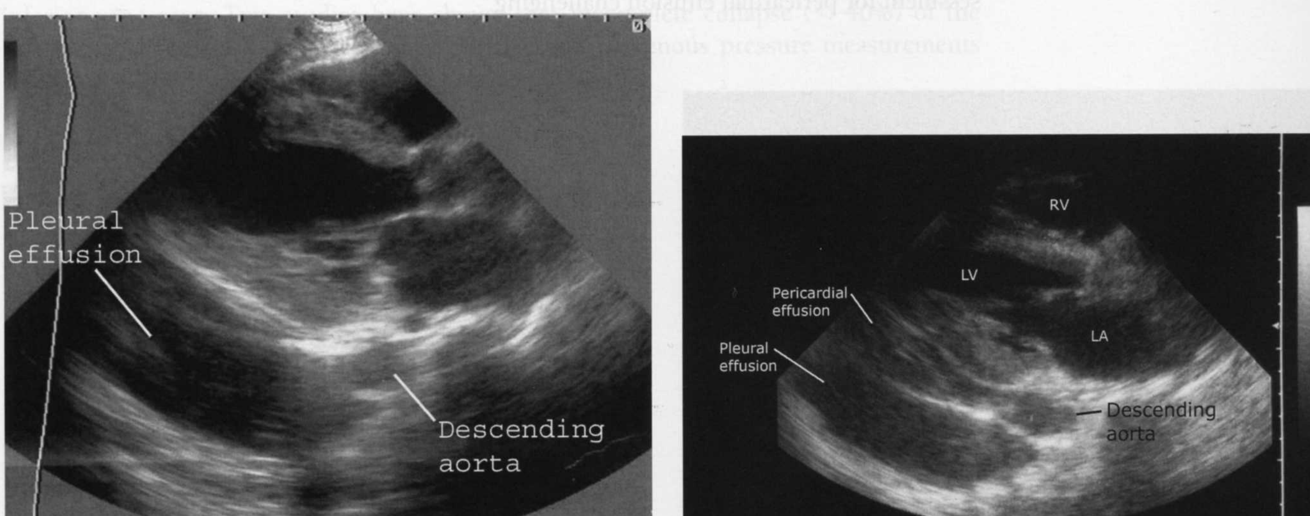


Figure 4.53. Parasternal long axis view of the heart showing fluid in the pericardial space.

A



B

Figure 4.54. Ultrasound images demonstrating pericardial and pleural effusions from the long axis parasternal transducer position. (***a***) Note that the descending aorta is the structure that delineates pericardial from pleural fluid (***b***) (RV = right ventricle, LV = left ventricle, LA = left atrium).

Circumferential effusion

Various methods have been suggested for quantifying pericardial effusions viewed by ultrasound. One of the most straightforward methods is to determine whether the effusion is circumferential. Those that are circumferential but less than a centimeter in width are considered moderate-sized collections, whereas those greater than one centimeter in width are classified as large (Fig. 4.55). It is important to note that even small pericardial effusions can cause tamponade, so quantifying the amount of fluid within the pericardial space is secondary to assessing the patient's hemodynamic status.

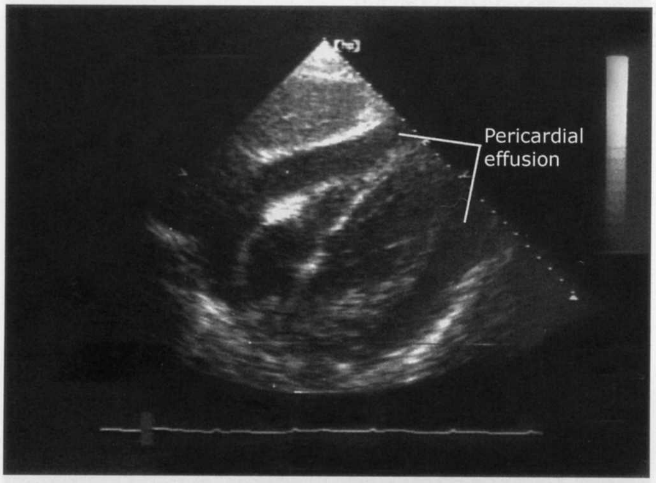


Figure 4.55. Ultrasound image demonstrating a circumferential pericardial effusion viewed from the subxiphoid transducer position.

Echogenic effusions

Effusions that are echogenic present a diagnostic challenge. Echogenic effusions may occur if blood clots are present, but may be due to preexisting pathology such as infection (pus), inflammation (fibrinous material), or malignancy. Instead of an anechoic appearance to the effusion, the fluid may have a similar echogenic character to surrounding structures such as the liver or ventricular tissue (Fig. 4.56 a–c). This isoechoic character can make the assessment for pericardial effusion challenging.

A

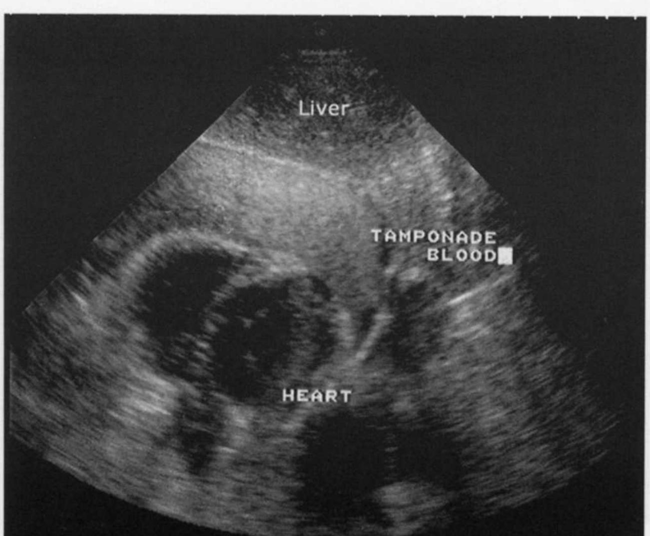
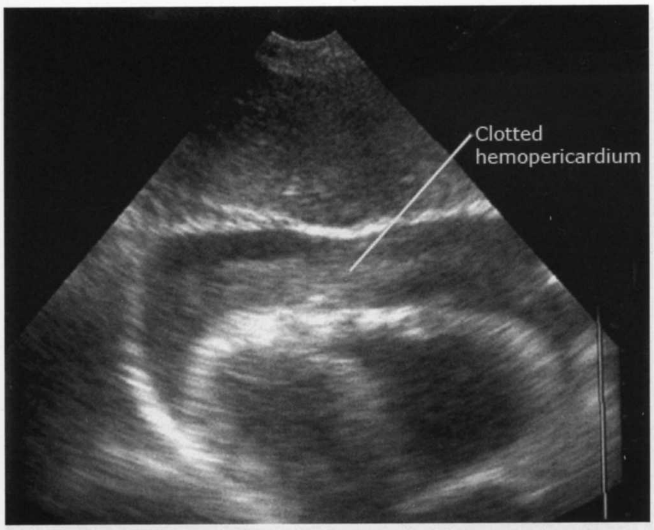
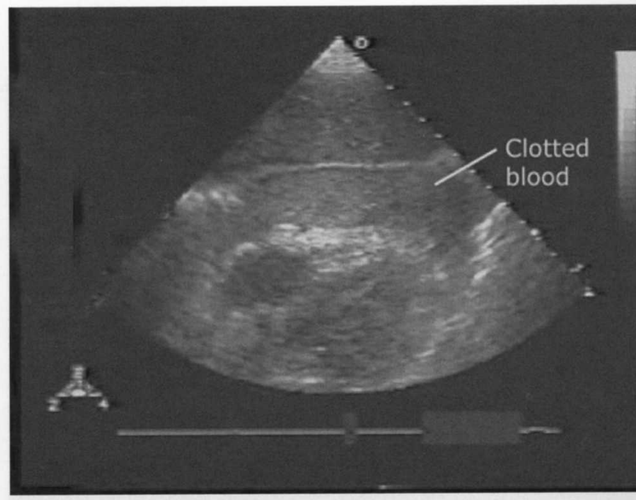


Figure 4.56 a–c. Images demonstrating clotted hemopericardium.



B



C

Figures 4.56 (continued)

Cardiac tamponade

After determining that a pericardial effusion is present, the next step is to determine whether there is sonographic evidence of cardiac tamponade. The pathophysiology of tamponade is characterized by increasing pericardial pressure that eventually exceeds atrial and ventricular pressures, thus inhibiting cardiac filling. As pericardial pressure increases, there is sequential collapse of the right atrium and subsequently the right ventricle (Fig. 4.57). Although the right atrial collapse occurs sooner than right ventricular collapse, this finding is less specific for diagnosing tamponade (38). Another potentially helpful sonographic finding is bowing of the interventricular septum into the left ventricle. This late finding is very specific for tamponade (39).

An additional means of assessing for elevated central venous pressure is to image the inferior vena cava. One method is the "sniff test," in which the patient is instructed to inhale quickly through his or her nose while the examiner simultaneously visualizes the inferior vena cava. Two studies have shown that incomplete collapse (< 40%) of the inferior vena cava correlates well with elevated central venous pressure measurements (Fig. 4.58 a, b) (40,41).

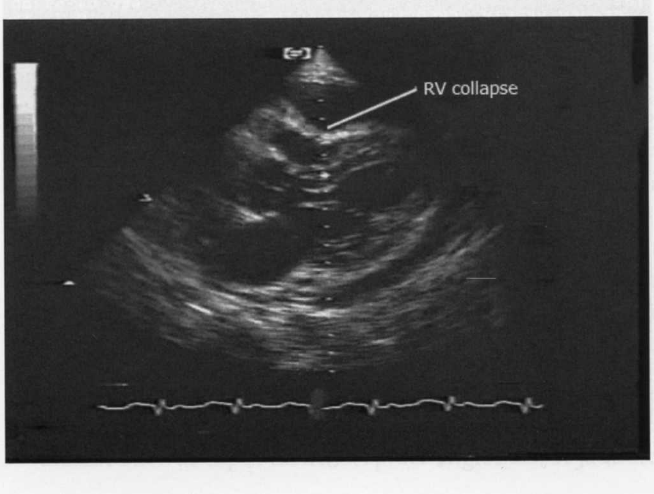


Figure 4.57. Long axis parasternal ultrasound image demonstrating collapse of the right ventricle in a patient with cardiac tamponade.

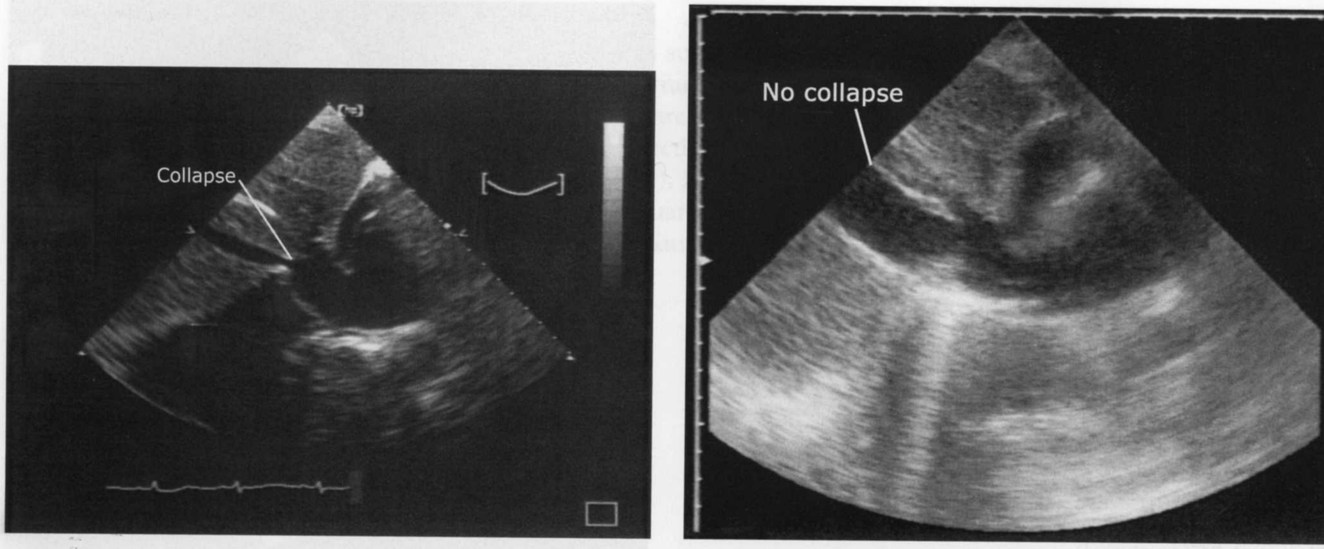


Figure 4.58 a. Image taken of a patient with a moderate-sized pericardial effusion. Note how the vena cava collapses with respiration. ***b.*** Image taken of another patient with a moderate sized pericardial effusion. In this case, note how there is no evidence of collapse of the vena cava with respiration. This patient had cardiac tamponade.

PLEURAL ABNORMALITIES

Pleural fluid

The sonographic appearance of hemothorax is an anechoic fluid collection localized to the costophrenic angle (Fig. 4.59). While it is imperative to visualize the diaphragm in order to be assured that the fluid is contained within the pleural cavity, other structures will frequently be seen, such as the lung. It appears as a triangular structure superior to the diaphragm that will exhibit wave-like movement that corresponds with the patient's respirations (Fig. 4.60).

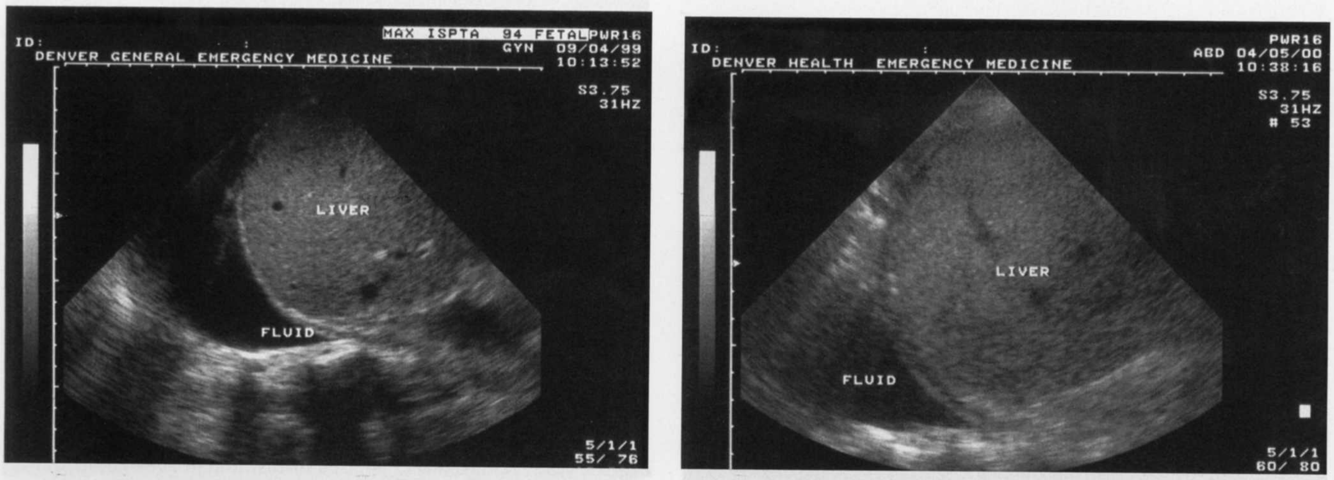
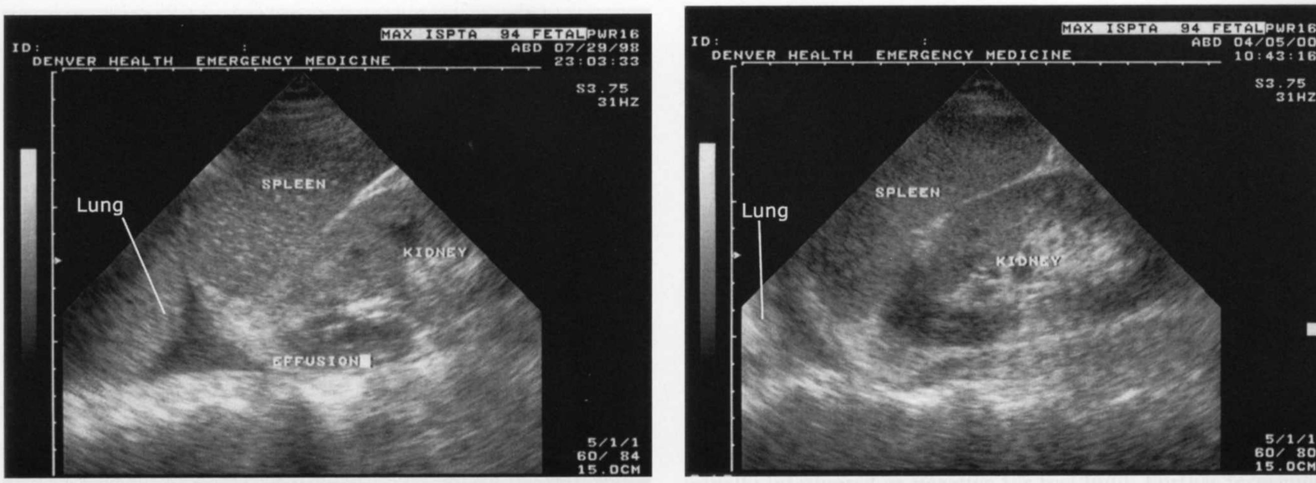


Figure 4.59 a, b. Images of fluid localized to the costophrenic angle.



A B

Figure 4.60 a, b. Ultrasound images demonstrating fluid in the costrophrenic angle and the triangular appearance of lung tissue.

Pneumothorax

The value of the ultrasound for the evaluation of pneumothorax is in its negative predictive value. If the sliding sign, ring down artifact, or the power slide sign are present, the diagnosis of pneumothorax is essentially excluded. Absence of these findings for making the diagnosis of pneumothorax has less diagnostic accuracy and has not been correlated with the size of the pneumothorax.

ARTIFACTS AND PITFALLS

GENERAL ISSUES

A variety of conditions create particular challenges for ultrasound in the trauma patient.

1. Prior surgery with accompanying adhesions can affect how fluid will collect and move within the peritoneal cavity. As a result, fluid may be seen in different areas than those scanned during the standard FAST exam. Particular attention should be paid to the exam performed on patients with evidence of prior abdominal surgery. If the suspicion for injury is high and the ultrasound is negative for fluid, CT scanning is a better method for fully evaluating the peritoneal cavity.
2. Obese patients can be difficult scanning subjects. Increased adipose tissue distances the transducer from the target organ or area. In addition, fat that collects in and around organs can distort normal anatomy.
3. Subcutaneous emphysema is problematic for scanning. Just as air in the lung or bowel distorts the ultrasound signal, air in the subcutaneous tissue prevents penetration of sound waves and limits the usefulness of ultrasound imaging.

Types of Fluid

Ultrasound is extremely sensitive for detecting peritoneal fluid, but it does not discriminate between types of fluid, i.e., blood versus ascites, succus entericus, or urine. The following are types of fluid that may cause false-positive ultrasound exams.

1. Preexisting ascites is the main diagnostic pitfall in the evaluation of trauma patients with free peritoneal fluid (Fig. 4.61). Clues to this condition include physical stigmata of liver disease such as caput medusa, spider angiomas, or jaundice; past medical history for liver

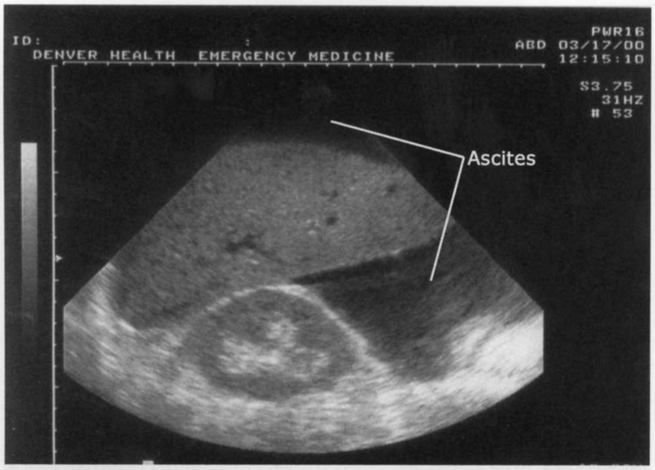


Figure 4.61. Ascites visualized in the perihepatic area.

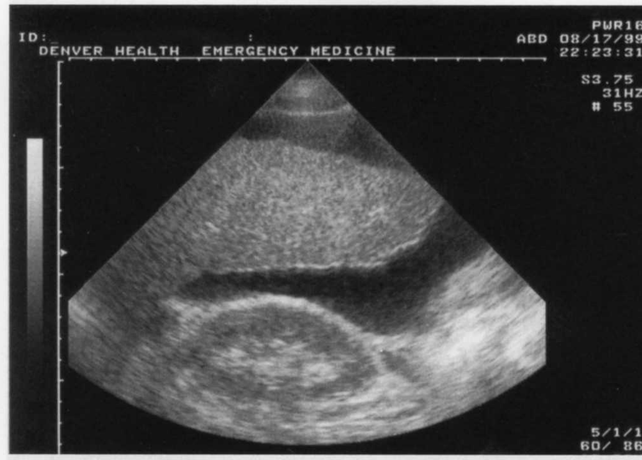


Figure 4.62. Fluid detected in the perihepatic region in a patient with sonographic evidence of liver disease.

disease; or sonographic findings such as a small, contracted, nodular, or echogenic liver (Fig. 4.62).

2. Hollow viscous injuries are another etiology of positive ultrasound exams. Examples include bowel, gallbladder, and intraperitoneal bladder rupture. While these may be considered false-positive exams for hemoperitoneum, in fact, each requires some form of operative intervention and, therefore, in the authors' opinion, should be considered true-positive exams.

Exam quality

While many pathologic findings of the trauma ultrasound exam are straightforward and easy to detect, a poor-quality study can obscure even the most obvious abnormalities. The following are some of the technical factors that can affect the quality of the trauma ultrasound exam.

1. Too much overall gain creates artifact and may obscure the presence of anechoic fluid (Fig. 4.63).
2. "Static imaging," or failing to scan through the full extent of an anatomical area, is a frequent error that limits the exam. At any one moment, ultrasound only provides a two-dimensional image. However, a three-dimensional view can be created by gently

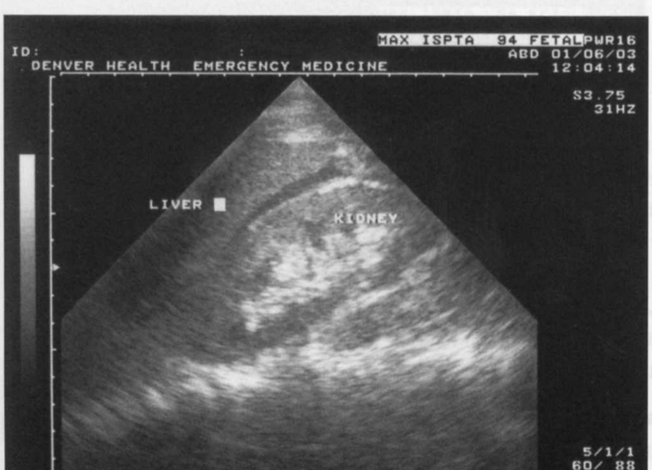


Figure 4.63. Ultrasound image of hemoperitoneum in Morison's pouch. The gain is set too high, making the fluid difficult to discern.

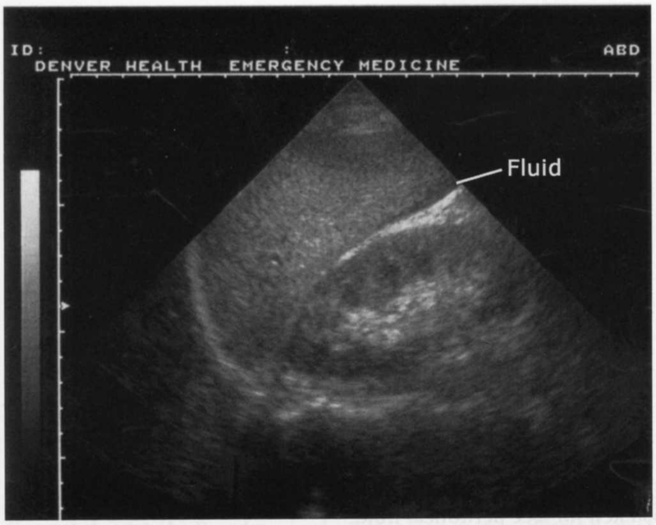


Figure 4.64. Ultrasound image of the perihepatic region that was initially interpreted as negative for free fluid. Further inspection detected a small amount fluid in Morison's pouch.

rocking and maneuvering the transducer to view multiple planes through an anatomical space. Each potential space should be interrogated with biplanar views and frequent angling of the transducer. Static imaging limits the view, minimizes the amount of information gained from the scan, and can miss small fluid collections (Fig. 4.64).

3. Failing to appreciate fluid in "non-classic" areas is another common scanning problem. For example, free fluid may accumulate superior to Morison's pouch, inferior to the left kidney, superior to the dome of the bladder, and inferior to the diaphragm. Dynamic movement of the transducer will allow for visualization of these and other potential spaces that are not considered "classic."

Perihepatic View

1. Perinephric fat may cause a common and sometimes confusing sonographic finding in the right upper quadrant (Fig. 4.65). Fat in the perinephric area creates an echogenic space between the kidney and liver that can be mistaken for organized, clotted peritoneal blood. It can usually be distinguished from hemoperitoneum because it has a more homogeneous echodensity than hematoma and has no anechoic rim. Perinephric fat is adherent and has no motion with respiration, in contrast to hematoma that can move independent of the kidney.

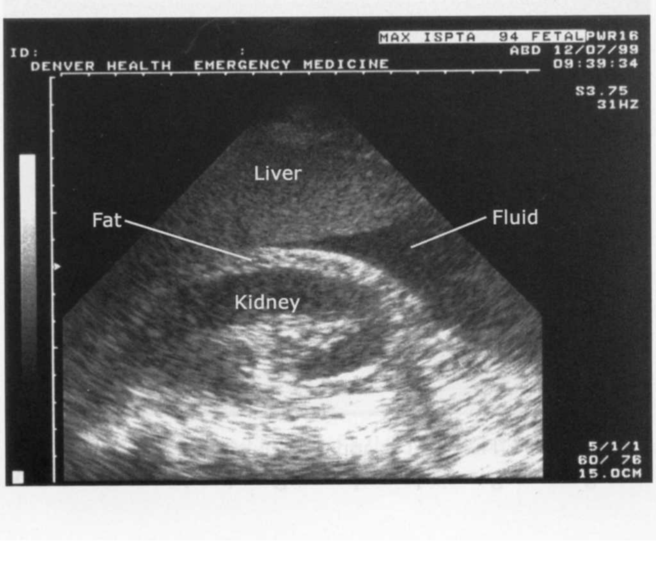
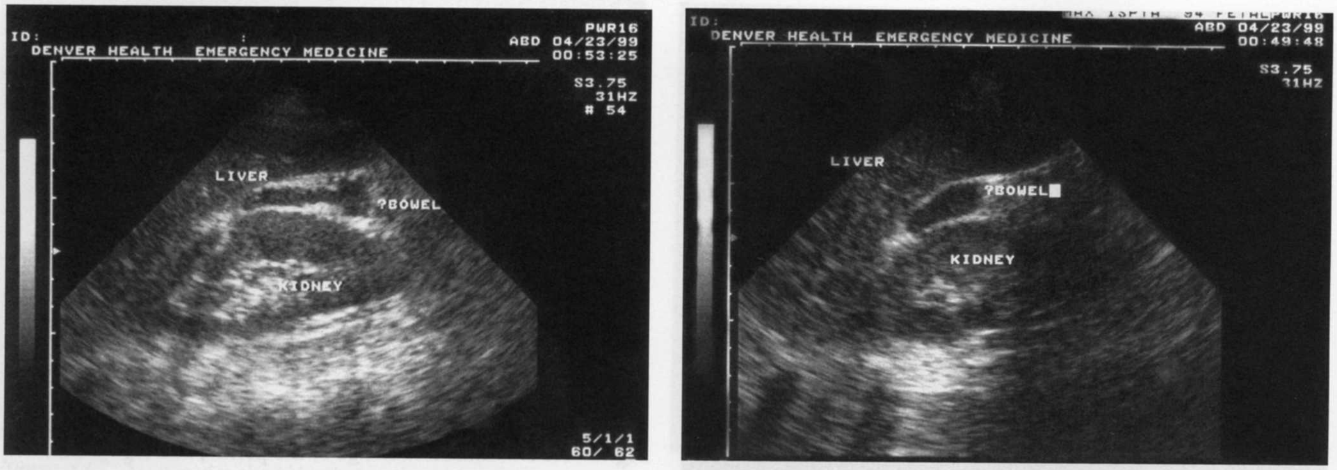


Figure 4.65. The sonographic appearance of perinephric fat in a patient who also has fluid in Morison's pouch.



A

B

Figures 4.66 a, b. Ultrasound images demonstrating the appearance of fluid-filled bowel seen in Morison's pouch which can be mistaken for free peritoneal fluid.

2. Either fluid-filled bowel (Fig 4.66) or the gallbladder (Fig. 4.67) can be visualized in the perihepatic area and misinterpreted as free peritoneal fluid. In each case, a careful examination usually demonstrates characteristics of each structure that distinguishes them from peritoneal blood. The gallbladder has echogenic walls, and the rounded fundus is usually visible near the tip of the liver. This is in contrast to fluid in Morison's pouch, which tends to have sharp corners and angles. Fluid-filled bowel is an uncommon finding of the FAST exam (42). It can usually be distinguished by an echogenic wall bounding the lateral aspects of the fluid. As well, there will typically be several discrete, echogenic lines that appear to originate from and run perpendicular to the echogenic wall. These structures represent the valvulae conniventes or haustral sacculations of the bowel (43).
3. Retroperitoneal hemorrhage from a renal parenchyma laceration may initially appear as fluid within Morison's pouch. A more detailed examination will demonstrate that the anechoic fluid collection is deep to the echogenic line of Gerota's fascia (Figure 4.68 a). The fluid may also form an anechoic rim surrounding the kidney or the architecture of the kidney may be distorted (4.68 b).
4. Clotted blood in Morison's pouch can have a similar echogenic appearance to the liver parenchyma and therefore can be challenging to assess (Fig. 4.45). In most cases there will be a rim of anechoic fluid outlining the clotted blood that helps discern the presence of a pathologic condition (Fig. 4.46).

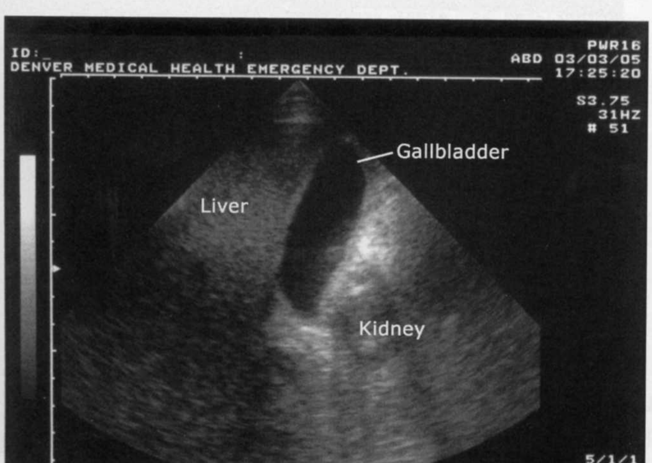


Figure 4.67. The typical appearance of the gallbladder seen during scanning in the perihepatic region.

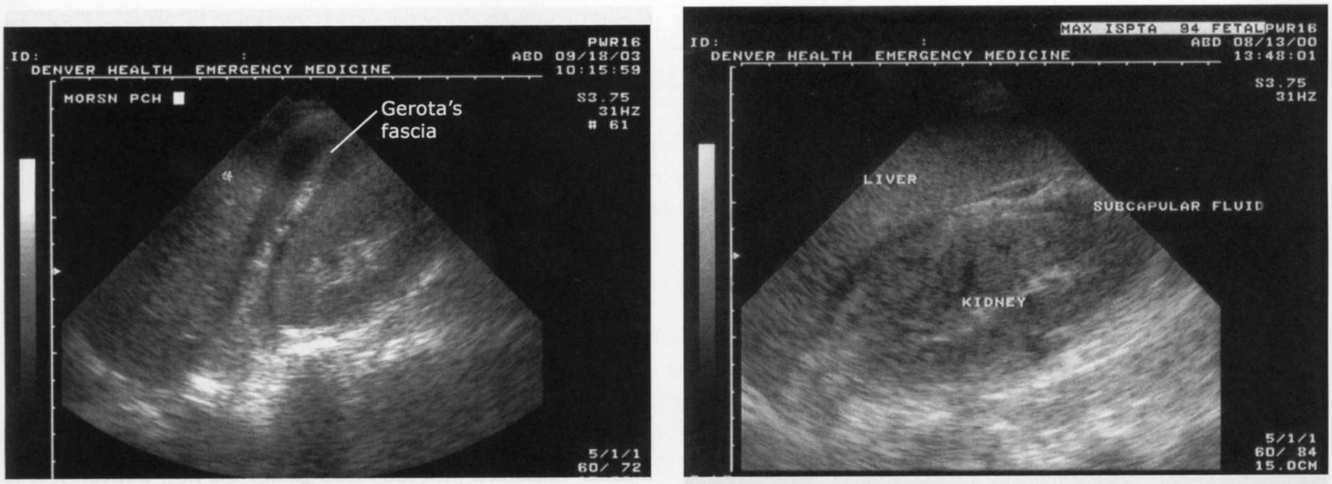


Figure 4.68 (***a***) Ultrasound image of retroperitoneal and intraperitoneal hemorrhage that outlines Gerota's fascia. (***b***) Renal parenchymal injury seen as disruption of the normal renal architecture and subcapsular fluid.

Perisplenic View

1. The most challenging aspect of scanning the left upper quadrant is obtaining adequate views. Not only does the spleen offer a much smaller acoustic window than the liver, but it is also more posterior and superior. If an acceptable image of the perisplenic area is not obtained, it is usually because the transducer is not high and posterior enough.
2. Another common error is assuming that fluid in the left upper quadrant collects in a manner similar to the right upper quadrant. The phrenicocolic ligament restricts the amount of fluid that will collect in the splenorenal space, so the focus of the exam should be directed towards the subdiaphragmatic area and the tip of the spleen.
3. The stomach is commonly visualized and may confuse the exam of the perisplenic area. It has a variable sonographic appearance, depending on its contents. If the stomach contains fluid, it may appear anechoic. If it contains mostly food particles, it may appear echogenic (Fig. 4.69). When seen, it almost appears contiguous with the spleen (Fig. 4.70), but angling the transducer slightly posterior will usually remove it from view.

Figure 4.69. Ultrasound image of a fluid and food-filled stomach seen in the left upper quadrant.

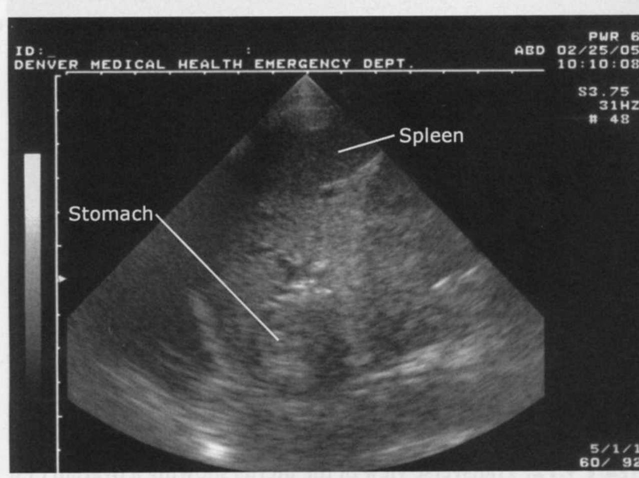


Figure 4.70. A view of the perisplenic region that illustrates the close proximity of the spleen and stomach.

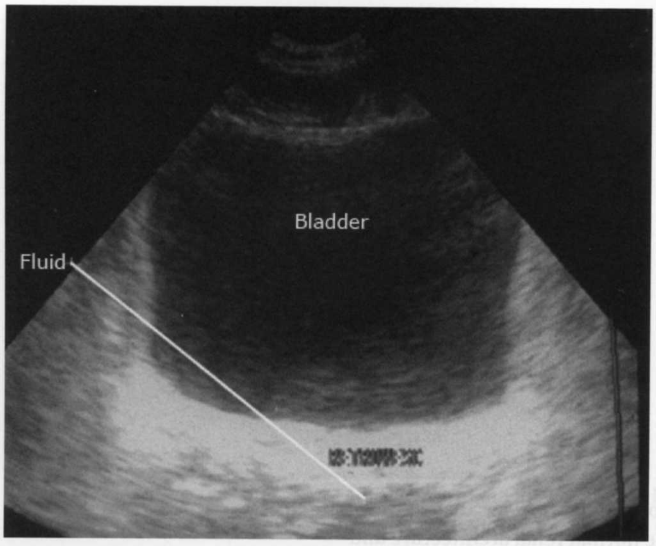


Figure 4.71. Ultrasound image of the male pelvis showing the bladder visualized with too much gain. Note how difficult it is to appreciate the fluid in the retrovesicular space due to the brightness of the image.

Pelvic View

1. Too much gain or acoustic enhancement can dramatically alter images of the retrovesicular area (Fig. 4.71) where fluid typically collects in the pelvis. The retrovesicular area is easiest to image in patients with a filled bladder. However, objects behind fluid-filled structures are enhanced acoustically. While this enhancement allows deeper structures to be visualized, it can also distort them. It may be necessary to minimize the gain to optimize the image behind the bladder and avoid artifact. This can usually be accomplished by decreasing the TGC in the affected area.
2. Ovarian cysts can occasionally be mistaken for peritoneal fluid (Fig. 4.72). A detailed exam that includes different planes of view will demonstrate that these fluid collections have well-demarcated borders and are contained within ovarian tissue.
3. The prostate and seminal vesicles have a hypoechoic appearance posterior to the bladder in male patients (Fig. 4.73). These may be mistaken for free fluid unless a sagittal view of the area is obtained that confirms the inferior, regular appearance of the prostate and the triangular shape of the seminal vesicles. Familiarity with normal ultrasound anatomy in the pelvis will avoid potential misinterpretations.

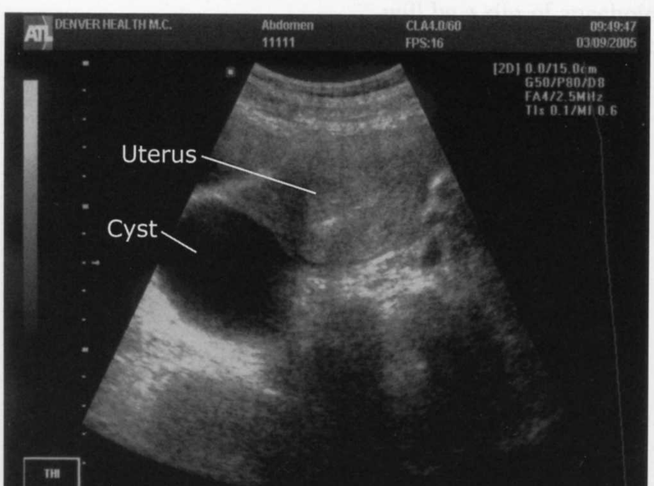


Figure 4.72. Transverse view of the uterus showing a ovarian cyst in the right lower quadrant that could be mistaken for free peritoneal fluid.

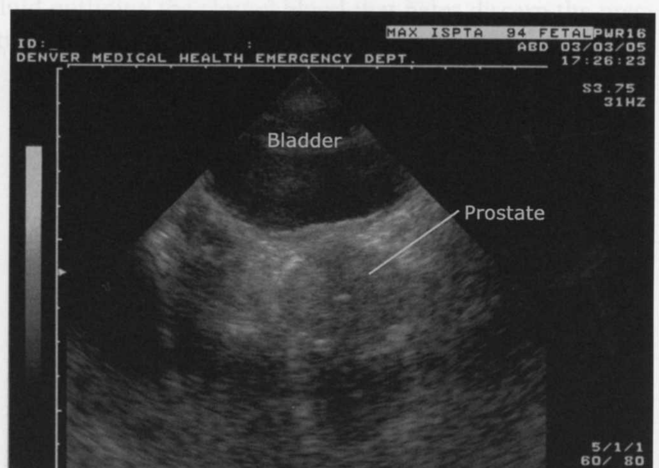


Figure 4.73. The appearance of the prostate posterior to the bladder in the transverse plane.

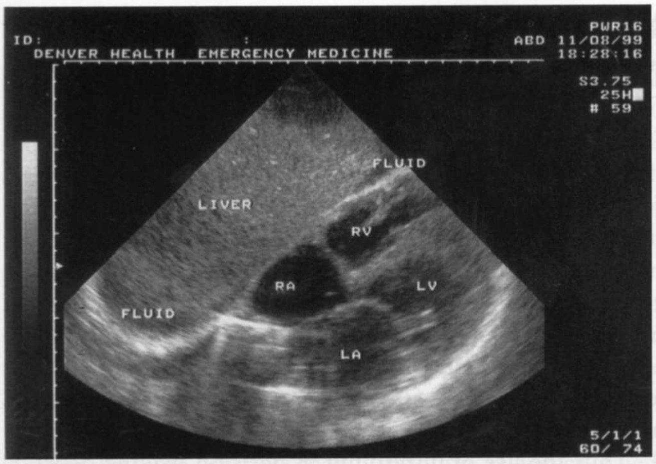


Figure 4.74. Ultrasound image demonstrating the appearance of peritoneal fluid seen from the subxiphoid transducer position.

Pericardial View

1. One of the most common pitfalls in scanning the pericardial area is failing to adjust the depth controls to adequately visualize deep structures. Without optimal depth adjustment, scans may fail to visualize all the cardiac structures and miss posterior pericardial effusions.
2. A pleural effusion, especially on the left side, may mimic a pericardial effusion. The parasternal long-axis view is the best approach to conclusively differentiate pericardial from pleural fluid. Using this transducer position, the descending aorta is viewed in transverse orientation posterior to the heart. Fluid in the pleural space is localized posterior to the descending aorta, whereas pericardial fluid will collect between the posterior wall of the left ventricle and the descending aorta (Fig. 4.54) (44).
3. Occasionally, large amounts of perihepatic fluid can be mistaken for a pericardial effusion when imaged from the subxiphoid transducer position. This can be distinguished from a pericardial effusion by an echogenic band (pericardium) that is between the echo-free space and the free wall of the right ventricle. Additionally, perihepatic fluid collections will conform to Glisson's capsule whereas a pericardial effusion will conform to the rounded aspect of the pericardium adjacent to the apex of the heart (Fig. 4.74).
4. Epicardial fat appears as an echo-free space anterior to the heart that can be as wide as 15 mm (Fig. 4.75). This space will generally narrow toward the apex of the heart, whereas an echo–free space caused by a pericardial effusion tends to be broader near the left ventricular apex than near its base. Additionally, although epicardial fat appears grossly as an echo-free space, there will usually be scattered, soft, isolated reflections adhering to and moving with the myocardium.

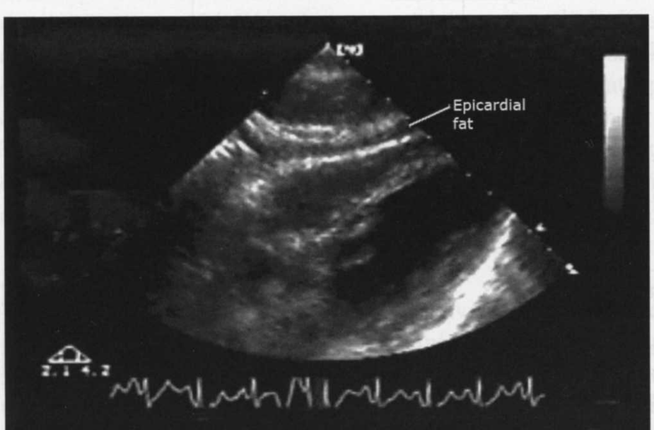


Figure 4.75. Subxiphoid orientation with epicardial fat visualized between the free wall of the right ventricle and the liver.

Use of the Image in Medical Decision Making

The most practical and significant use of ultrasound in all trauma patients is the rapid identification of the source of hypotension and detection of immediate life-threatening injuries, including free intraperitoneal blood and pericardial effusions. In the setting of hypotension and trauma, ultrasound may help identify patients who need immediate surgical intervention, bypassing all other diagnostic procedures. In the setting of mass casualties, ultrasound can help prioritize operative intervention and direct the use of limited resources to those most in need of immediate definitive care. In rural areas and settings remote from trauma centers, ultrasound can help rapidly identify victims who should be moved to higher levels of care. In some cases, ultrasound alone may be sufficient to triage patients to the operating room, while in others, ultrasound will be used in conjunction with CT and DPL. Thus the use of ultrasound in decision making depends upon the stability of the patient, the nature of the trauma, the number of patients undergoing simultaneous evaluation, and the level of care available at the hospital.

Blunt Trauma (Fig. 4.76)

The FAST exam is best known for its role in the detection of free fluid in patients with blunt abdominal trauma. General guidelines for how ultrasound impacts immediate, bedside decisions follow.

Peritoneal free fluid in the unstable patient

The finding of free peritoneal fluid in the unstable traumatized patient suggests the findings of intraperitoneal injury necessitating immediate operative intervention. The decision to operate will depend on the patient's other injuries, the amount and location of free peritoneal fluid, and whether the vital signs stabilize after resuscitation. Large peritoneal fluid collections associated with unstable vital signs usually mandate laparotomy (45,46).

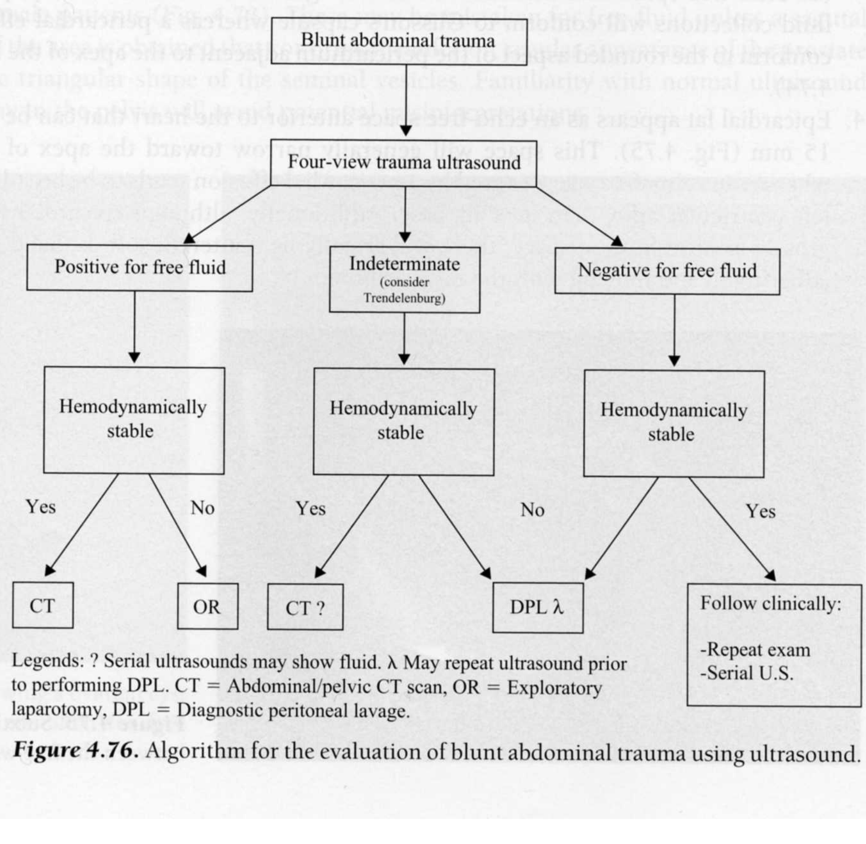


Figure 4.76. Algorithm for the evaluation of blunt abdominal trauma using ultrasound.

Peritoneal free fluid in the stable patient

A patient with stable vital signs, but an ultrasound that demonstrates peritoneal fluid is a candidate for nonoperative management. Therefore, regardless of whether any other ultrasound findings such as specific organ injury are present, a CT of the abdomen and pelvis should be performed. This form of management utilizes the strength of the CT scan for determining the source of hemoperitoneum; thus, it can usually differentiate between lesions that are operable versus those that can be managed nonoperatively.

No free fluid in the unstable patient

Ultrasound is virtually 100% sensitive for hemoperitoneum in the hypotensive patient (47). However, the patient with unstable vital signs and a negative ultrasound remains problematic, since hemoperitoneum remains a lethal, albeit remote, possibility. A few options exist for this diagnostic dilemma. Some have suggested a repeat ultrasound, potentially by a more experienced operator (48). Others opt for an immediate DPL, which is generally more sensitive than ultrasound. However, a negative ultrasound suggests that the source of hypotension is outside the peritoneum. Diagnostic efforts to identify alternative injuries should focus on other common causes, including retroperitoneal injuries and neurogenic shock. In one study of 47 hypotensive trauma patients with a negative ultrasound, none required a laparotomy for acute control of hemorrhage (49). The primary cause of hypotension in these patients was extraperitoneal, such as retroperitoneal hemorrhage caused by pelvic fractures or neurogenic shock.

No free fluid in the stable patient

The finding of no free fluid in a hemodynamically stable patient does not "clear" that patient of injury (50–52). Patients may still have encapsulated solid organ injury, mesenteric or bowel injury, retroperitoneal hemorrhage, or delayed intraperitoneal injury. Patients who are at higher risk include those with lower rib, lumbar spine, or pelvic fractures. Prior to discharge, every patient should have a repeat clinical exam and any new findings of abdominal pain, tenderness, distracting injury, or laboratory abnormalities should prompt further diagnostic evaluation. In this case, management of the patient will be influenced largely by the mechanism of trauma, suspicion of occult injury, and the presence of other injuries.

Indeterminate findings

Certain patients will have indeterminate ultrasound exams. Anatomic defects (pectus excavatum), acquired pathology (open wounds, subcutaneous air), difficult habitus (obesity), and poor acoustic windows (evacuated bladder) are situations that may result in an indeterminate ultrasound exam (53). These patients should receive further clinical, radiographic, or alternative diagnostic evaluation.

Pericardial Effusion (Fig. 4.77)

Transthoracic cardiac ultrasound can detect pericardial effusion associated with blunt cardiac rupture (54–56). Patients with a pericardial effusion should be evaluated for cardiac tamponade, which includes both a targeted physical exam and echocardiographic evaluation. Those with tamponade require an immediate procedure—either pericardiocentesis, pericardiocentesis with pigtail catheter placement, or therapeutic thoracotomy. Those without signs of tamponade might be considered for consultative imaging such as a cardiology echo. Although it is a diagnosis of exclusion, pericardial effusion detected incidentally has been described as a finding of the FAST exam (57).

Solid organ injury

The clinical utility of positive and negative sonographic examinations for specific organ injuries is limited. Some studies have inferred that a negative exam, in certain patients, is sufficient to change medical decision making (58,59). Each of these studies recommended that ultrasound be the initial diagnostic modality for evaluating patients with renal trauma. If a stable, nomotensive patient has a normal renal ultrasound, no hematuria, and no other

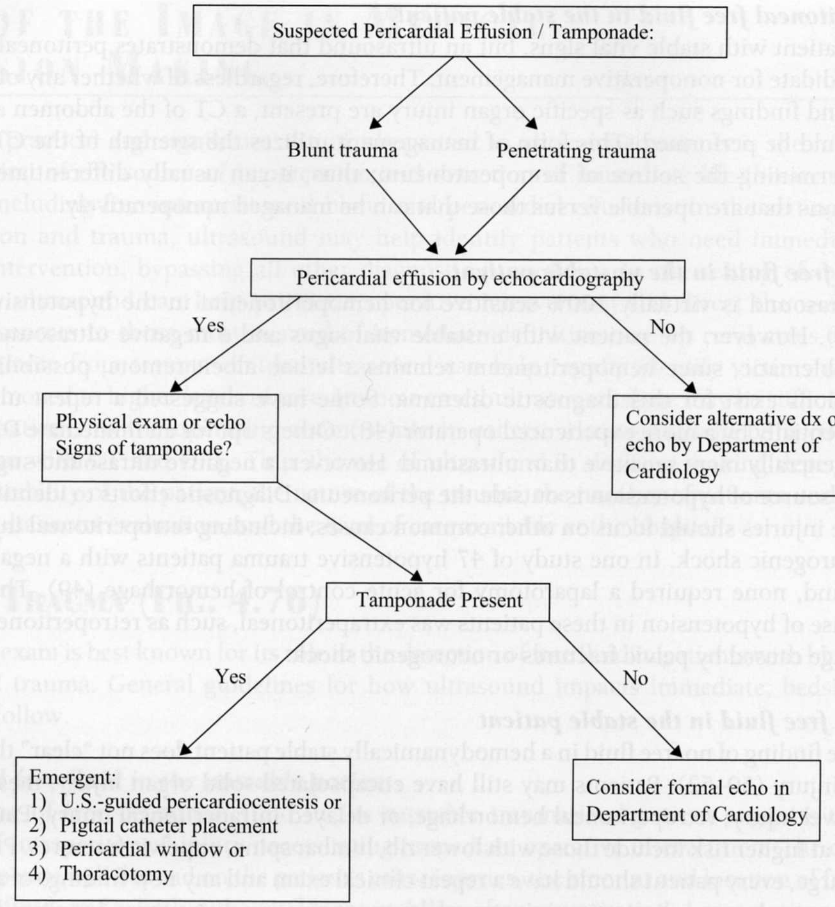


Figure 4.77. Algorithm for the evaluation of pericardial effusion using ultrasound.

significant injuries, then their evaluation was complete. There have been no similar recommendations for the ultrasound evaluation of other organs.

A positive result, on the other hand, may direct certain aspects of the diagnostic evaluation. For instance, in most series, a positive ultrasound exam in a hemodynamically stable patient is an indication for additional diagnostic testing. Commonly this is a CT scan of the abdomen and pelvis, which provides specific information regarding the extent and severity of the organ injuries. Another benefit is that CT scanning can determine whether there are injuries to other organs.

The identification of solid organ injury in the hemodynamically unstable patient provides very little useful information. If a specific etiology for the hypotension is not identified, yet the patient has free intraperitoneal fluid, invariably the patient will undergo laparotomy. Knowing that a specific organ injury exists does not change the approach, technique, or decision making in hemodynamically unstable patients. Another important issue is that ultrasound is poor at identifying injuries to multiple organs, so there is no assurance that an injury identified sonographically is the primary or only etiology of the instability. As a result, there are no widely recognized algorithms that include the presence or absence of specific organ injury identified by ultrasound into clinical decision making.

Penetrating Trauma

Patients with penetrating trauma confront physicians with many of the same diagnostic dilemmas as in blunt trauma: the need to make a diagnosis is imperative, but the diagnostic options are sometimes limited. The utility of ultrasound in this setting should not be underestimated.

Abdomen

Trauma patients with isolated penetrating abdominal wounds who have an obvious indication for laparotomy (eviscerated bowel or peritonitis) do not need an ultrasound, although a positive ultrasound exam is very specific for injury (60,61). Defining the role of ultrasound in the stable patient is problematic as neither a positive or negative exam for peritoneal fluid can be relied upon to absolutely predict or exclude significant injury (61). A patient with a stab wound and a negative ultrasound exam can have significant mesenteric or bowel injury, whereas a positive study may be associated with injuries that can be managed nonoperatively. However, in patients with multiple penetrating wounds, the sonographic evaluation of the peritoneum and pericardium can direct the operative approach to the chest, abdomen, or both. As well, the presence or absence of hemopericardium from gapping or even innocuous–appearing wounds to the chest or epigastrium can be definitively assessed with sonographic evaluation of the pericardial space. As in blunt abdominal trauma, ultrasound can also quantitate the amount of free fluid and potential for sudden deterioration.

Chest (Fig. 4.77)

The ultrasound finding of pericardial fluid can rapidly identify patients who need immediate treatment to avoid hemodynamic deterioration secondary to cardiac tamponade. In the setting of penetrating trauma to the torso, the presence of pericardial fluid suggests penetration of the pericardium and possible injury to a cardiac chamber (62,63). Sonographic signs of impending cardiovascular collapse include right atrial systolic collapse, right ventricular diastolic collapse, a dilated inferior vena cava without respiratory variation, and intraventricular septal flattening.

The patient with penetrating trauma to the torso and no pericardial fluid should have a period of observation prior to ruling out the possibility of cardiac injury (64,65). Delayed presentations of pericardial effusions have occurred, especially with injuries to the right atrium and ventricle, which are low pressure chambers that may not leak until increased intravascular volume causes clot breakdown. Another concern is the presence of a left-sided pleural effusion. It should alert the resuscitating physician that penetration of both anterior and posterior surfaces of the pericardium may have occurred, thus allowing spontaneous evacuation of the pericardial effusion into the pleural space (66,67).

Expanded Applications: Thoracic Trauma

In addition to the primary clinical applications for the FAST exam, other uses for ultrasound in trauma patients have recently been suggested. These include the sonographic assessment of the pleural spaces for blood or air.

Pleural fluid

The detection of hemothorax in a supine trauma patient can be problematic as the supine portable chest radiograph can be insensitive for small fluid collections. Ultrasound, on the other hand, has been estimated to detect as little as 20 mL of pleural fluid (68). Ultrasound may be useful for the detection of hemothorax in both blunt and penetrating thoracic trauma, however this is an evolving standard that has not yet been widely accepted (69–71). Pleural fluid detected during trauma ultrasound should be interpreted in the clinical context of the effusion. Patients with decreased breath sounds, evidence of chest trauma, hypoxemia, chest radiography with pleural effusion, hypotension, or other findings suggestive of tension hemothorax, may be aided by the sonographic findings of fluid in the pleural space. Decompression and evacuation procedures can then proceed. However, an ultrasound exam that does not demonstrate pleural fluid should not be interpreted as eliminating traumatic pleural effusion from the differential, especially in the patient with blunt chest trauma (71).

Pneumothorax

The use of ultrasound to evaluate for pneumothorax is a relatively new concept, and its role in trauma decision making is evolving. At this time, it is an adjunctive technique that may identify pneumothorax earlier than chest radiography, especially in the supine patient or those with small pneumothoraces. Several studies provide support for the use of ultrasound to detect or exclude pneumothorax in the trauma patient (72,73). In one study, a single ultrasound exam of the anterior thorax was 95% sensitive and 100% specific for pneumothoraces that were detected by chest radiography (72). A second study found similar results (73), adding weight to this conclusion. Standard radiographs for the detection of pneumothorax may be limited by patient position. Air that collects anteriorly or inferiorly, rather than in the apices, may be difficult to appreciate on a supine chest radiograph. Ultrasound findings that suggest pneumothorax include the absence of a sliding sign or comet tail artifact. These findings should be followed by clinical correlation of breath sounds and chest radiography. Ultrasound is probably most useful in its negative predictive value. In other words, if the ultrasound exam performed by an experienced sonographer is interpreted as negative for pneumothorax, the diagnosis can be excluded or considered less likely.

Special Considerations

Obstetric patients

The use of ultrasound for the diagnostic evaluation of the pregnant blunt trauma patient has the benefits of not exposing the mother and fetus to ionizing radiation and invasive procedures, while also being able to assess for peritoneal fluid and fetal viability (74–76). The primary application of trauma ultrasound in the pregnant patient is no different than that in the nonpregnant patient, which is the noninvasive evaluation of the peritoneal and thoracic cavities for blood. While the peritoneal anatomy will change in pregnancy, especially in the late second and third trimesters, the FAST exam technique is the same and fluid is still readily identifiable in the standard potential spaces.

Another equally useful application of ultrasound in the pregnant trauma patient is the assessment of fetal gestational age and fetal cardiac activity. In later pregnancy, the easiest estimation of gestational age is obtained by measuring the biparietal diameter. Although there is some institutional variation, fetuses greater than 24 weeks gestational age are considered viable. Fetal cardiac activity should be assessed for presence and rate as bradycardia is a marker of fetal distress caused by poor perfusion or hypoxia. Blood may be shunted away from the fetus before the mother exhibits obvious signs of hypotension.

Pediatric patients

One of the primary roles of emergency sonography of pediatric patients is the evaluation of blunt abdominal trauma. While the finding of peritoneal fluid is a similar primary goal for adult and pediatric patients, results have been somewhat discouraging for the latter (77–82). This is surprising, because one of the limitations of sonography, obesity, is encountered much less commonly in pediatric patients. Although the sensitivity is reported to be lower in pediatric patients, the specificity is still excellent.

Even more discouraging have been the pediatric studies citing the accuracy of ultrasound in the evaluation of solid organ injury. Little useful information can be gleaned from an ultrasound to evaluate the solid organs; CT is far superior in this regard.

Ultimately, the role of ultrasound in pediatric blunt abdominal trauma is limited by the increasingly conservative management of solid organ injuries in children. While ultrasound may detect free peritoneal fluid, this information has little impact on management since CT and clinical observation will determine the course of action in pediatric patients with splenic and liver injuries.

Pelvic Fracture

There are a number of confounding factors to be considered when interpreting an ultrasound exam in the patient with a pelvic fracture. The first is that a significant amount of bleeding from a pelvic fracture may be isolated to the retroperitoneum, which is an area where ultrasound is unreliable (52). Another concern is the association of intraperitoneal bladder rupture with pelvic fractures, especially in the patient with hemodynamic instability (83). In this case, free fluid detected by ultrasound may represent urine, not blood.

As a result, it has been suggested that the patient with a positive ultrasound and severe pelvic fractures undergo a DPL as their next diagnostic test (83).

Triage of multiple patients or disaster situations

Ultrasound has qualities, such as being quick, noninvasive, portable, and sensitive, that make it an ideal imaging modality for the evaluation of large numbers of traumatically injured patients. In trauma centers it is not unusual to experience the simultaneous presentation of multiple, potentially critically injured patients. Decisions regarding patient priority for the operating room, CT scan, or procedural intervention are magnified when resources are stretched to their limits. One study demonstrated that the results of a FAST exam could be used to determine patient priority for operative intervention (84). Others have incorporated an ultrasound exam into the evaluation of patients sustaining injuries on the battlefield and during a natural disaster (85,86).

Comparison with Other Diagnostic Modalities

The diagnostic approach to the traumatically injured patient typically involves a variety of diagnostic tests, including plain radiographs, DPL, ultrasound, CT, and clinical observation with serial exams. Each test has advantages and disadvantages and the integration of each in the management of trauma is influenced by many factors, including the nature of the trauma and the stability of the patient (Table 4.1).

Patients with blunt abdominal trauma present a distinct challenge to physicians. The workup for blunt abdominal trauma primarily focuses on the detection of free intraperitoneal fluid. The physical exam for significant injuries is notoriously unreliable with error rates reported to be as high as 45% (87) and accuracy rates at best being 65% (88). DPL has a long history in the evaluation of patients with blunt abdominal trauma, but it is invasive, time-consuming, not specific for organ injury, and sometimes overly sensitive, resulting in nontherapeutic laparotomies. CT comprises the majority of diagnostic imaging in blunt abdominal trauma, however it is expensive, time-consuming, and requires that the patient be stable in order to be transported out of the ED. Ultrasound offers many advantages compared with DPL and CT. It is sensitive for hemoperitoneum, noninvasive, can be performed quickly and simultaneously with other resuscitative measures, and provides immediate information at the patient's bedside. Ultrasound has not completely replaced CT or DPL, but has assumed a primary role in the early bedside assessment of blunt trauma.

Table 4.1: Comparison of Common Diagnostic Modalities for the Trauma Patient

Comparison Category	*US*	*DPL*	*CT*
Speed	2.5 min	20 min	20–60 min
Cost	Low	Low	High
Bedside Test	+++	+++	–
Repeatable	+++	–	++
Blunt Trauma	+++	+++	+++
Penetrating Trauma	++	++	+++
Unstable Patient	+++	++	–
Identifies Bleeding Site	+/–	–	++
Nonoperative Management	++	–	+++
Retroperitoneal / Renal	++	–	+++
Pancreas	+/–	+	+++
Pelvic Fracture	+/–	–	+++
Accuracy	94–97%	97.6%	92–98%

While detecting intraperitoneal fluid is of some importance, the more critical issue is whether a laparotomy is indicated. In the past, this question was often answered by the results of a DPL. A positive DPL by either initial aspiration or subsequent cell counts was an indication for an exploratory laparotomy. While looking for a noninvasive, less time-consuming alternative to DPL, a number of studies have assessed the ability of ultrasound as an adjunct in making this decision (4–8,89). All of these studies report favorable results when comparing sensitivity and specificity of ultrasound to DPL. Many trauma centers, therefore, have abandoned the use of DPL in favor of ultrasonography.

There are a few exceptions to the generalization that ultrasound can entirely replace DPL. The unstable hypotensive patient with blunt trauma and a negative ultrasound and the patient with penetrating abdominal trauma are important exceptions. While it has been suggested that a negative ultrasound for peritoneal fluid in the hemodynamically unstable patient is reliable enough to prompt a search for an extraperitoneal source of instability (49), in some EDs, DPL will still be the study of last resort after a thorough consideration for other sources of shock. As well, the results of an ultrasound exam in a patient with an abdominal stab wound can be deceiving; many centers will opt to proceed with wound exploration, DPL, laparoscopy, or laparotomy.

Detecting hemoperitoneum or predicting the need for laparotomy are significant diagnostic endpoints for the emergency physician, but it is also important to determine the extent of specific organ injury. Recently this has become even more relevant as many surgeons are managing splenic and liver injury nonoperatively. In most centers indications for laparotomy are currently based, to some extent, on CT grading of organ injury. Enthusiasm for a similar role for ultrasound has been present for some time (90). Despite the early interest, investigators have failed to establish a definitive role for ultrasound in specific organ injury detection. Not only is ultrasound not accurate for evaluating retroperitoneal hemorrhage or bowel injuries, but it also cannot be relied upon to grade the severity of organ injury, detect active bleeding, or isolate injury to a single organ. These limitations of ultrasound are in competition with the fact that access, speed, and accuracy of CT scanning has increased significantly in recent years. Therefore, in trauma centers, where timely access to high-speed CT scanners is not limited, there is little sound evidence for ultrasound supplanting CT scan in the diagnostic evaluation of the stable blunt abdominal trauma patient.

Unfortunately, unlimited access to abdominal CT scanning is not always available. Trauma centers may be presented with multiple stable patients requiring CT scanning and ultrasound may be used to triage which, and in what order, patients should be scanned. As well, patients can present with blunt abdominal trauma to hospitals where there is limited or no access to a CT scanner. A positive ultrasound exam in this setting can be used to mobilize a CT technologist from home, alert a trauma surgeon on call, or initiate immediate transport to a trauma center.

It is important to recognize the limitation of physical exams for detecting traumatic intraperitoneal injuries (87,88). Many physicians rely on the physical exam to detect occult injuries from relatively minor trauma from mechanisms such as falls or low-speed motor vehicle accidents. This is potentially a dangerous practice. One case series reported on six alert, non-intoxicated patients with seemingly minor trauma who had no complaints of abdominal pain or tenderness, yet were found to have significant hemoperitoneum detected incidentally by ultrasound (91). While the true incidence of this scenario is unknown, the presentation of these cases is still alarming and suggests that even patients with minor blunt trauma should have an ultrasound exam, rather than relying on a physical exam alone to exclude significant intraperitoneal injury.

Incidental Findings

As clinicians apply bedside ultrasound, they will inevitably encounter a variety of incidental conditions, both normal and pathological. The responsible clinician should be prepared to recognize common variants and appreciate abnormalities that require follow-up.

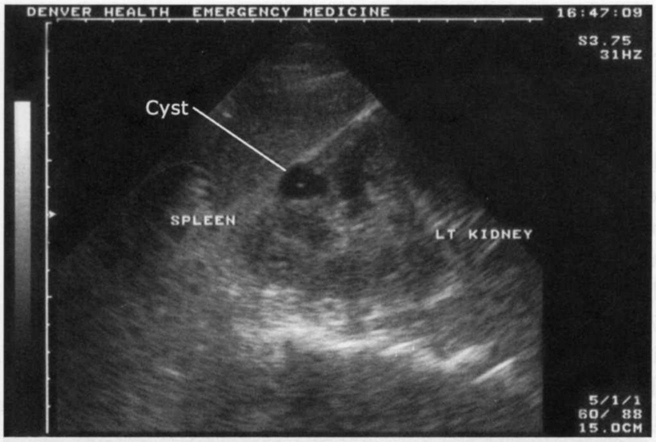


Figure 4.78. The appearance of a renal cyst that was detected during a FAST exam.

Cysts

Cysts may be found in the liver, spleen, kidneys, or ovaries. Sonographically, benign cysts appear as unilocular round structures that exhibit good sound transmission, lack internal projections, and have thin walls and an anechoic center (Fig. 4.78). All cysts, whether or not they appear benign, should have follow-up arranged after their ED visit or inpatient hospitalization.

Masses

Masses may take different forms with variable patterns of echogenicity (Fig. 4.79). Concerning findings include heterogeneity of solid organs, abnormal patterns of normal layers, and abnormal organ size. All masses should have confirmatory diagnostic testing and follow-up.

Abnormal Organ Size or Chambers

The FAST exam may also detect organs that appear smaller or larger than normal. Examples include cardiomegaly, abdominal aortic aneurysm, small or absent kidneys, or large uteri or ovaries. The severity of the abnormality and clinical circumstances will dictate the immediacy, type, and location of the follow-up.

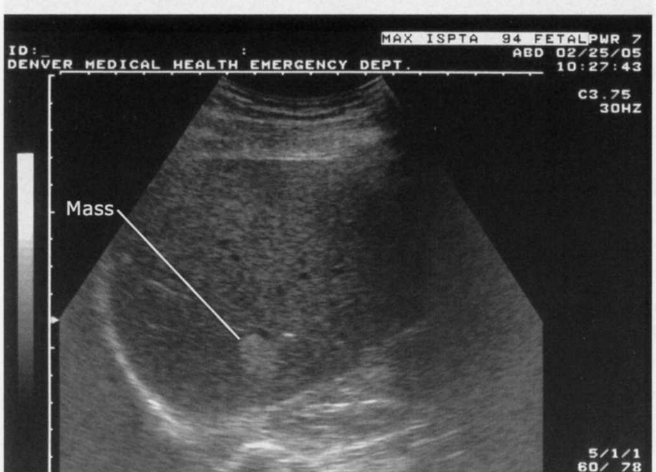


Figure 4.79. Ultrasound image of a lesion in the liver that was detected during a FAST exam. It was determined by CT to be a hemangioma.

Clinical Cases

Case One

A 31-year-old male was brought in by paramedics after being involved in a head-on motor vehicle accident. His initial blood pressure was 110/40 mm Hg with a pulse rate of 130 beats per minute. The patient is intubated and unresponsive to all stimuli. He has been given 750 cc of crystalloid via two intravenous lines. On arrival to the ED, his primary survey is significant for decreased breath sounds bilaterally with associated vital signs of a pulse of 140 beats per minute and a blood pressure of 70 mm Hg systolic. Blood products are given and an ultrasound is performed simultaneously with radiographs of the chest and pelvis. The chest and pelvis x-rays were interpreted as normal. The FAST exam findings are shown in Figures 4.80–4.81.

The resuscitating physician's impression of the trauma ultrasound was that free peritoneal fluid was present in Morison's pouch, the pelvis, and the right pleural cavity. The left flank and the subxiphoid view were interpreted as negative for fluid. Based on the patient's ultrasound findings and hemodynamic status, the decision was made to insert a right tube thoracostomy and then proceed directly to the operating room. The exploratory laparotomy was significant for a grade-4 spleen laceration with 1500 cc of associated hemoperitoneum. The patient had a splenectomy with control in peritoneal bleeding and made an uneventful post-operative recovery.

Case Two

A 45-year-old male was brought to the ED by ambulance with a single stab wound to the left anterior chest. The injury occurred approximately 20 minutes prior to ED arrival by an unknown assailant with an unknown object. Prehospital vital signs were a systolic blood pressure of 110 mm Hg, pulse of 100 beats per minute, and respirations of 24 per minute. Upon arrival to the ED, the patient's vital signs were a systolic blood pressure of 70 mm Hg, pulse rate of 110 beats per minute, and a respiratory rate of 30 breaths per minute. His physical exam was remarkable for a 2-centimeter wound to the left anterior chest with no other wounds visualized after full exposure. The patient was awake, alert, diaphoretic, and in moderate distress. The physical exam was otherwise unremarkable. An ultrasound exam of his heart was performed immediately on arrival which was significant for a moderate-

Figure 4.80. Case One. FAST exam, image 1.

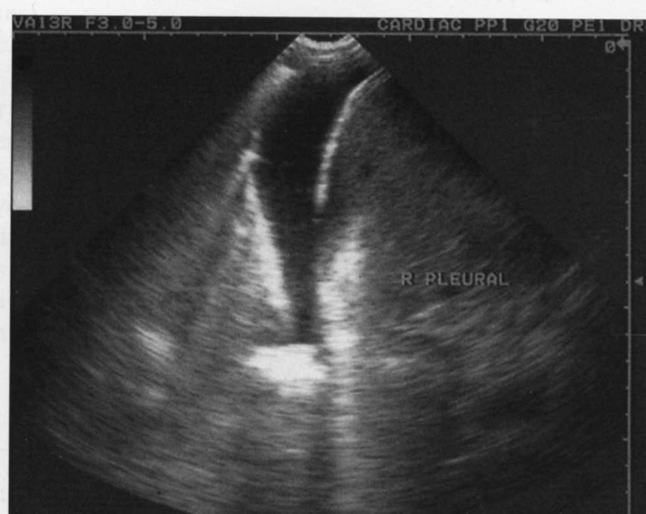


Figure 4.81. Case One. FAST exam, image 2.

Figure 4.82. Case Two. An ultrasound exam of the heart significant for a moderate sized pericardial effusion.

Figure 4.83. Case Two. A repeat ultrasound done 4 minutes after the first was interpreted as being free of pericardial fluid.

sized pericardial effusion (Fig 4.82). The patient was then intubated and a successful pericardiocentesis was performed. A repeat ultrasound done 4 minutes after the first was interpreted as being free of pericardial fluid (Fig 4.83). The patient was taken emergently to the operating room where a 1-centimeter laceration in his right ventricle was repaired. He was discharged from the hospital two days later after an uneventful hospital course.

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