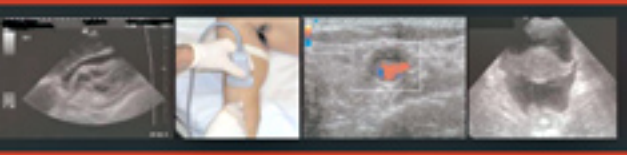
# Manual of Emergency and Critical Care Ultrasound



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## Manual of Emergency and Critical Care Ultrasound

The use of ultrasound has revolutionized the way many acute injuries and conditions are managed in emergency departments (ED) and critical care units, with several accrediting agencies mandating that physicians become proficient in the applications and interpretation of ultrasound. Today, EDs and critical care units nationwide are outfitted with ultrasound equipment, allowing acute conditions such as ectopic pregnancy or abdominal aortic aneurysm rupture to be diagnosed within critical seconds.

This book is a practical and concise introduction to bedside emergency ultrasound. It covers the full spectrum of conditions diagnosed via this modality and gives useful instruction for using ultrasound to guide commonly performed invasive procedures. It introduces the major applications for emergency ultrasound by using focused diagnostic questions and teaching the image acquisition skills needed to answer these questions. Images of positive and negative findings for each application (FAST, echocardiography, etc.) are presented, as well as scanning tips for improved image quality. Each section also contains a review of the literature supporting each application.

Dr. Vicki E. Noble is the director for emergency ultrasound at Massachusetts General Hospital in Boston, MA. She received her MD from the University of Pennsylvania in 1999 and completed a fellowship in emergency ultrasound at St. Luke's–Roosevelt Hospital in New York. She is a Fellow of the American College of Emergency Physicians and is the Ultrasound Section subcommittee chair for education and practice standards. She is also a member of the American Institute of Ultrasound in Medicine and has been a member of the American Registry of Diagnostic Medical Sonographers since 2004. She has been awarded the Society for Academic Emergency Medicine Excellence Award and has been nominated for the Harvard University Medical School Teaching Award and the Brian McGovern Award for Clinical Excellence at Massachusetts General Hospital. She has taught extensively in emergency ultrasound both in the United States and internationally.

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# Manual of Emergency and Critical Care Ultrasound

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# Contents

# Acknowledgments



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– VEN

My life is richer because of my wife, Susan, and everything I do is made better through her love and support. I also thank Nick, whose idea for a student handbook has grown into this work, and Vicki, whose tenacity and attention to detail made this book a reality. Thanks as well to my residents and students, who drive me to improve with every shift.

– BPN

This book is dedicated to the devoted frontline providers at the Massachusetts General Hospital and the Brigham and Women's Hospital Emergency Departments, who taught me how to practice emergency medicine amidst all the noise and haste. Special thanks to Dr. Vicki Noble, who constantly reminded me to keep faith in my career and sparked my interest in emergency ultrasound. Finally, thank you to my family and my wife, Lisle. Thank you for reminding me daily how beautiful the world is – even after a disenchanting day at "the office."

– ANS

The authors thank Dr. Manny Colon for contributing many of the illustrations found in this book, and Dr. Thomas Wu for providing photographs of proper patient positioning.

# 1 Fundamentals

To become versed in the language of ultrasonography, it is necessary to review some of the basic principles of physics. The wave physics principles of ordinary (i.e., audible) sound apply to ultrasound (US) and its applications. Thus, to create a foundation for further discussions, a number of definitions and basic concepts are presented here.

## Basic Definitions and Physics Principles

*Amplitude* is the peak pressure of the wave (Figure 1.1). When applied to ordinary sound, this term correlates with the loudness of the sound wave. When applied to ultrasound images, this term correlates with the intensity of the returning echo.

Ultrasound machines can measure the intensity (amplitude) of the returning echo; analysis of this information affects the brightness of the echo displayed on the screen. Strong returning echoes translate into a bright or white dot on the screen (known as *hyperechoic*). Weak returning echoes translate into a black dot on the screen (known as *hypoechoic* or *anechoic*). The "gray scale" of diagnostic ultrasonography is the range of echo strength as it correlates to colors on a black–white continuum (Figure 1.2).

*Velocity* is defined as the speed of the wave. It is constant in a given medium and is calculated to be 1,540 m/s in soft tissue (i.e., the *propagation speed* of soft tissue is 1,540 m/s). Using this principle, an ultrasound machine can calculate the distance/depth of a structure by measuring the time it takes for an emitted ultrasound beam to be reflected back to the source (Figure 1.3). (This is likened to the use of sonar devices by submarines.)

*Frequency* is the number of times per second the wave is repeated. One Hertz is equal to one wave cycle per second. Audible sound has frequencies from 20 to 20,000 Hz. By definition, any frequencies above this range are referred to as ultrasound. The frequencies used in diagnostic ultrasound typically range from 2 to 10 MHz (1 MHz = 1 million Hz).

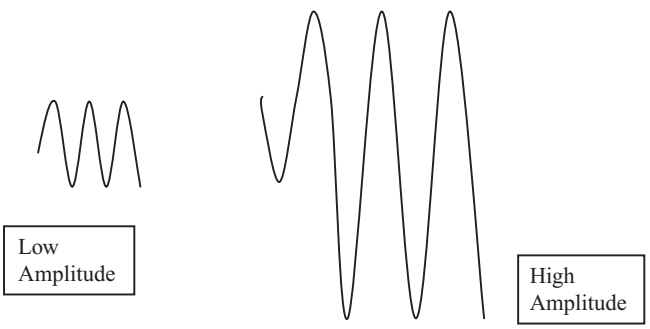



**Figure 1.1**
Low- and high-amplitude sound waves.

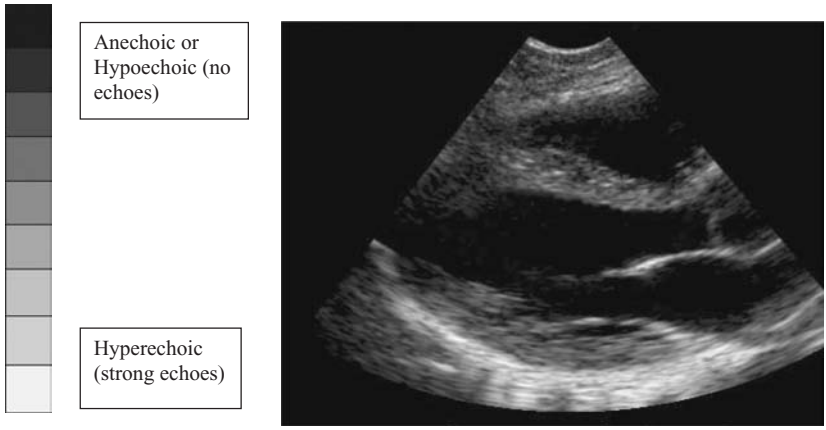



**Figure 1.2**

Most ultrasound machines have 256 shades of gray that correspond to the returning amplitude of a given ultrasound wave.

Figure 1.4 shows that high-frequency sound waves generate high-resolution pictures. High-frequency sound waves use more energy because they generate more waves, which send back more echoes over short distances to the machine, creating detailed pictures of shallow depth. However, because they lose energy more rapidly, high-frequency ultrasound does not penetrate long distances. Conversely, lower-resolution waves conserve energy, and although not creating pictures of equally high resolution, they are able to penetrate deeper into tissue.

*Wavelength* is the distance the wave travels in a single cycle. Wavelength is inversely related to frequency because of the principle velocity = frequency × wavelength. Therefore, high frequency decreases wavelength (and thus penetration), and lower frequency increases wavelength (and thus penetration).

*Attenuation* is the progressive weakening of a sound wave as it travels through a medium. Following is the range of attenuation coefficients for different tissue densities in the body:

| | | |
|---|---|---|
| Air | 4,500 | Poor propagation, sound waves often scattered |
| Bone | 870 | Very echogenic (reflects most back, high attenuation) |
| Muscle | 350 | Echogenic (bright echo) |
| Liver/kidney | 90 | Echogenic (less bright) |
| Fat | 60 | Hypoechoic (dark echo) |
| Blood | 9 | Hypoechoic (very dark echo) |
| Fluid | 6 | Hypoechoic (very dark echo, low attenuation) |

Several factors contribute to attenuation: the type of medium, the number of interfaces encountered, and the wavelength of the sound. Diagnostic ultrasound does not transmit well through air and bone because of scatter and reflection. However, ultrasound travels well through fluid-containing

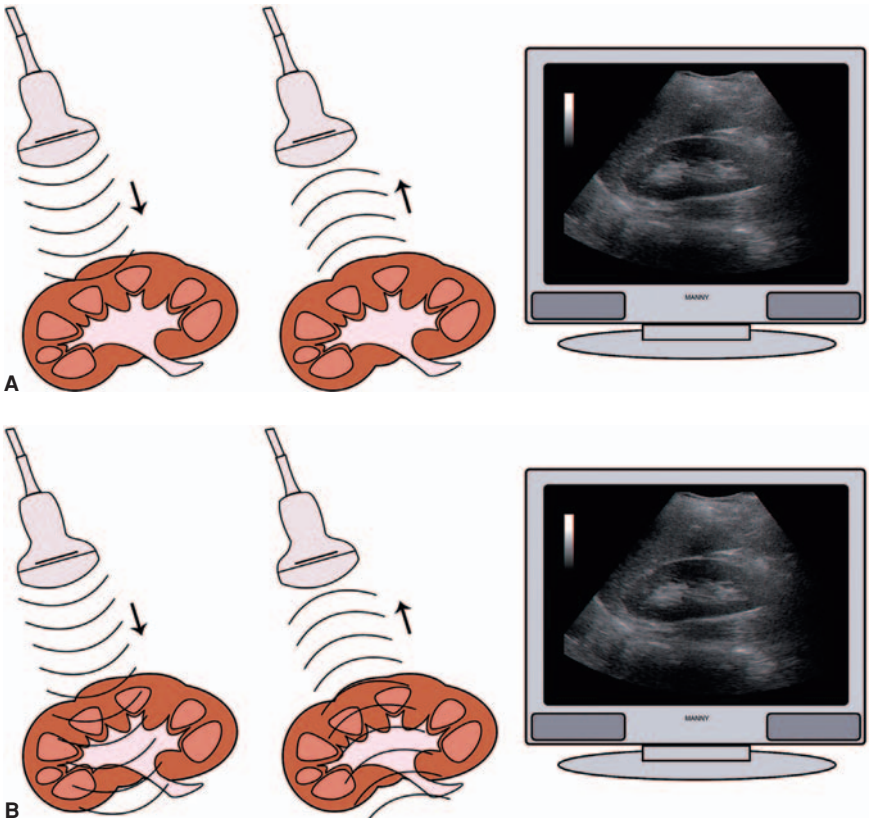



**Figure 1.3**

(a) The near field of the screen shows objects closest to the probe. (b) The far field of the screen shows images further from the probe. Courtesy of Dr. Manuel Colon, University of Puerto Rico Medical Center, Carolina, Puerto Rico.

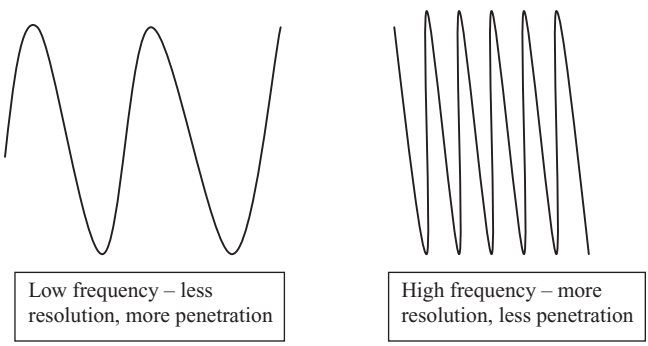



**Figure 1.4**

Low- and high-frequency sound waves.

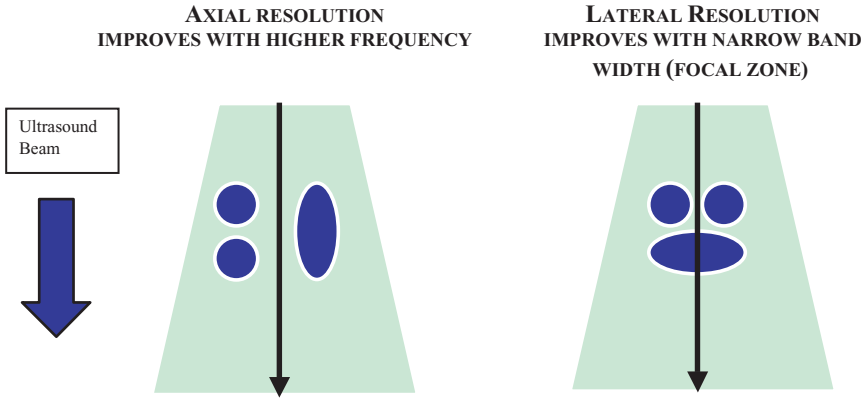



**Figure 1.5**

Axial resolution improves with higher frequency. Lateral resolution improves with narrow bandwidth (focal zone).

structures such as the bladder. Attenuation also occurs as sound encounters interfaces between different types of media. If a tissue is homogeneous and dense, then the number of interfaces is reduced and less attenuation occurs. If a tissue is heterogeneous and less dense, then more attenuation occurs.

*Reflection* is the redirection of part of the sound wave back to its source. *Refraction* is the redirection of part of the sound wave as it crosses a boundary of different media (or crosses tissues of different propagation speeds such as from muscle to bone). *Scattering* occurs when the sound beam encounters an interface that is relatively smaller or irregular in shape (e.g., what happens when sound waves travel through air or gas). *Absorption* occurs when the acoustic energy of the sound wave is contained within the medium.

*Resolution* refers to an ultrasound machine's ability to discriminate between two closely spaced objects. The following images represent two points that are resolved as distinct by a machine with higher resolution (the paired dots) and the same structures visualized by a machine with lower resolution (the two dots are seen as a single indistinct blob). *Axial resolution* refers to the ultrasound machine's ability to differentiate two closely spaced echoes that lie in a plane parallel to the direction of the traveling sound wave. Increasing the frequency of the sound wave will increase the axial resolution of the ultrasound image. *Lateral resolution* refers to the ultrasound machine's ability to differentiate two closely spaced echoes that lie in a plane perpendicular to the direction of the traveling sound wave (Figure 1.5). In most portable ultrasound machines, the machine self-adjusts the focal zone (or narrowest part of the ultrasound beam) automatically over the midrange of the screen. However, some machines have a button that allows you to shift that narrow part of the beam up and down.

Finally, *acoustic power* refers to the amount of energy leaving the transducer. It is set to a default in most machines to prevent adverse biologic effects, such

as tissue heating or cell destruction. This is to adhere to the ALARA or "as low as reasonably acceptable" principle – meaning the lowest amount of energy is used to obtain the information clinically needed to care for the patient. Therapeutic ultrasound operates differently from the diagnostic ultrasound discussed so far in that it purposely uses the heating properties of ultrasound to affect tissue. Often, therapeutic ultrasound is used in physical therapy or rehabilitation after orthopedic injuries to help mobilize tissue that has been scarred.

## Basic Instrumentation

Ultrasound devices all use the same basic principle for generating ultrasound waves and receiving the reflected echoes. This principle is made possible by a property that quartz (and some other compounds, natural and synthetic) possesses called the *piezoelectric effect*. The piezoelectric effect refers to the production of a pressure wave when an applied voltage deforms a crystal element. Moreover, the crystal can also be deformed by returning pressure waves reflected from within tissue. This generates an electric current that the machine translates into a pixel. As mentioned, this pixel's gray shade depends on the strength or amplitude of the returning echo and thus the strength of the electric current it generates.

Many different arrangements of this basic piezoelectric transducer/probe have been developed (Figure 1.6). For example, a convex probe has crystals embedded in a curved, convex array. The farther the beams have to travel, the more the ultrasound beams fan out. This reduces lateral resolution in deeper tissue. It also produces a sector- or pie-shaped image.

A linear array probe (Figure 1.7) has crystals embedded in a flat head. As a result, the ultrasound beams travel in a straight line. Because the ultrasound beams are directed straight ahead, a rectangular image is produced.

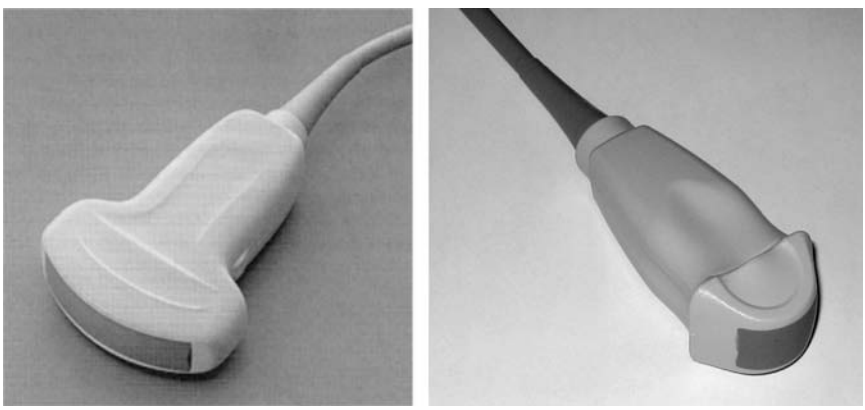


**Figure 1.6**
Curvilinear probe on left, and microconvex probe on right.

**Figure 1.7**
Linear probe.

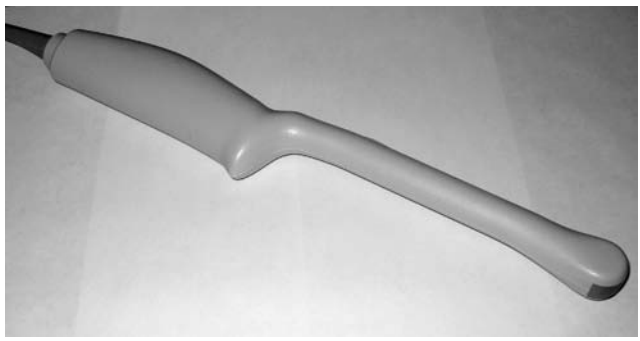


**Figure 1.8**
Intercavitary probe.

Probes also come in different sizes or "footprints" because sometimes you will need smaller probes to sneak through ribs or other structures that are not ultrasound-friendly. Finally, each probe has a range of frequencies it is capable of generating. Usually, linear probes have higher frequency ranges, and curved probes have lower frequency ranges. One exception to this is the intercavitary probe used in obstetric and gynecologic ultrasound (Figure 1.8). Although it has a curved footprint, it also uses higher-frequency ultrasound to obtain high-resolution pictures of smaller structures close to the probe.

## Using the Transducer/Probe

When scanning with the transducer, use adequate amounts of ultrasound gel to facilitate maneuvering the transducer and to optimize the quality of images obtained. Any air between the probe and the surface of the skin will mean that sound waves traveling through that space will scatter and the strength of the returning echoes will decrease. In addition, several scanning planes should be used whenever imaging any anatomic structure. This means that it is always important to image structures in two planes (i.e., transverse and longitudinal)

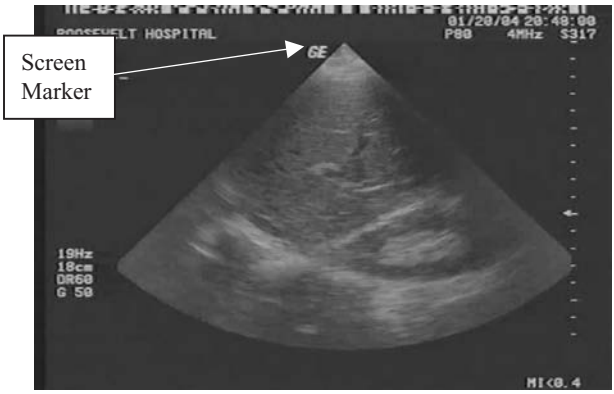



**Figure 1.9**
Screen markers are found on the top of the screen, usually on the left for emergency ultrasound applications. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

because we are looking at three-dimensional structures with two-dimensional images.

## Probe Markers

One of the first principles to remember is that every probe has a raised marker or indentation on it that correlates to the side of the screen with a dot, the ultrasound manufacturer's logo, or some other identifier (Figure 1.9). Objects located near the probe marker on the transducer will appear near the probe marker on the screen. Objects opposite the probe marker will appear on the other side of the screen marker.

For the most part, bedside ultrasound keeps the screen marker on the left-hand side of the screen. However, formal echocardiography is performed with the marker on the right-hand side of the screen, so most machines have a button that lets you flip the screen marker back and forth. This manual describes all images with the marker on the left to keep machine settings constant. It is important to know this fact because echocardiographers will have different probe positions (180 degrees different) based on their different screen settings.

## Proprioception

As one grows more comfortable with scanning, the probe and ultrasound beam become an extension of the arm (Figure 1.10). It becomes natural to understand that moving your hand a certain way yields predictable changes in the image orientation. For novice users, it is helpful to review the standard orientation of the probe. Like any object working in three dimensions, the probe (and therefore the ultrasound beam) can be oriented in an $x$, $y$, or $z$ axis. A simple analogy would be the orientation of an airplane. An ultrasound transducer is pictured in the figure in three different orientations (short side, long side, and facing out of the page), with its beam colored green to illustrate the concept.

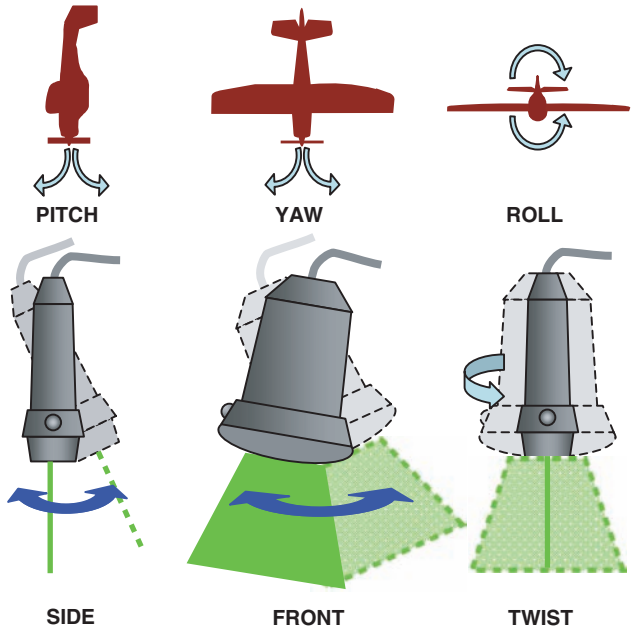



**Figure 1.10**
Orienting the probe in three dimensions.

*Pitch* refers to movement up or down. For a transducer in a transverse orientation on the abdomen, this would refer to tilting or "fanning" the probe toward the head or feet. *Yaw* refers to a side-to-side turn. This would correspond to angling the same probe left or right toward the patient's flanks. Finally, *roll* refers to spinning on a central long axis. If this motion is done with the aforementioned probe, the transverse orientation would become sagittal. At first, focus on moving the probe in one plane at a time, and note the impact on the image. Novice users often become disoriented when they believe that they are moving in one plane but are truly twisting through multiple axes at once.

## Probe Positioning When Scanning

When obtaining a longitudinal or sagittal view (Figure 1.11), the transducer is oriented along the long axis of the patient's body (i.e., the probe marker is pointed toward the patient's head). This means that you will see the cephalad structures on the side of the screen with the marker (here, on the left side).

The transverse or axial view (Figure 1.12) is obtained by orienting the transducer 90 degrees from the long axis of the patient's body, producing a cross-sectional display. For the vast majority of indications, the probe marker should be oriented toward the patient's right. Again, if the marker is pointed to the right, the structures on the right side of the body will appear on the side of the screen with the marker.

The coronal view (Figure 1.13) is obtained by positioning the transducer laterally. The probe marker is still pointed to the patient's head so the cephalad

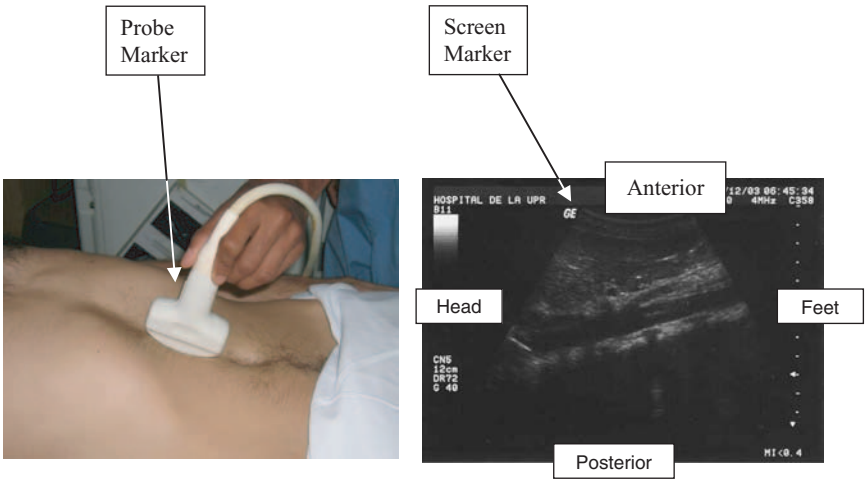



**Figure 1.11**
Longitudinal probe position.

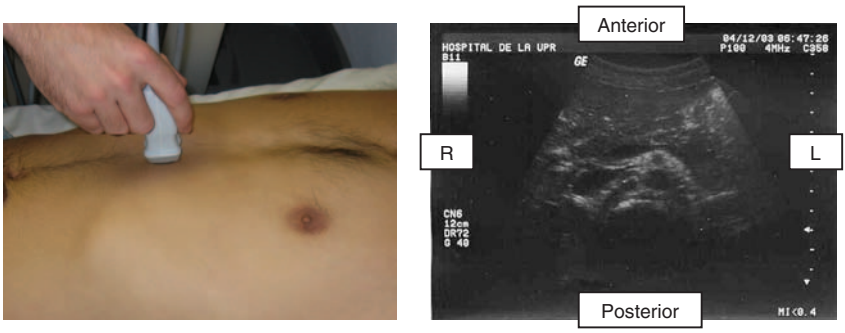



**Figure 1.12**
Transverse probe position.

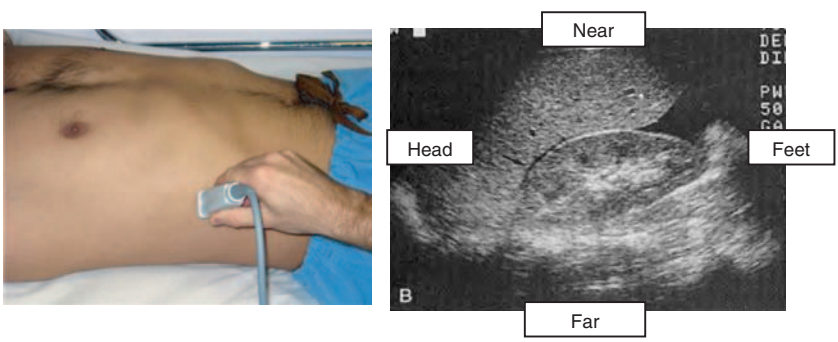



**Figure 1.13**
Coronal probe position.

structures are on the left side of the screen (marker side). In this view, the structures closest to the probe are shown on the top of the screen, and as the beam penetrates, the tissues furthest from the probe are on the bottom of the screen.

## Understanding the Formed Image

To review, a number of conventions have been almost universally adopted for translating the electrical information generated by the transducer into an image on a display screen. We say "almost" because, as mentioned previously, cardiologists have reversed their screen marker; instead of placing it on the left side of the screen, they place it on the right. Because bedside ultrasound includes abdominal and other imaging, we leave the marker on the left side and teach you to hold the probe 180 degrees reversed from the cardiology standard when doing bedside cardiac imaging. By doing this, the images you create will appear the same as the cardiologists' on the screen.

Again, to obtain these conventional views, you must know the orientation of the transducer's beam. The convention is that the probe indicator or marker should be to the patient's right or the patient's head. The screen marker should be on the left of the screen (see figures in previous section).

## Adjusting the Image

Some ultrasound machines allow the operator to choose where to focus the narrowest part of the ultrasound beam. By adjusting the *focal zone* (Figure 1.14), you can optimize lateral resolution. Focus is usually adjusted by means of a knob or an up/down button on the control panel.

Focal depth is usually indicated on the side of the display screen as a pointer. By moving the pointer to the area of interest, the beam is narrowed at that

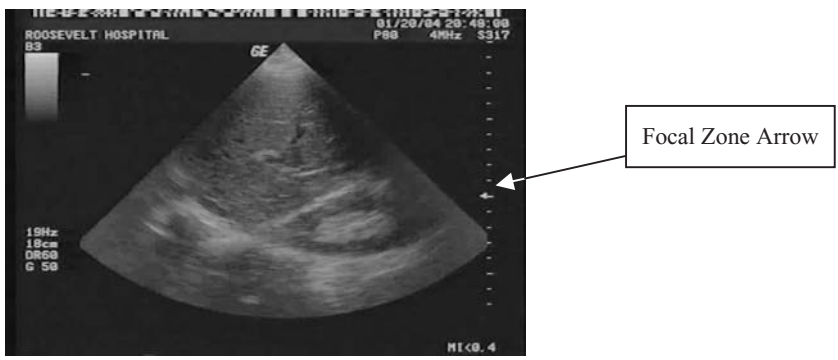



**Figure 1.14**

Focal zone. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

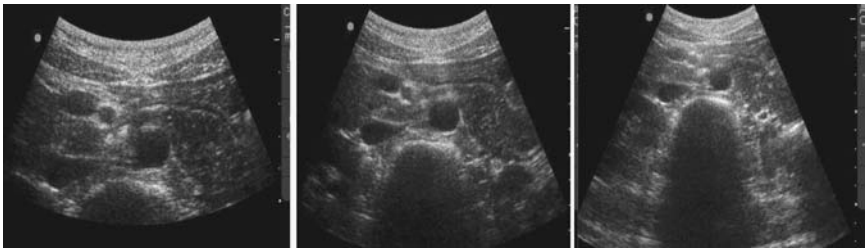


**Figure 1.15**
Depth. Increasing depth from left to right panels.

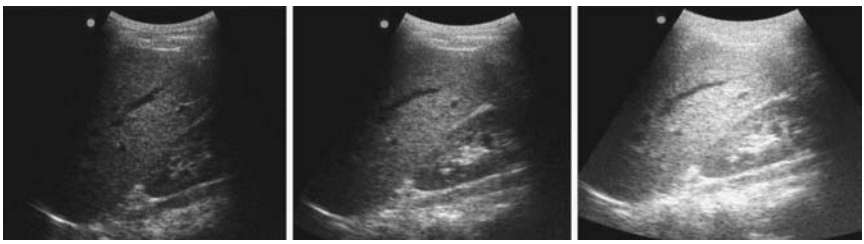


**Figure 1.16**
Gain. Increasing gain from left to right panels.

depth to improve the image quality. Not all machines allow this function to be done manually; however, some perform this function automatically at the midpoint of the screen.

Another parameter that can be adjusted by the ultrasound operator is the *depth* (Figure 1.15). By adjusting the imaging depth, the operator can ensure that the entire tissue or structure of interest is included on the screen. Depth is usually adjusted by means of a knob or an up/down button on the control panel. A centimeter scale is usually located on the side of the display screen to indicate the depth of the tissue being scanned.

The *gain* (Figure 1.16) control offers an additional parameter for adjusting the intensity of returned echoes shown on the display screen. In other words, by increasing the gain, you brighten the entire ultrasound field (i.e., the entire display). When you decrease the gain, the ultrasound field darkens. The gain function is somewhat akin to adjusting the volume on your stereo – it increases the overall volume but does not improve the quality of the sound. In the case of diagnostic imaging, it increases the brightness but does not increase the number of pixels per image.

A knob or up/down button on the control panel allows the operator to adjust gain. The gain function has *no* effect on the acoustic power.

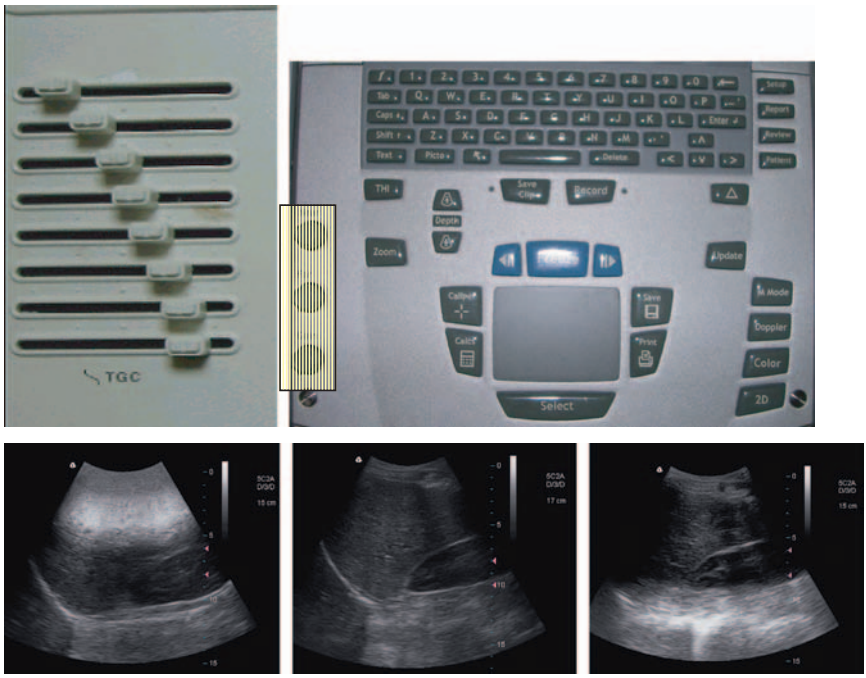



**Figure 1.17**

Time gain compensation (TGC). Ultrasound machines control TGC with either sliders that divide the screen into segments or buttons that allow adjustment on in the near or far field (top panels). The bottom panels show increased far field gain on left and increased near field gain on right with a well-gained image in the middle.

*Time gain compensation* (TGC) (Figure 1.17) controls on an ultrasound machine allow the operator to adjust the gain *at varying depths*. Echoes returning from deeper structures are more attenuated simply because they have to travel through more tissue. Without TGC, the far field (bottom of the screen, deeper tissue) would always appear darker than the near field (top of the screen, tissue closest to probe). TGC boosts the gain on the echoes returning from the far fields. Some machines have one button that allows you to adjust the near field relative to the far field. Other machines have multiple slider levers that allow you to control the gain throughout the entire scanning depth.

## Scanning Modes

There are a variety of imaging modalities used in diagnostic ultrasound.

*A*, or *"amplitude," mode* is an imaging modality largely of historical interest, although it is used in ophthalmologic applications today (Figure 1.18). It uses an oscilloscope display for returning amplitude information on the vertical

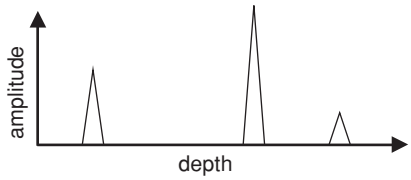



**Figure 1.18**
A-mode.

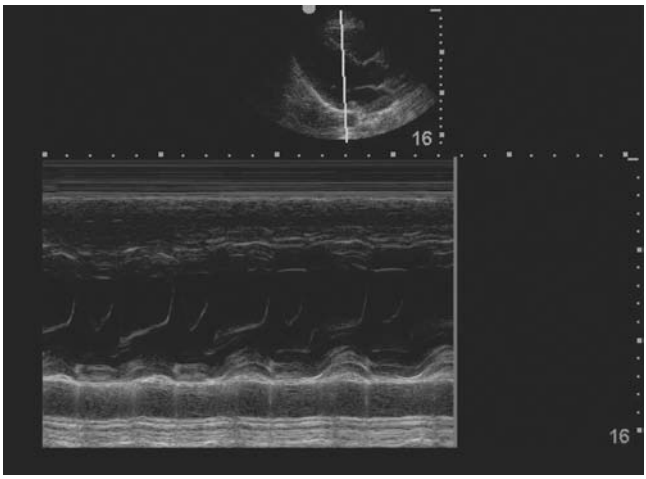



**Figure 1.19**
M-mode.

axis and the reflector distance information on the horizontal axis. There is no picture; distance and amplitude are represented by a graph. In the following figure, the vertical axis A represents the amplitude of the signal returned to the transducer, and the depth D is calculated based on the roundtrip time of the ultrasound beam signal.

*B*, or *"brightness," mode* is the modality we have been reviewing up to this point; it is what we use for diagnostic imaging. B-mode scanning converts these amplitude waveforms into an image by using the gray scale converter discussed previously. Most scanners now display images with up to 256 shades of gray, allowing for visualization of subtle differences within tissues/structures. As mentioned, the gray scale assignment of each pixel is based on the signal amplitude or strength of the returning wave from a given point.

*M*, or *"motion," mode* plots a waveform that depicts the motion of the tissue/structure of interest relative to the transducer's image plane (line through the structure) on the vertical axis, and time on the horizontal axis (Figure 1.19). This is often used simultaneously with B-mode scanning to study the motion of valves or to measure/document fetal cardiac activity. Many new bedside ultrasound machines are capable of performing this function.

*D*, or *"Doppler," mode* is an imaging modality that relies on the principle of Doppler/frequency shift. Consider the example of a moving train: a pedestrian at a crossing will hear an increase in the pitch of the train whistle as it

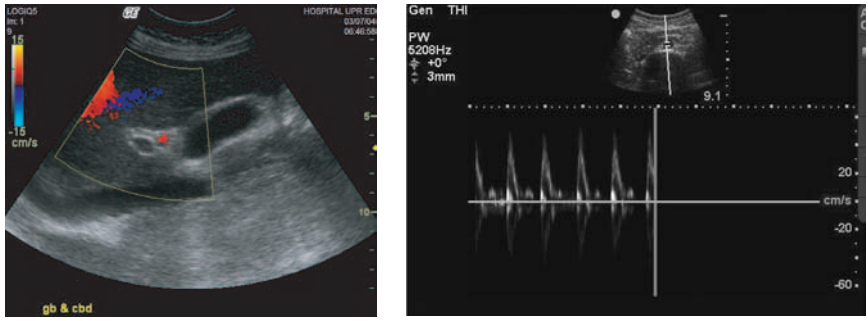



**Figure 1.20**
Color Doppler (*left*) and spectral Doppler (*right*).

approaches and a decrease in pitch as it moves away. However, the train engineer will not hear this change in pitch – this audible shift in frequency – because he or she is traveling with the sound. Doppler ultrasound can sense the movement of the reflected ultrasound waves toward and away from the probe – this is represented either by color changes (color Doppler) or by audible or graphical peaks (spectral doppler).

The left image in Figure 1.20 shows color Doppler. The blue and red do not identify venous and arterial flow – rather, they describe whether flow is toward or away from the probe and depend on probe orientation. The legend on the left of the screen defines the directional color assignment. In this example, red flow is toward the transducer (toward the top of the screen), and blue flow is away from the transducer (toward the bottom of the screen). The right image in Figure 1.20 is an example of pulsed wave or spectral Doppler. Spectral Doppler waveforms can be helpful in identifying and distinguishing venous from arterial waveforms.

Power Doppler is a form of color Doppler that uses a slightly different component of returned signal and seems to be more sensitive in low-flow states (Figure 1.21). This mode sacrifices the ability to demonstrate the direction of flow to gain sensitivity in detecting lower levels of flow. Again, many of the new bedside ultrasound machines are now capable of performing these functions, and physicians can use these capabilities to augment their diagnostic capabilities.

We review when D- and M-mode functions are useful in the applications sections.

## Effects and Artifacts

Understanding image artifacts and their formation is of the utmost importance. Unrecognized artifacts can lead to misinterpretation and can undermine the utility of the bedside ultrasound exam.

*Acoustic shadowing* is a characteristic ultrasound effect that can aid in the diagnosis of certain conditions (e.g., cholelithiasis) and act as a hindrance to

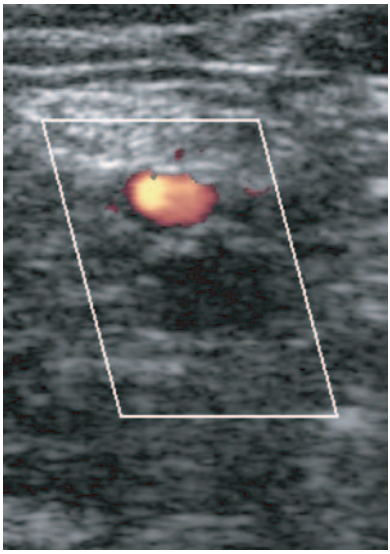


**Figure 1.21**
Power Doppler.

the visualization of distal structures (e.g., rib shadows) (Figure 1.22). It occurs when a sound beam encounters a highly reflective (high attenuation) surface such as bone or calcium. Shadowing appears as a hypoechoic/anechoic area deep to the reflecting structure because so few sound waves can get around or behind the highly reflective structure. Air can also cause shadowing because the ultrasound energy is scattered in all directions at the interface between tissue and air.

*Reverberation* occurs when the sound beam "bounces" between two highly reflective structures (Figure 1.23). It appears as recurrent bright arcs, called *A lines*, are displayed at equidistant intervals from the transducer. One clinically important variation on this is when sound gets trapped between two highly reflective structures that are closely opposed, such as visceral and parietal pleura. The fibrous tissue traps the sound beam, and it "bounces" infinitely back and forth such that the reflected echo is interpreted as a straight bright white echo also known as a *comet tail* or *B line*. This concept is reviewed again in subsequent chapters because a "comet tail" artifact is a normal finding in a typical lung exam. The reverberation artifacts are clinically important in Chapter 12.

*Refraction* occurs when a sound beam obliquely crosses a boundary of tissue with different propagation speeds (Figure 1.24). It appears as an acoustic shadow, originating from the point where the sound beam changes direction.

*Mirror images* occur when an ultrasound beam undergoes multiple reflections and an incorrect interpretation results. When the beam encounters a bright reflector (R), some of the acoustic energy is reflected backward. When this beam path encounters an object (A), information about its relative brightness is relayed back to the transducer. However, its depth is miscalculated because the machine assumes the ultrasound beam took a straight path

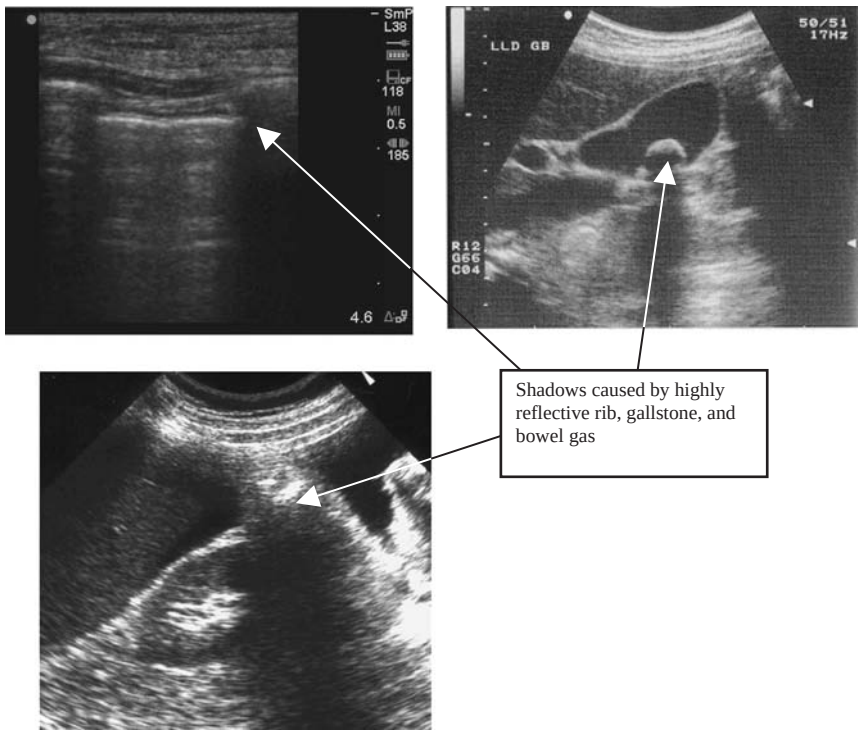



**Figure 1.22**
Shadowing.

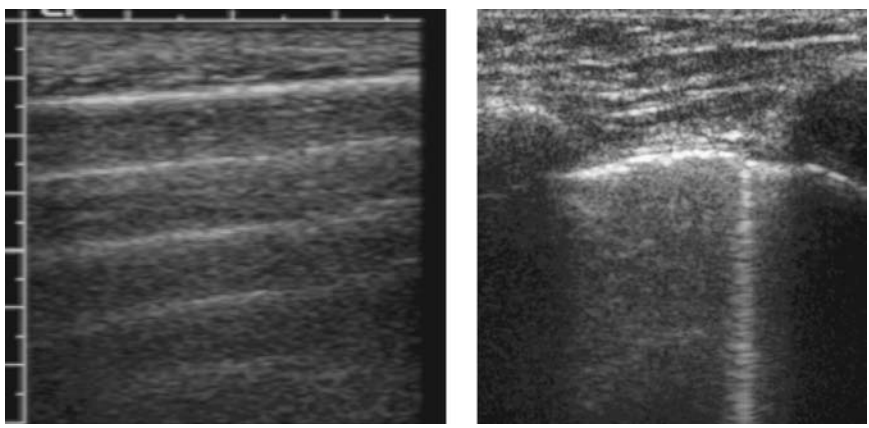


**Figure 1.23**
Reverberation and comet tail artifacts.

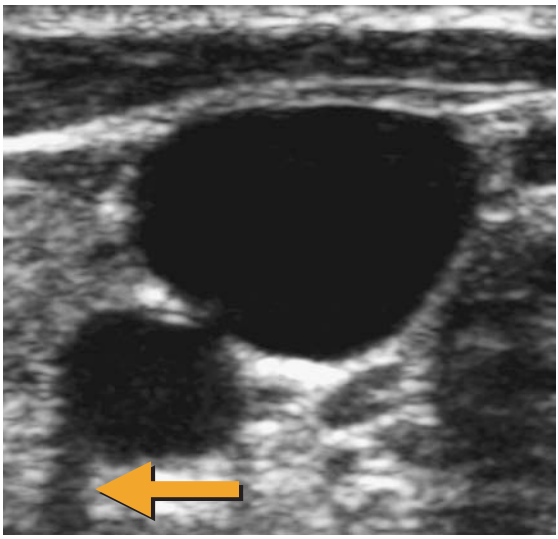
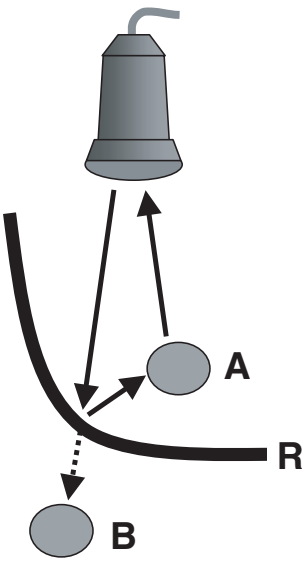


**Figure 1.24**
Refraction artifact (see arrow).



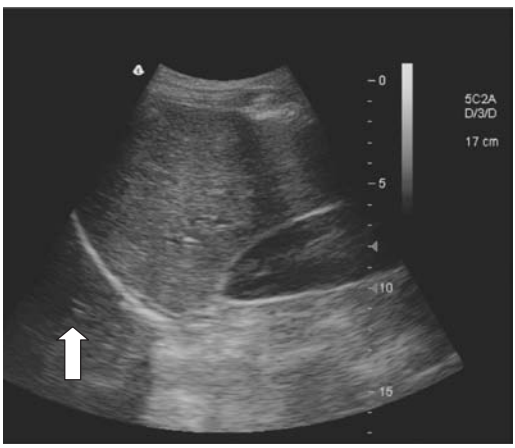




**Figure 1.25**
Mirror image artifact. Block arrow shows mirror image of liver tissue superior to diaphragm.

toward the target object. Because the reflected path (solid arrows) has a longer roundtrip time than a path directly to and from the target, the machine calculates that the structure is deeper than it is. This yields a false object (B), calculated by the machine to lie along a linear path from the initial ultrasound beam. Mirroring appears as a duplication of structures, with the mirror image always appearing deeper than the real structure (Figure 1.25). The mirror image will

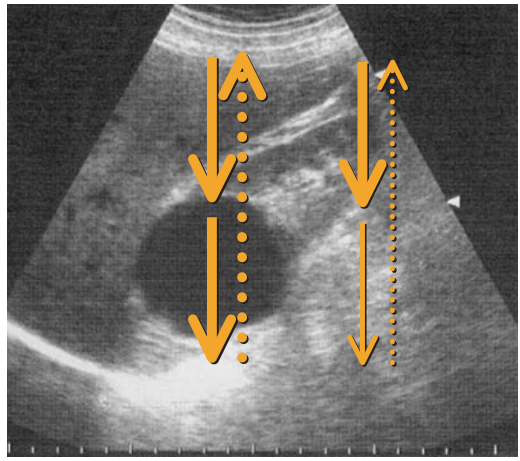


**Figure 1.26**
Posterior acoustic enhancement.

disappear with subtle changes in position of the transducer, whereas the real image should be visible in multiple planes.

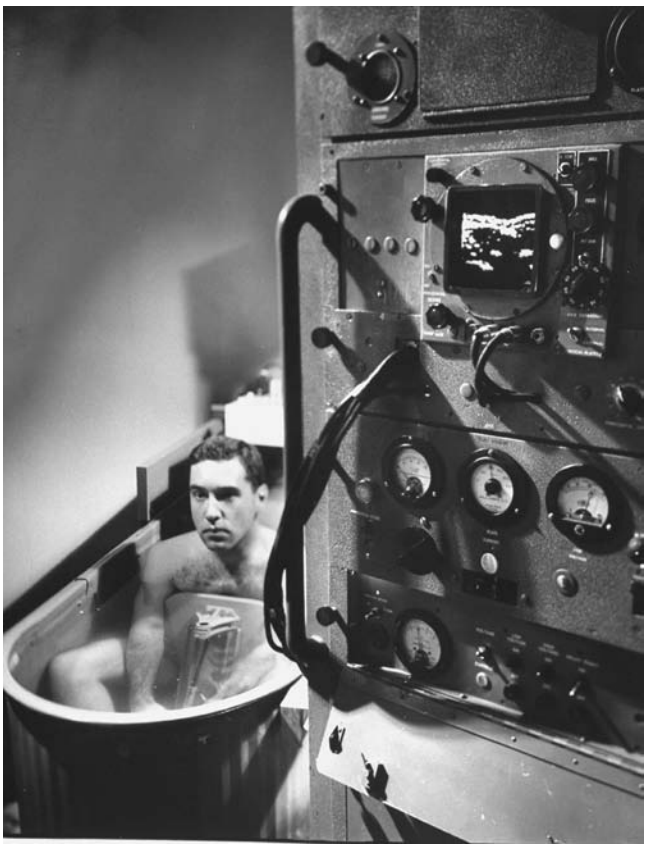
*Enhancement* (or *posterior acoustic enhancement*) is artifactual brightness deep to an anechoic structure (commonly a cystic structure or blood vessel) (Figure 1.26). It occurs when sound crosses an area of low signal attenuation. There is an increase in echogenicity posterior to the low attenuation structures because the sound returns to the transducer with greater intensity than adjacent areas. For example, the beams on the right are uniformly attenuated as they pass through the body. They return to the transducer with far less energy (thinner arrow) than they started with. The beam in the center loses no energy as it passes through the cyst, and thus it has much more energy to return to the transducer.

# Part I

# Diagnostic Ultrasound

In the 1950s, when medical diagnostic ultrasonography was in its infancy, it was hard to imagine that the average physician would find it helpful. The technology required that patients be immersed in a tub of water and be hemodynamically stable enough to spend long periods of time in the tub. Ultrasound waves generated a graph representing the strength of returning echoes from the patient and were challenging to translate into anatomic images. Not only was the whole process cumbersome (and likely chilly and uncomfortable), it also required much training and skill to interpret the data generated.

In the second millennium, technology is changing faster than most of us can keep up with it. The digital camera that I bought 5 years ago was ridiculed by my nephew for being "ancient and out-of date" when I brought it out to take holiday photos – and indeed it was. I couldn't take videos, download music, take photos with six or more megapixels, or make phone calls from my



Life Magazine, 1954

camera! Ultrasound technology is no different. Machines are now the size of laptops and much of the technical skill required to operate the older machines is now part of the software in new machines. The images created by the new generation ultrasound probes are clear and easier to interpret than they have ever been. Moreover, competition and innovation have meant that machines that were financially beyond the reach of most are now more economically viable.

This revolution in technology would not be important to physicians if ultrasound were not so useful. Not only can it assist the physician at the bedside in making diagnoses, it can do so without exposing the patient to harmful radiation and it can be repeated infinitely without requiring transportation as clinical situations change. It can assist in performing invasive procedures under direct visualization. It can help guide the physician in mobilizing further resources or consultations, direct which testing should be done next, or provide the proof needed to undertake more invasive procedures to stabilize patients. Most importantly, it enables physicians to understand and diagnose pathophysiology directly with moving images in real time.

In fact, the applications for which bedside ultrasound can be used are now only limited by the innovations and imagination of physicians using the technology. This textbook introduces physicians to the way the machine works and gives an overview of the basic principles needed to operate a bedside ultrasound machine. It also reviews the most common applications of bedside ultrasonography. Techniques for acquiring images and pictures of normal and abnormal findings are reviewed.

However, the main intent of this manual is to remove some of the mystery from the technology and to inspire physicians to see this tool as another innovation in the advancement of our diagnostic capability and in the ability to provide safe and efficient treatment for patients.

Vicki Noble

# 2 Focused Assessment with Sonography in Trauma (FAST)

## Introduction

Ultrasound (US) was first used in the evaluation of trauma patients in Europe in the 1970s. The German surgery board has required certification in ultrasound skills since 1988. Since the mid-1980s in the United States, the use of ultrasound in trauma has become more widespread and has all but replaced diagnostic peritoneal lavage (DPL) in most trauma centers. The FAST exam has been included as part of the advanced trauma life support course since 1997 (1). In addition, the American College of Surgeons has included ultrasound as one of several "new technologies" that surgical residents must be exposed to in their curriculum. Both the American College of Emergency Physicians and the Society for Academic Emergency Medicine support the use of ultrasound to evaluate blunt abdominal trauma as well. Since 2001, training in emergency ultrasound has been required for all emergency medicine residents (2–4). All physicians who will be evaluating trauma patients must become proficient in the use of trauma ultrasound.

The objective of the FAST exam is to detect free intraperitoneal and pericardial fluid in the setting of trauma. The cardiac windows are especially critical in penetrating trauma and are reviewed in this section and in Chapter 3. In advanced applications of the FAST exam, pleural fluid and other signs of thoracic injury can be assessed as well. Although computed tomography (CT) scanning provides excellent and more detailed solid organ evaluation, it often requires transportation of the patient to a less monitored setting (thus the trauma adage "death begins in radiology"). In addition, CT requires exposure to radiation and is more expensive. DPL is more sensitive for detecting intraperitoneal blood than US. It is considered positive with 100,000 red blood cells (RBCs)/$mm^3$, which is 20 mL of blood per liter of lavage fluid. However, DPL is an invasive test that can be complicated by pregnancy, previous surgery, and operator inexperience. In addition, because DPL has such a high sensitivity, it has a higher rate of nontherapeutic laparotomies (6%–26%) (5). With the evolution from surgical treatment of splenic and liver injuries to nonoperative management, the high sensitivity and invasive nature of the DPL has become less useful (5–8). Ultrasound can reliably detect as little as 250 mL of free fluid in Morison's pouch (9). It is also inexpensive, rapid, and easily repeated. In addition, US also has a higher specificity for therapeutic laparotomy than DPL (10).

To take advantage of the strengths and weaknesses of all three diagnostic options for trauma (CT, US, and DPL), a combination approach is best. There is an overwhelming amount of data supporting the use of the FAST exam as the initial screening tool for evaluation of the abdomen and thorax in trauma

(10–21). In addition, in an era of cost consciousness, there is even evidence that shows that using FAST as a screening tool helps decrease testing, hospital stays, and intensive care unit requirements and thus can also significantly decrease cost (11,21). Therefore, it is important to remember the strengths and weaknesses of all three diagnostic options for trauma. In this chapter, we discuss the FAST scanning techniques, review positive and negative images, and present potential clinical algorithms for FAST use.

## Focused Questions of the FAST Exam

The focused questions of the FAST exam are as follows:

1. Is there free fluid/blood in the abdomen?
2. Is there fluid/blood in the pericardium?

There has also been a lot of research demonstrating the utility of using ultrasound to evaluate the thorax as part of the FAST examination to detect pneumothorax and hemothorax (22–24). This has been called the extended FAST (eFAST), and most trauma centers are now using this technique. We discuss ultrasound diagnosis of pneumothorax at the end of this chapter and show how the eFAST can diagnose blood in the thorax during the following discussion. For the eFAST, there are two additional focused questions:

1. Is there fluid/blood in the thorax?
2. Is there a pneumothorax?

## Anatomy

The shape of the peritoneal cavity provides several dependent areas when a patient is in the supine position. The site of accumulation of fluid depends on the source of bleeding and the position of the patient. Because most trauma patients are transported supine on a backboard, we use this as the starting position.

The right paracolic gutter runs from Morison's pouch to the pelvis. The left paracolic gutter is not as deep as the right paracolic gutter. In addition, the phrenocolic ligament blocks fluid movement to the left paracolic gutter. As a result, fluid flows more freely toward the right paracolic gutter.

The hepatorenal recess (Morison's pouch) is the potential space located in the right upper quadrant (RUQ) between Glisson's capsule of the liver and Gerota's fascia of the right kidney (Figures 2.1–2.3). In a normal exam, there is no fluid between these two organs, and the fascia appears as a bright hyperechoic line separating the liver from the kidney.

The splenorenal recess is the potential space located in the left upper quadrant (LUQ) between the spleen and Gerota's fascia of the left kidney (Figures 2.4 and 2.5). Again, in the normal ultrasound exam of this quadrant, there is no

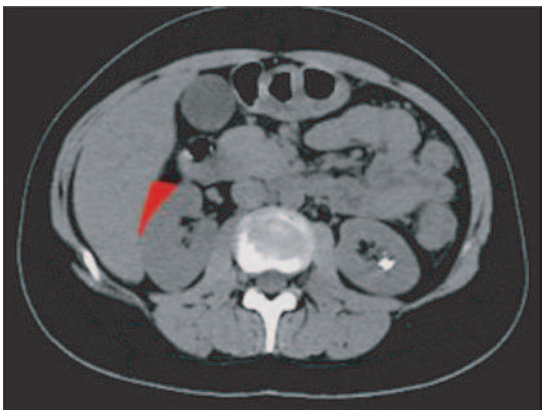


**Figure 2.1**
Computed tomography view of Morison's pouch. Courtesy of Dr. Lauren Post, Mount Sinai School of Medicine, New York.

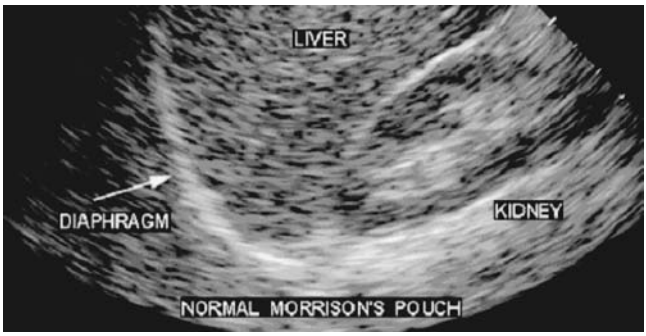



**Figure 2.2**
Ultrasound view of Morison's pouch.

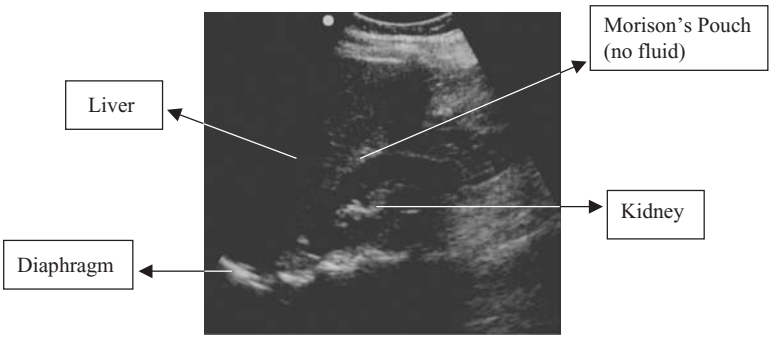



**Figure 2.3**
Labeled view of Morison's pouch.

fluid or hypoechoic area separating the spleen from the kidney, and the fascia appears as a bright hyperechoic line separating the two organs.

The rectovesical pouch (Figures 2.6a and 2.7) is the pocket formed by the reflection of the peritoneum from the rectum to the male bladder. It is the most dependent area of the supine male.

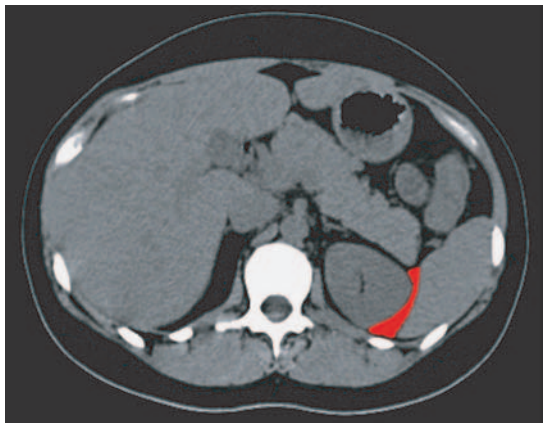


**Figure 2.4**

Computed tomography view of splenorenal recess. Courtesy of Dr. Lauren Post, Mount Sinai School of Medicine, New York.

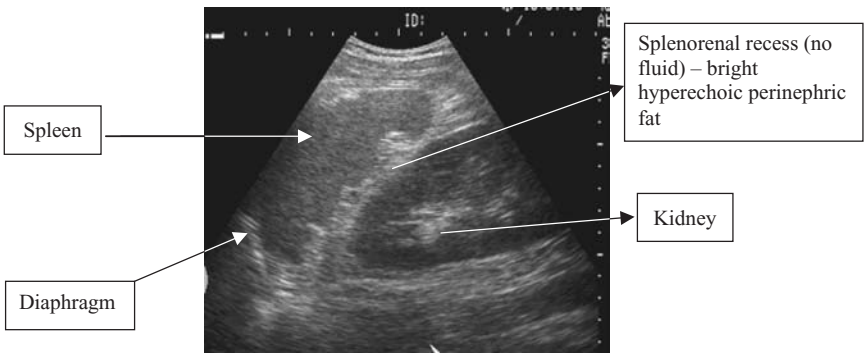
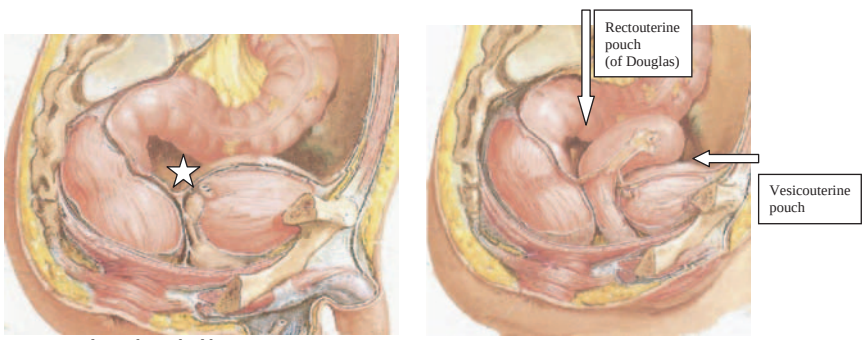



**Figure 2.5**

Labeled view of a normal splenorenal recess.




Rectovesical pouch marked by star.

**Figure 2.6**

Drawings from Netters Atlas of Human Anatomy, 2nd ed. 1997, plate 363. Male (left panel) and female (right panel) pelvic anatomy.

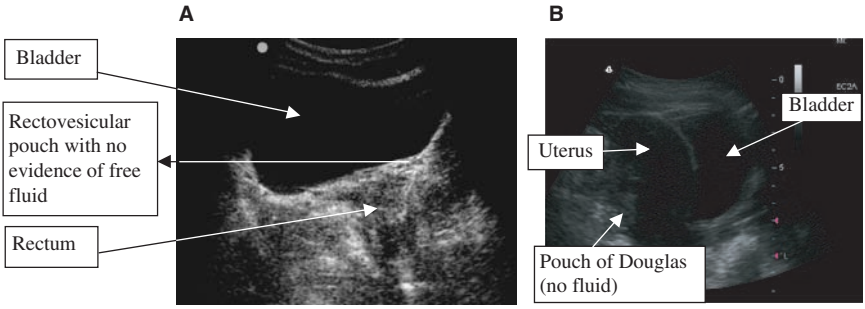



**Figure 2.7**

Labeled transverse suprapubic view in male (panel A) and longitudinal suprabic view in female (panel B).

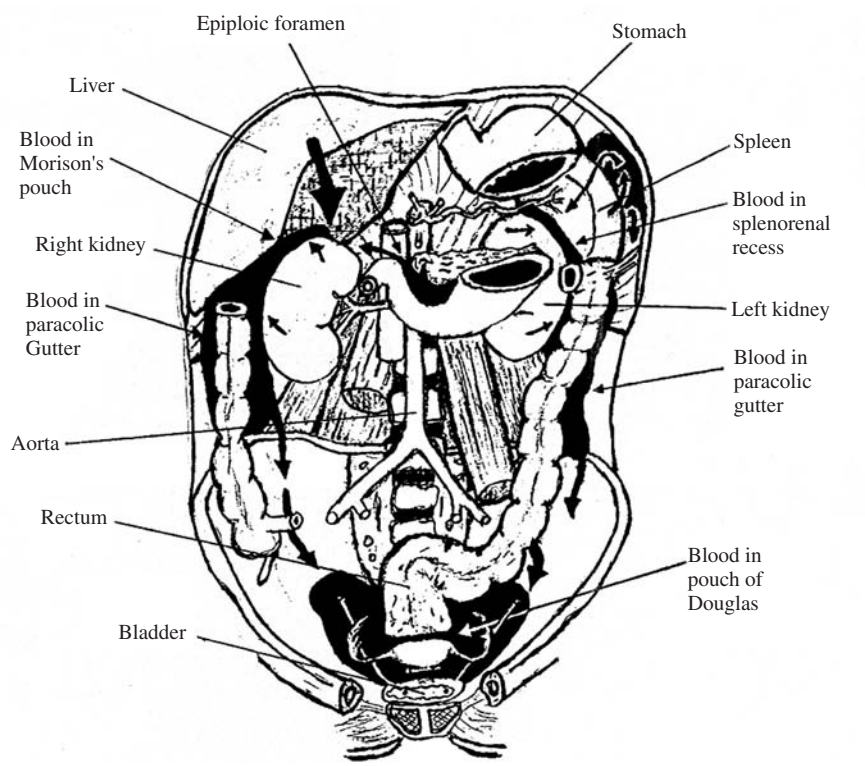



**Figure 2.8**

Movement patterns of free intraperitoneal fluid. Courtesy of Dr. Mark Hoffman, Dr. Ma, and McGraw-Hill.

The pouch of Douglas (Figure 2.6b) is the pocket formed by the reflection of the peritoneum from the rectum and the back wall of the uterus. It is the most dependent area of the supine female.

Figure 2.8 shows movement patterns of free intraperitoneal fluid. In the supine patient, fluid in the right upper quadrant will collect first in Morison's pouch. Overflow will travel down the right paracolic gutter into the pelvis. Free fluid in the left upper quadrant will collect first between the spleen and the left hemidiaphragm. Fluid will then move into the splenorenal recess, toward the left paracolic gutter into the pelvis. As mentioned, the phrenocolic ligament often shunts fluid to Morison's pouch before filling the left paracolic gutter. Free fluid in the pelvis will first collect either in the rectovesical pouch or the pouch of Douglas and then start to flow cephalad toward the paracolic gutters.

# Technique

## Probe Selection

A phased array or curvilinear 2.5- to 5-MHz probe is most commonly used for the FAST exam. The views and windows used in the exam may all be obtained with a single probe. Some sonographers prefer larger footprint probes that provide greater resolution of deep structures, whereas others prefer narrower footprint microconvex or phased array probes to obtain images in between the ribs more readily.

## Views

The FAST exam is performed by using four views:

1. Hepatorenal recess or Morison's pouch
2. Splenorenal view
3. Pelvic view
4. Pericardial or subcostal view

The four views of the FAST exam are depicted in Figure 2.9. With the eFAST exam, the probe slides superiorly from the standard RUQ and LUQ views to visualize the costophrenic angle and assess for blood in the thorax pooling in the costophrenic space and for normal sliding of the lung pleura with respiration (discussed in the next section).

### *Morison's Pouch*

The starting probe position when looking for Morison's pouch should be the anterior axillary line in the seventh to ninth intercostal space (Figure 2.10). The probe marker (red circle on the probe in Figure 2.9) should be pointing to the patient's head. To get a good view of the entire recess, the probe can then be moved toward the head and then back toward the feet along this plane. If rib shadows obscure the image, the probe's orientation may be rotated from a pure sagittal plane to a slightly oblique plane parallel to the ribs (usually 10–20 degrees). Thus, the probe will sit within a rib space, and the plane of the ultrasound beam will cut across fewer ribs.


**Figure 2.9**
Four views that comprise the FAST exam.

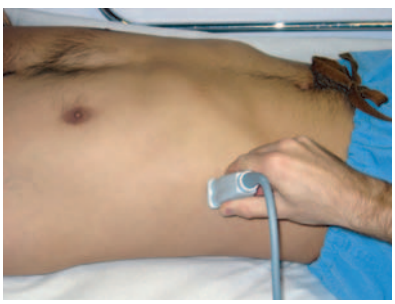


**Figure 2.10**
Probe positioning in the right upper quadrant.

Do not forget to visualize the inferior pole! In a supine patient, the inferior pole of the kidney on both right and left upper quadrant views is the most posterior or dependent part of the peritoneal cavity (Figure 2.11). It is seen by sliding the probe more inferiorly or toward the feet along the axillary line.

Figure 2.12 shows how it is possible to miss the more subtle stripe of free fluid between the liver and the kidney more superiorly if you do not image the inferior pole.

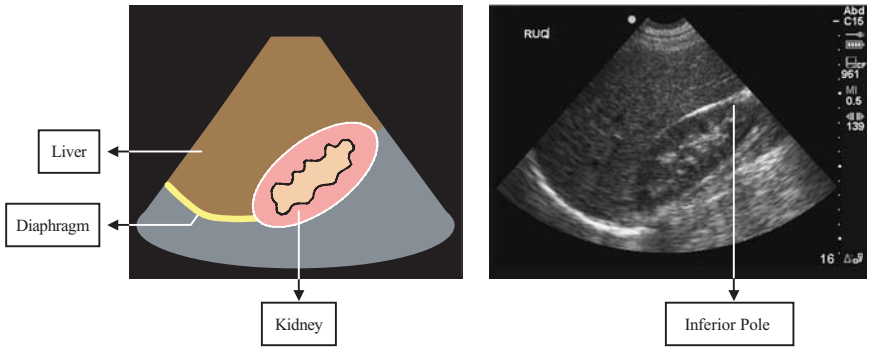



**Figure 2.11**

Normal ultrasound view of right upper quadrant/Morison's pouch. Hyperechoic Gerota's fascia seen here.

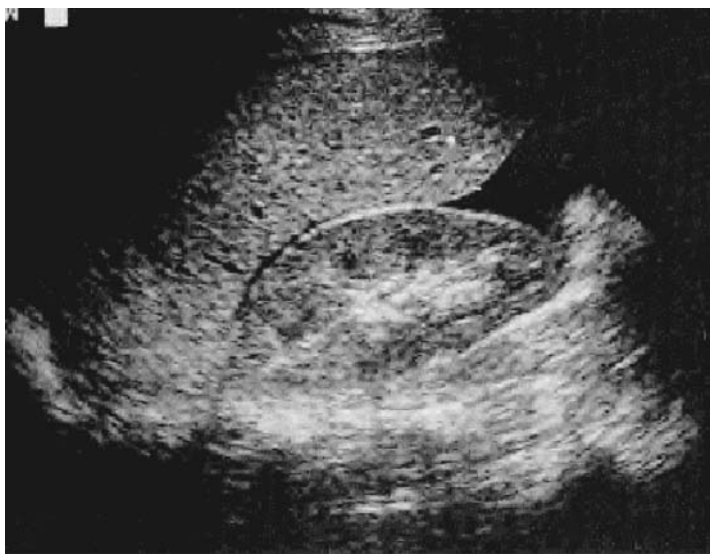


**Figure 2.12**

+FAST. View of Morison's pouch showing fluid along the inferior pole of the right kidney.

### *Splenorenal Recess*

The spleen is smaller than the liver, so the left kidney is more posterior and superior than the right kidney. Therefore, the starting probe position on the left should be in the posterior axillary line in the fifth to seventh intercostal space (Figure 2.13). Again, the marker should be pointed toward the patient's head. As with the RUQ view, the probe's orientation may be rotated to a slightly oblique plane parallel to the ribs (usually 10–20 degrees more posterior). Thus, the probe will sit within a rib space, and the plane of the ultrasound beam will cut across fewer ribs (Figure 2.14).

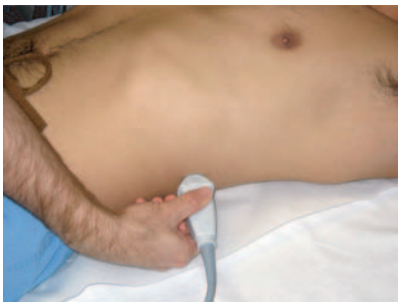


**Figure 2.13**
Probe positioning in the left upper quadrant.

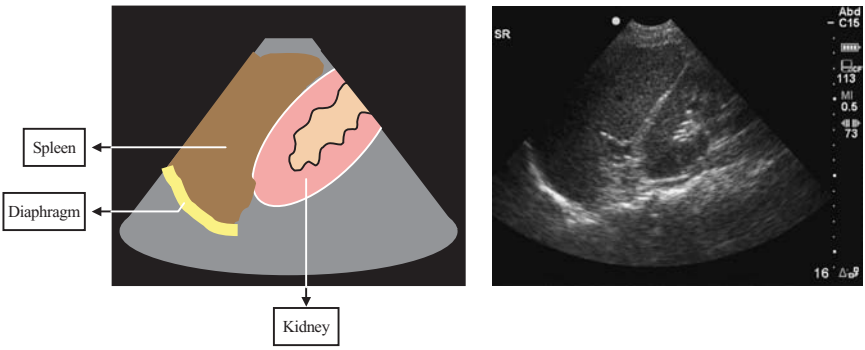



**Figure 2.14**
In the RUQ, it is critical to visualize the inferior pole of the right kidney, since fluid tracks here first and the large liver maintains an interface with the kidney through most of the kidney's length. In contrast, the LUQ has a much smaller interface between the smaller spleen and kidney. Early fluid tracking tends to be close to this interface or even between the spleen and the diaphragm as a result of the splenocolic ligament and so the inferior pole of the left kidney is not as critical to visualize as the right kidney inferior pole.

### *Pelvis*

If this part of the exam can be done before the bladder is emptied (i.e., Foley catheter placed), it is much easier. If a bladder catheter has already been placed, accuracy of the study can be increased by instilling saline into the bladder until it is easily visualized using ultrasound. Place the probe in the transverse position (probe marker to the patient's right) on the symphysis pubis and angle toward the patient's feet (Figure 2.15). The bladder is not always perfectly midline, so sometimes sliding to the right and left on the symphysis pubis will bring the bladder into view (Figure 2.16). The most common reason for difficulty visualizing the bladder is a probe position that is too superior. Remember that the bladder is a pelvic organ and only emerges from above the symphysis pubis as it becomes distended. Examine for fluid posterior to the bladder, posterior to the uterus, and between loops of bowel. It is important to look in both transverse and longitudinal planes for fluid behind the bladder as the sagittal or longitudinal view is more sensitive for small amounts of fluid. Once the bladder is identified transversely, rotate the probe ninety degrees for the longitudinal view.

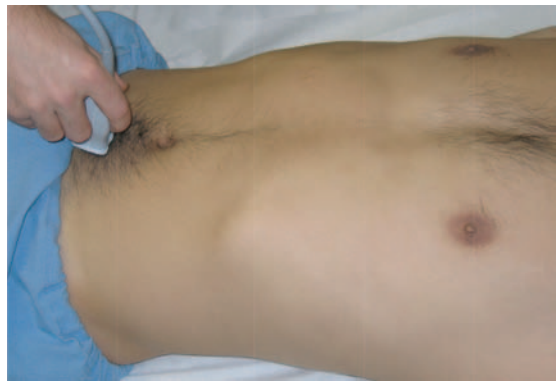


**Figure 2.15**
Probe positioning for the suprapubic view.

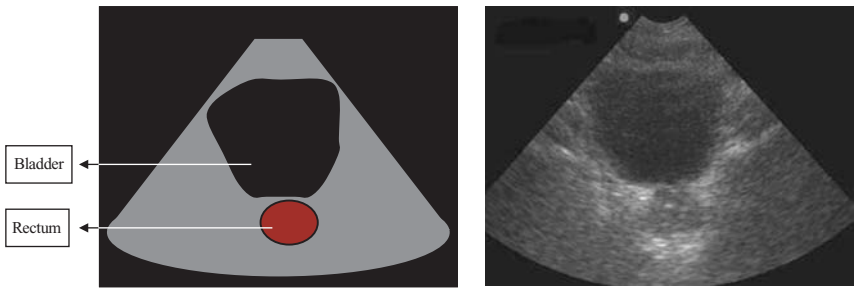



**Figure 2.16**
Normal suprapubic view.

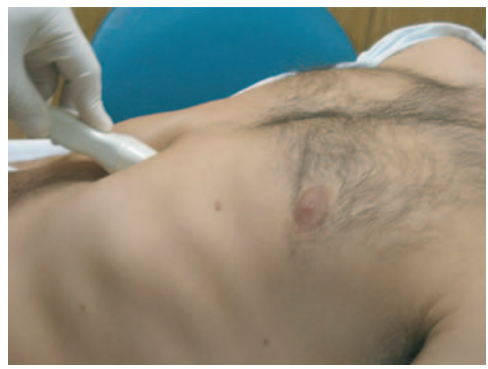


**Figure 2.17**
Probe positioning for subxiphoid view.

### *Subxiphoid*

Cardiac views are reviewed in more detail in Chapter 3. For the FAST subxiphoid view, position the probe almost flat on the abdomen with the marker to the patient's right and angle the probe to the patient's left shoulder (Figure 2.17). If the patient can bend the knees, sometimes this helps relax the abdominal wall muscles. It is also important to remember to bring the depth out to its maximal level for this view because often the distance from the

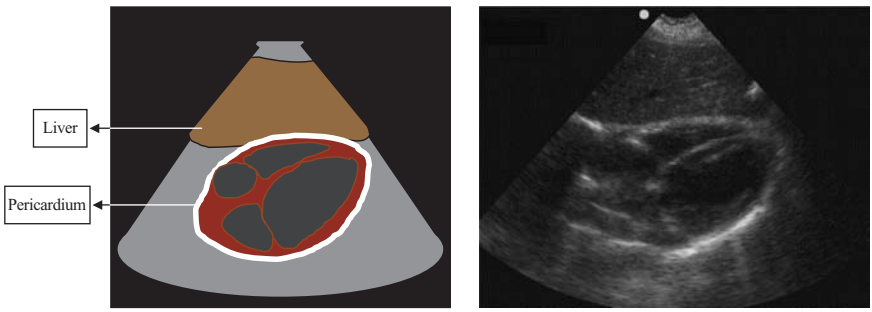



**Figure 2.18**
Normal subxiphoid view.

subxiphoid to the heart is ≥6 cm. With shallow depth settings, the heart will not be visualized. In addition, sometimes a stomach full of air can scatter the ultrasound beams before they reach the heart in the left chest. If this is a problem, slide the probe to the right and shoot through the left lobe of the liver. The liver will act as a better acoustic window than the stomach, and the heart will be easier to visualize (Figure 2.18).

# Scanning Tips

## Trouble with the RUQ View

*Rib shadow in the way?*

- Try angling the probe obliquely to sneak in between the ribs.
- Have the patient take a deep breath to lower the diaphragm and bring Morison's pouch lower in the abdomen below the ribs.

*Can't see the diaphragm?*

- Try bringing the probe lower on the abdominal wall (toward the stretcher in a more posterior coronal plane).
- Try sliding the probe on the same coronal plane toward the head or toward the feet to see if something familiar pops into view.

## Trouble with the LUQ View

*Rib shadow in the way?*

- Try same techniques as listed previously.
- Sometimes because the spleen is so much smaller than the liver, it is actually easier to visualize the splenorenal recess from a more anterior plane – slide the probe over the spleen anteriorly and angle the probe through the spleen to the kidney from anterior to posterior.

## Trouble with the Pelvic View

*Can't find the bladder*?

- This is most often because the probe is too cephalad – bring the probe almost on top of the symphysis pubis angling toward the feet.
- The bladder is sometimes off midline – position the probe transverse (marker to the patient's right) and slide from right to left.
- Has the Foley catheter already been placed or the bladder decompressed? Come back and try again after some fluid is given.

## Trouble with the Cardiac View

*Can't find the heart*?

- This is most often because the angle of the probe is too steep when looking subcostally. Position the probe almost flat on the abdomen in the subxiphoid position.
- The second most common problem is that the depth on the machine is set too shallow. Bring the depth out as deep as the machine allows and look for the moving organ. The depth can be readjusted to a more shallow view once the heart is found.
- Often because a trauma patient has swallowed a lot of air, the stomach is distended. When looking subcostally, the beam is trying to reach the heart through an air-filled stomach. Slide the probe more to the right, and try looking for the heart through the liver, not the stomach. Occasionally, this just won't work, and a second cardiac view should be tried (see Chapter 3).

# Normal Images

The following images are examples of normal FAST ultrasound scans.

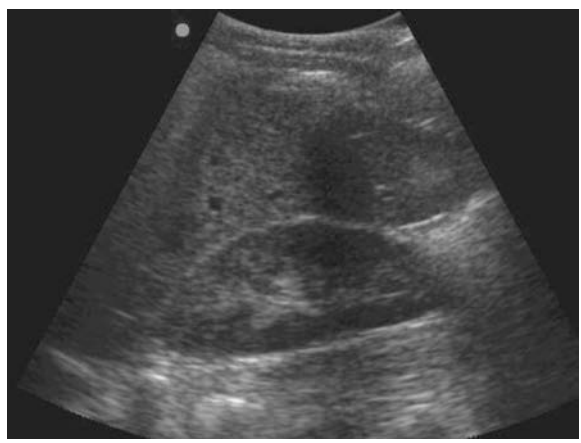


**Figure 2.19**
Normal RUQ.

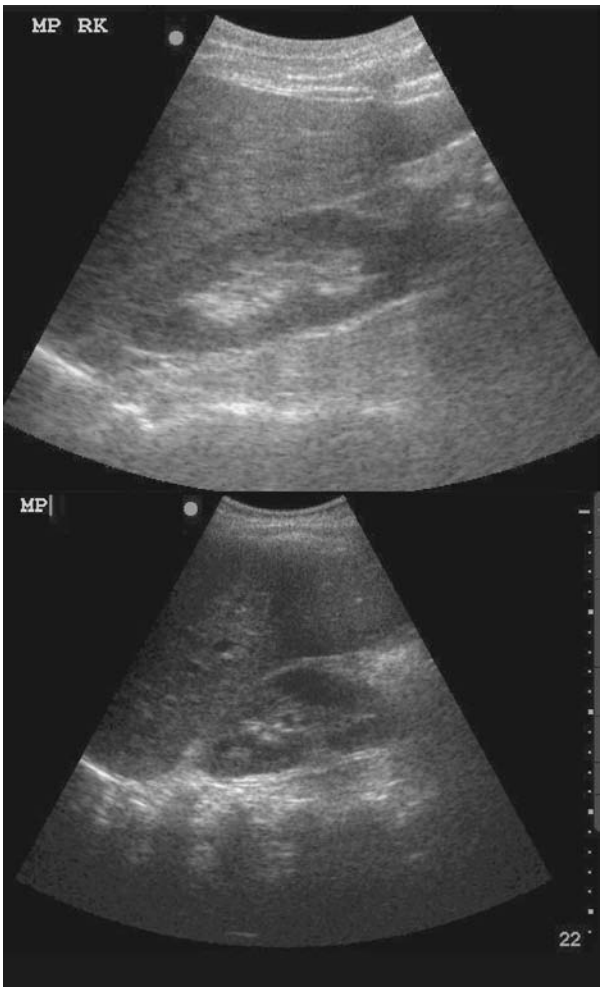



**Figure 2.20**
Two more views of a normal RUQ.

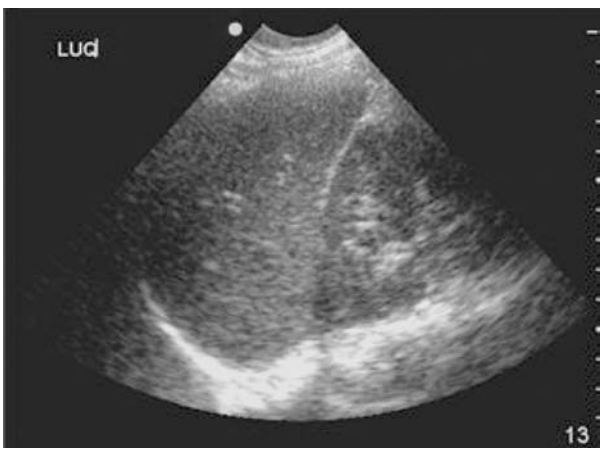



**Figure 2.21**
Normal left upper quadrant.

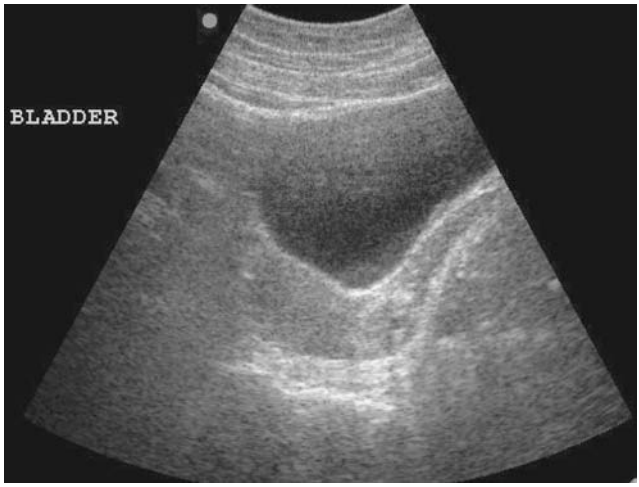



**Figure 2.22**

Normal female suprapubic view (this is a longitudinal view because you see the uterus in its longitudinal orientation and the probe marker is toward the patient's head).

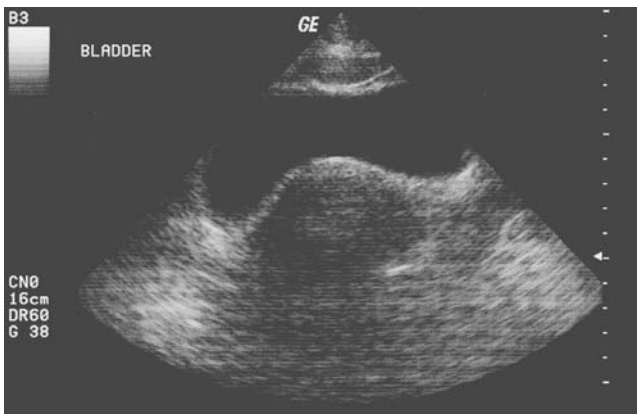



**Figure 2.23**

Normal transverse view of female pelvis.

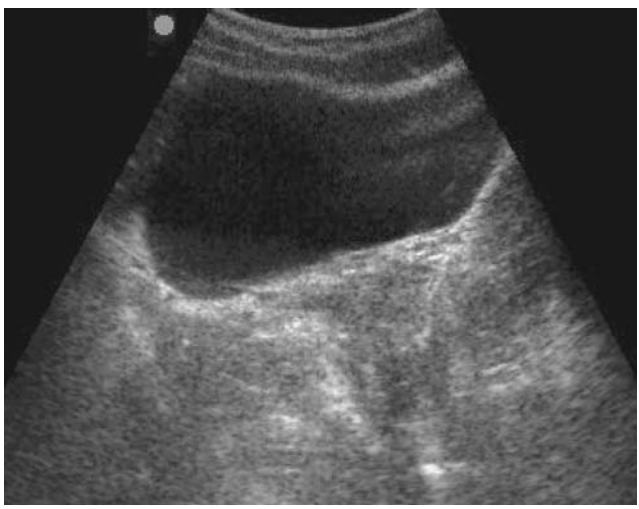


**Figure 2.24**

Normal transverse view of male pelvis.

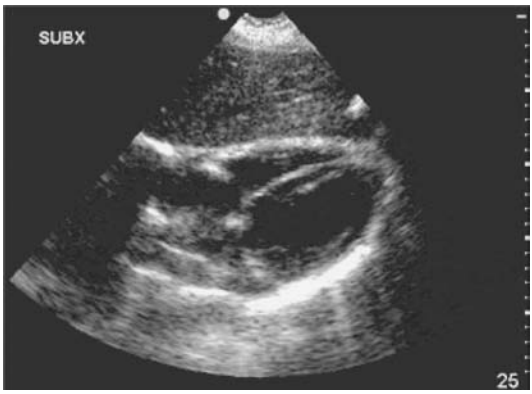



**Figure 2.25**
Normal subxiphoid view.

## Abnormal Images

The following images are examples of abnormal FAST ultrasound scans.

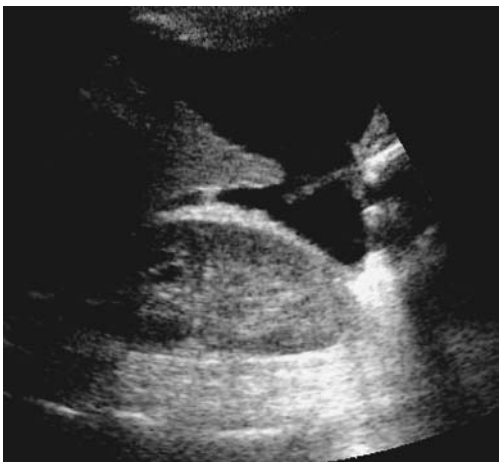


**Figure 2.26**
A large pocket of free fluid seen around liver edge.

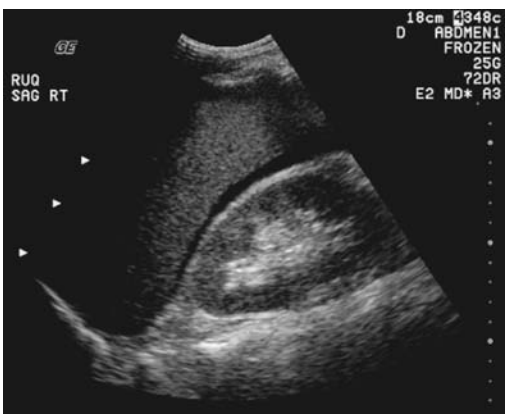



**Figure 2.27**
A stripe of fluid is seen in Morison's pouch. Diaphragm and Gerota's fascia well visualized as hyperechoic bright lines.

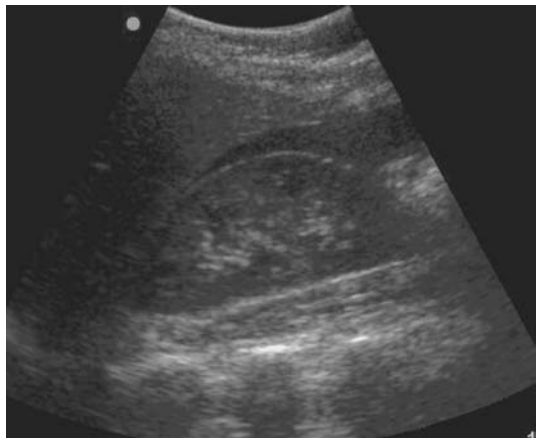


**Figure 2.28**

Fluid is seen more prominently at the inferior pole of the kidney, stressing the importance of this view.

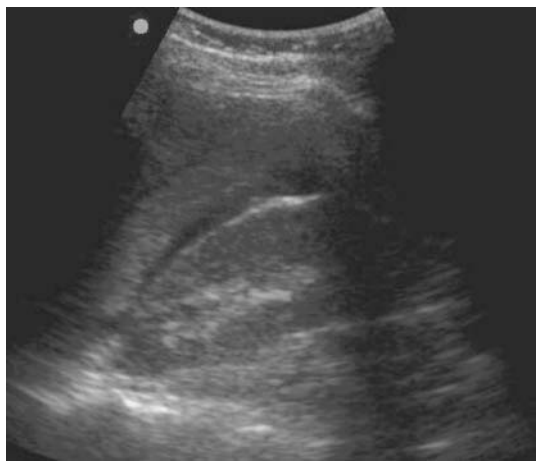


**Figure 2.29**

Fluid in Morison's pouch.

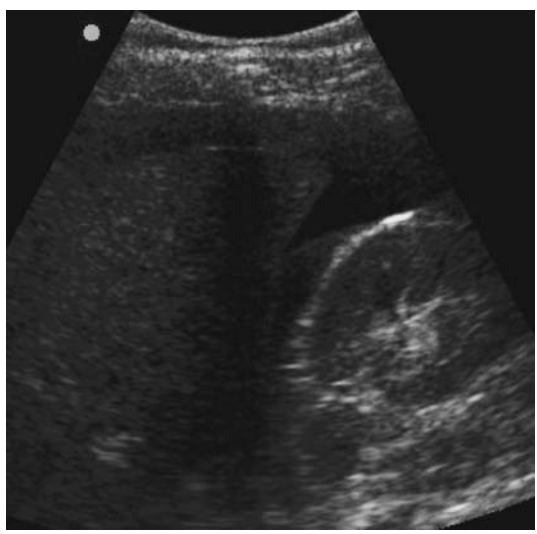


**Figure 2.30**

Fluid around tip of liver and heterogeneous material outside Gerota's fascia in the free fluid pocket suggests clot.

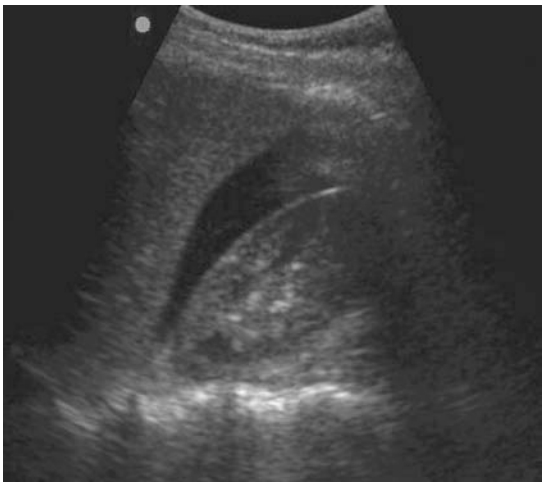


**Figure 2.31**

Large fluid stripe in Morison's pouch and at inferior pole of kidney. Heterogeneous echogenic material suggests clot.

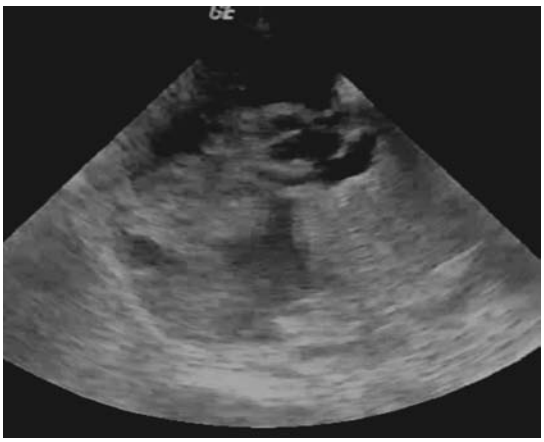


**Figure 2.32**

This is an unusual image in that the fracture of the spleen can be well visualized. In any case, large amounts of free fluid around the spleen are seen. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

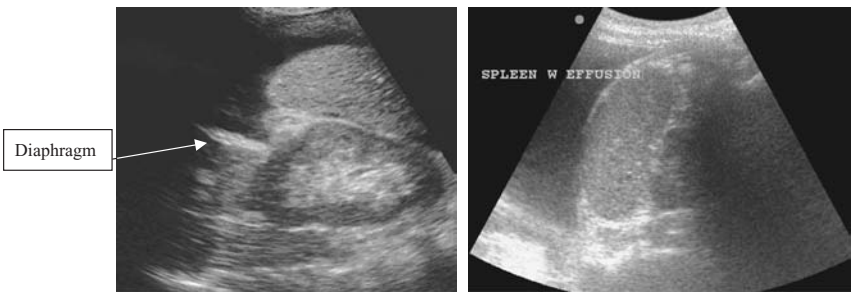



**Figure 2.33**

These images show how important it is to use the diaphragm as a landmark to identify whether fluid is intrathoracic or intraperitoneal. The image on the left shows fluid collecting above the spleen in the subphrenic space below the bright diaphragm before filling the splencrenal recess. The image on the right shows the fluid above the bright hyperechoic diaphragm and so is a pleural effusion.

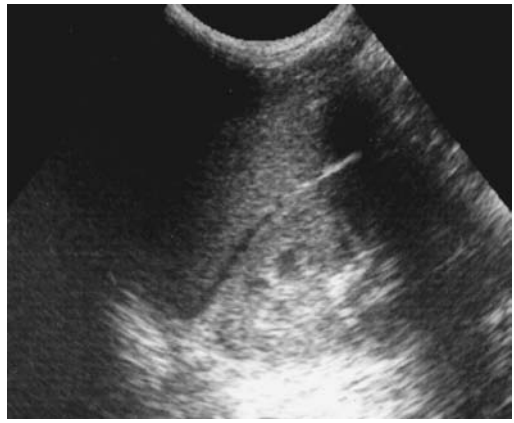


**Figure 2.34**

There is a sliver of free fluid between the spleen and the left kidney.

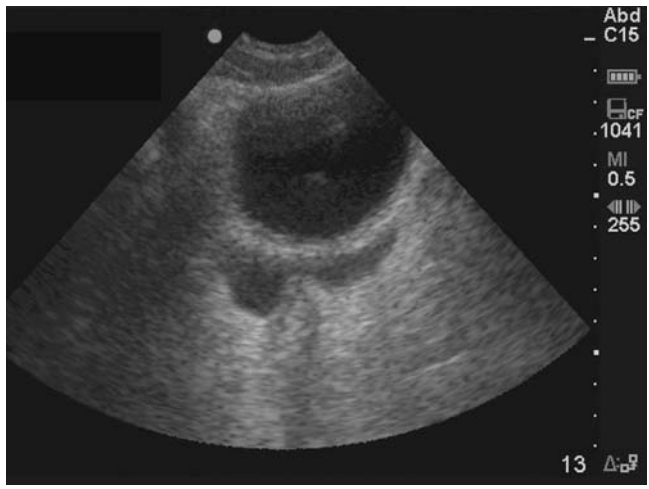



**Figure 2.35**

Fluid is seen outside the bladder wall and tracking into the rectovesicular space.

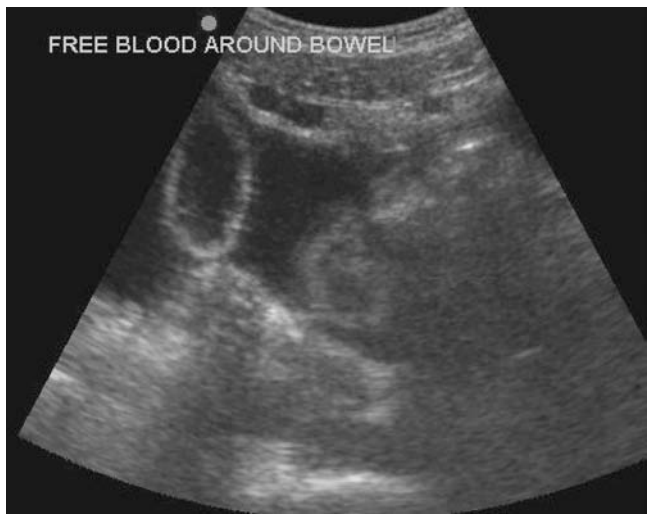



**Figure 2.36**

Bowel loops floating in free fluid in the pelvis.

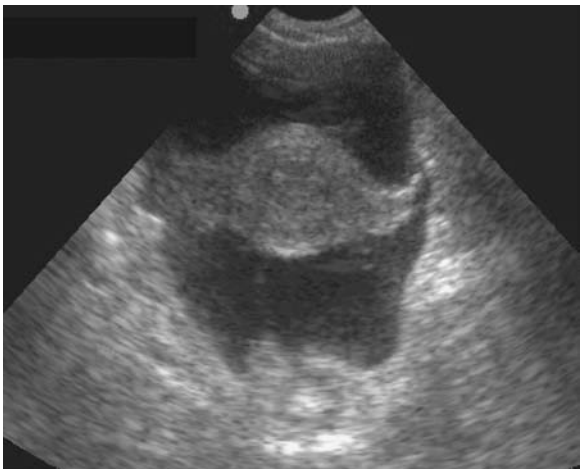


**Figure 2.37**

Free fluid in the pelvis seen surrounding the uterus and anterior to the rectum.

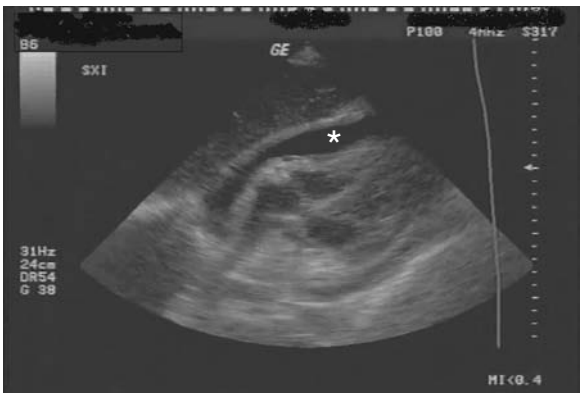



**Figure 2.38**

Fluid (*) is seen here both anteriorly and posteriorly separating the pericardium (bright white line) from myocardium. The right ventricle is also bowed inward, which is concerning for tamponade physiology (see Chapter 3). Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

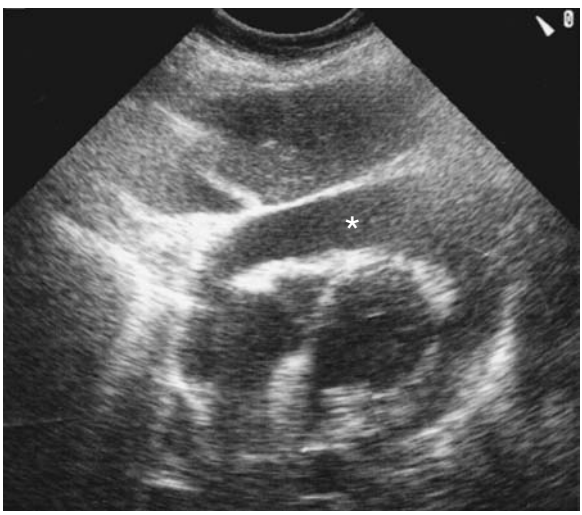



**Figure 2.39**

Free fluid (*) seen completely surrounding the heart (bright white pericardium separated from myocardium by approximately 1 cm of fluid).

## Extended FAST or eFAST

In the normal right upper quadrant and left upper quadrant views of the FAST exam, the diaphragm acts as a strong reflector of ultrasound beams. Therefore, if you can remember the description of the mirror image from Chapter 1, the diaphragm reflects the normal splenic or liver tissue so the "mirror image" is present on both sides of the diaphragm (Figure 2.40). The ability of the eFAST to rapidly and accurately diagnose traumatic hemothoraces has been well documented (22,23). Therefore, if there is fluid in either the right or the left chest, the mirror image is lost above the diaphragm and black fluid is seen instead (Figure 2.41).

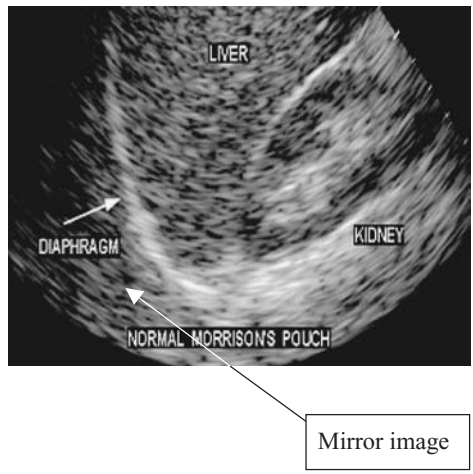



**Figure 2.40**
Mirror image. Liver tissue artifact seen above the diaphragm.

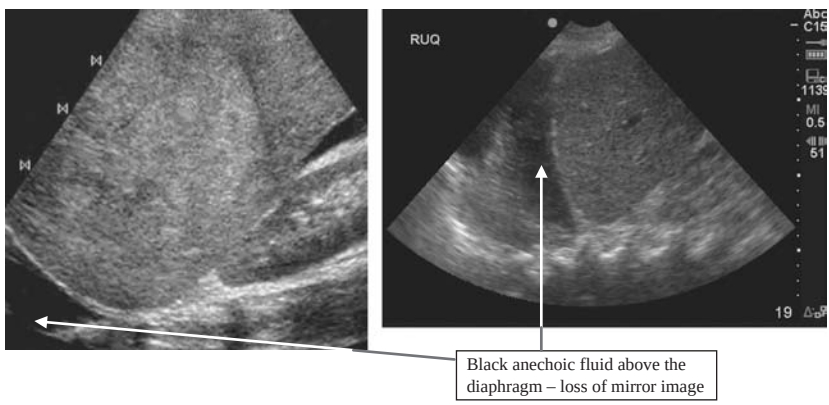



**Figure 2.41**
Loss of mirror image in both images because of fluid in the thoracic cavity.

## Sample Clinical Protocol

While it is important to remember that the FAST exam was introduced as a way to evaluate blunt trauma, it can also be done with penetrating trauma. Although this exam is particularly useful and lifesaving when evaluating penetrating thoracic or cardiac trauma to look for hemopericardium (25,26) (see Chapter 3), it can also be used in evaluating penetrating abdominal trauma if there is clinical concern for abdominal hemorrhage. If the FAST exam is positive in penetrating trauma, similar clinical algorithms to blunt trauma can be followed (see below). It should be remembered, however, that ultrasound is not sensitive in diagnosing specific solid organ injuries. Most penetrating trauma patients, including those with concern for bowel or diaphragmatic injuries, will require CT or exploratory laparotomy to evaluate their injuries further.

Figure 2.42 illustrates the International Consensus Conference recommendations (27).

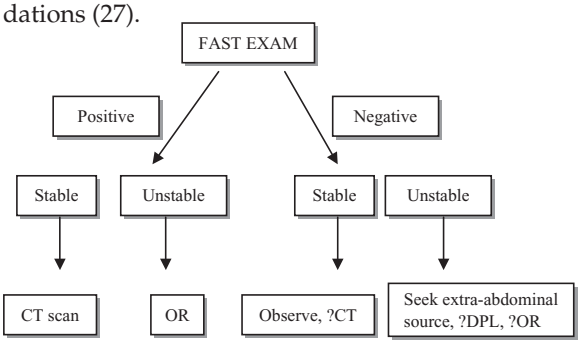



**Figure 2.42**
Consensus FAST protocol. From Scalea et al. (27)

The decision with what to do with negative FAST patients is still somewhat trauma center dependent. In some centers, patients with stable vital signs and a negative FAST exam are observed for 4 hours, have a repeat FAST exam, and are then discharged home if the FAST is still negative. In unstable patients with a negative FAST exam, extraabdominal sources of hypotension must be carefully ruled out (intrathoracic trauma, blood loss from extremity trauma, spinal shock, head injuries). DPL can also be performed if FAST images are not clear or difficult to obtain for technical reasons (subcutaneous air, bowel gas).

## Literature Review

| Reference | Method | Result | Note |
|---|---|---|---|
| Melniker et al. (21) | Randomized trauma patients to US-based pathway vs. trauma evaluations without FAST. | FAST led to more rapid time to OR, fewer CT scans, complications, length of stay, and charges. | Outcomes-based study on use of FAST exam supported positive FAST impact on improving outcomes in almost every clinical parameter evaluated. |

| Reference | Method | Result | Note |
|---|---|---|---|
| Branney et al. (9) | Blinded sonographer at RUQ while DPL performed and 1 L fluid infused. Blinded sonographer recorded at what volume of infused fluid first fluid stripe seen on US. | +FAST at 250 mL minimum. Average was 619 mL. | Identified that minimum detected fluid was probably more than conventional wisdom assumption. |
| Plummer et al. (25) | Penetrating trauma patients randomized to emergency department (ED) echo vs. "standard of care" evaluation (echo called in). | Not only diagnosis and disposition expedited in ED echo group, but there was a survival benefit if patients had ED echo. | Mortality benefit of ED echo in penetrating cardiac injury. |
| Branney et al. (11) | Randomized trauma patients to US-based pathway vs. "standard of care" trauma evaluations (no FAST). | In US-based pathway, DPL use decreased 13%, and CT use decreased 30%. No "significant" injuries missed. Cost savings estimated at $450,000. | First study to note cost savings with implementation of FAST. Also first to document decrease in DPL and CT use. |
| McKenney et al. (10) | Developed and tested FAST score to help predict need for therapeutic laparotomy. Measured depth of fluid in deepest pocket, and 1 point was added for fluid in each of the other areas (4 maximum). | 85% of patients with score >3 required therapeutic laparotomy, whereas 15% of patients with a score $\leq$2 required surgery. | Further define characteristics of +FAST that indicate need for therapeutic laparotomy. More evidence of US benefit over DPL because US predictive value more clinically useful. |
| Scalea et al. (27) | First consensus statement on how to use FAST in clinical algorithm. | NA | Has not been prospectively validated to date. |
| Sisley et al. (22) | Results from initial chest x-ray and chest US compared in 360 trauma patients. | US more sensitive (97.5 vs. 92.5% in 360 patients with 40 effusions) and faster (1.3 vs. 14.2 min) in diagnosing traumatic hemothoraces. | Comparison with gold standard showed ultrasound to be superior for hemothorax diagnosis. |

| Reference | Method | Result | Note |
|---|---|---|---|
| Rowan et al. (24) | Results from chest US compared to chest x-ray and CT scan test results. | 11 PTX in 70 pts: thoracic US detected 11/11, CXR 4/11. | US as sensitive as CT, significantly more sensitive than CXR for PTX diagnosis in trauma patients. |

## Detection of Pneumothorax

Traditionally, the standard test for the initial evaluation of the thorax in trauma patients is the supine chest x-ray. However, supine chest x-rays are notoriously inaccurate when looking for pneumothoraces because air layering anteriorly will be difficult to see. In this context, the sensitivity of ultrasound for diagnosing pneumothorax may be an improvement on the current gold standard (24). This improvement is true not only in trauma but also in many critical care fields of medicine. A review of the literature describes a technique that first identifies the pleural line. A normal ultrasound examination of the lung includes both lung sliding and comet tail artifacts. *Lung sliding* is the back-and-forth movement of the visceral pleural synchronized with respiration, as seen in real-time scanning. Comet tail artifacts occur when the ultrasound beam bounces back and forth between two closely spaced interfaces, causing multiple reverberations to merge and form a *comet tail pattern* or bright line. If a pneumothorax is present, air within the pleural space hinders the propagation of ultrasound waves, thereby preventing the formation of comet tail artifacts and obscuring lung sliding. Therefore, an ultrasound is positive for pneumothorax when lung sliding and comet tail artifacts are *absent*. One advantage of bedside ultrasound is that each patient will have his or her own control because comparing left to right thorax will often help make the diagnosis easier. A second technique uses M mode to visually demonstrate lung sliding or absence of lung sliding (see following images).

## Technique

Using a high-frequency linear transducer (5.0–10.0 MHz), longitudinal scans of the anterior chest wall are obtained with the patient in the supine position (Figure 2.43). Place the transducer over the third or fourth intercostal space anteriorly and in the third to fifth intercostal space in the anterior axillary line. The respiratory expansion of the lung (and thus the amount of sliding) may be greater in the anterior axillary line view. It is also possible to use the same lower-frequency probe (3–5 MHz) that is used for FAST exams. Although the image detail may be somewhat less with the lower-frequency probe, sliding or its absence is still readily detectable.

First, identify the rib shadow. This allows you to locate the intercostal plane. Next, identify the pleural line. This is the hyperechoic line located between and below two ribs. In the normal subject, this pleural line is characterized by lung

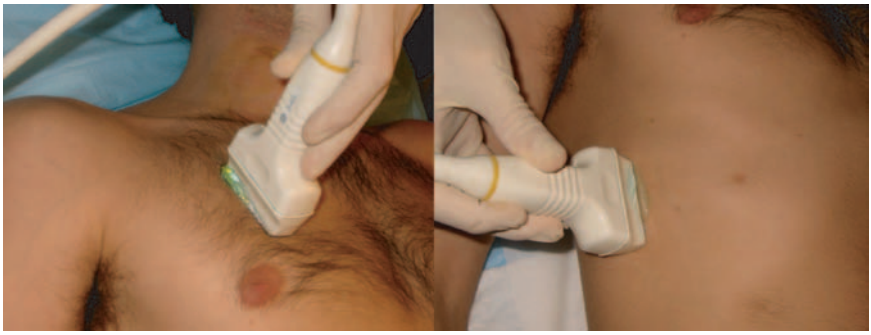


**Figure 2.43**

Left image shows anterior positioning of probe on chest wall. Right image shows anterior axillary line positioning. Greater lung sliding is usually seen with axillary line probe positioning because of greater lung excursion with respirations at this level. However, the anterior position is more sensitive in the supine patient because air layers anteriorly. Courtesy of Dr. Greg Press, University of Texas – Houston, Hermann Memorial Hospital, Houston, Texas.

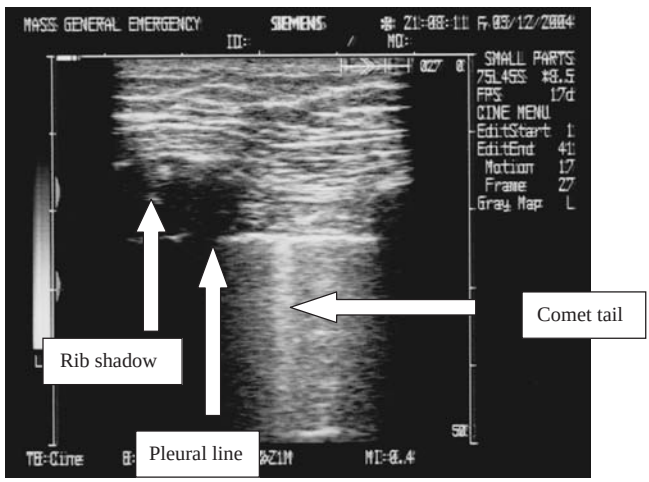



**Figure 2.44**

Longitudinal scan of the anterior chest wall of a normal patient. The "pleural line" and a comet tail artifact are labeled. The normal to-and-fro sliding movement of this pleural line, synchronized with the respiratory cycle, can be observed in real time.

sliding. You should also look for comet tail artifacts as seen in Figure 2.44 and Figure 2.45. Normal lung sliding and the presence of the comet tail artifact rule out pneumothorax with a 100% negative predictive value (Table 2.1).

There are three ways to assess the presence of lung sliding using ultrasound. First, the lung slide can be directly observed in real-time motion using two-dimensional ultrasonography, and images can be saved as video. Second, power Doppler can be used to highlight the motion of the pleura. Positive and negative Doppler images are demonstrated in Figure 2.46. Third, M mode can be used to demonstrate lung sliding on a static image. When using M mode for this technique, follow a line that includes subcutaneous tissue, chest wall musculature, pleura, and lung. In a normal lung, the image obtained using M mode

**Table 2.1** Literature support for US diagnosis of pneumothorax

| Reference | Feature | Performer | Probe | Patients | Standard | Sens | Spec | NP | PP |
|---|---|---|---|---|---|---|---|---|---|
| Blaivas et al. (29) | LS | ED | | 176 blunt trauma | CT | 98 | 99 | 99 | 98 |
| Rowan et al. (24) | LS, CT | Rads | 7.0 MHz | 27 ED trauma getting CT | CT | 100 | 94 | 100 | 92 |
| Dulchavsky et al. (30) | LS, CT | Surg | 4.0 Mhz | 382 trauma | CXR | 94 | 100 | 99.4 | 95 |
| Lichtenstein et al. (31) | LS, CT | ICU | 3.5 MHz | 115 ICU | CXR, CT | 100 | 96.5 | 100 | 89 |
| Lichtenstein et al. (32) | LS | ICU | 3.0 MHz | 111 hemitho-races in ICU | CXR, CT | 95.3 | 91.1 | 100 | 87 |

(LS = lung sliding, CT = comet tail, ED = emergency department, ICU = intensivist, Sens = sensitivity, Spec = specificity, NP = negative predictive value, PP = positive predictive value, CT = computed tomography).

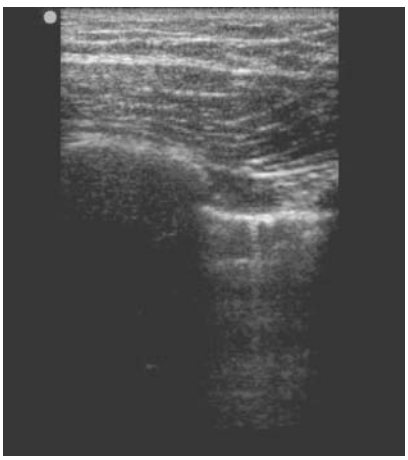


**Figure 2.45**
Here you can see the rib shadow, pleural line, and comet tail artifact of a normal lung image.

should demonstrate smooth lines superficially (because the chest wall should not move much with respiration in this view). Deep to the pleura, the sliding lung will produce enough motion artifact to create a rougher, grainier image. The interface between the smooth lines of the chest wall and the rough texture of the moving lung has been described as "waves on a beach" or "seashore" image (Figure 2.47). In the case of pneumothorax, no motion will be visible in the chest wall or lung. Thus, the lines will be uniformly straight and smooth. This has been called the "barcode" sign (Figure 2.48) (28).

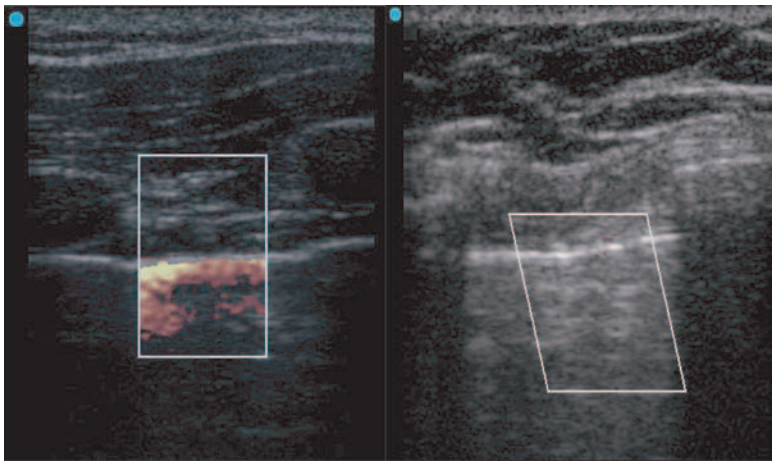


**Figure 2.46**

Presence of color indicates movement or sliding and thus normal lung when using power Doppler.

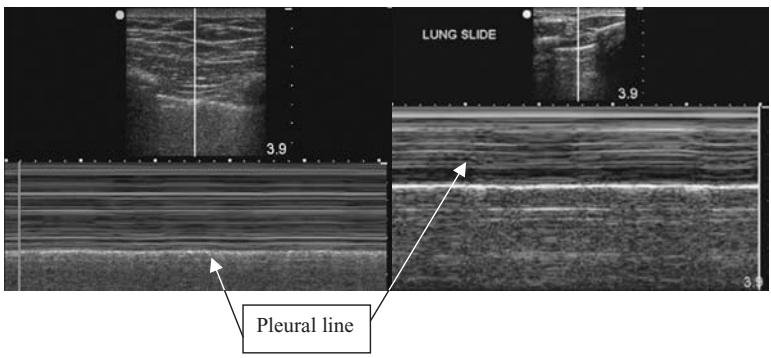



**Figure 2.47**

Both images show the “seashore” or normal lung. The pleural line in both marks a difference in texture above and below (moving lung below the pleura).

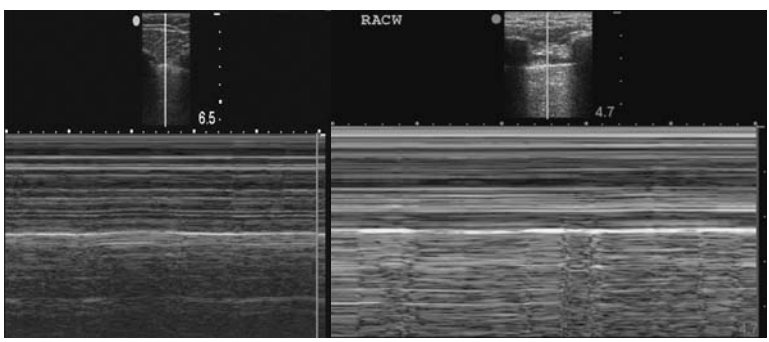



**Figure 2.48**

Both images show the “barcode” sign or the same texture above and below the pleural line.

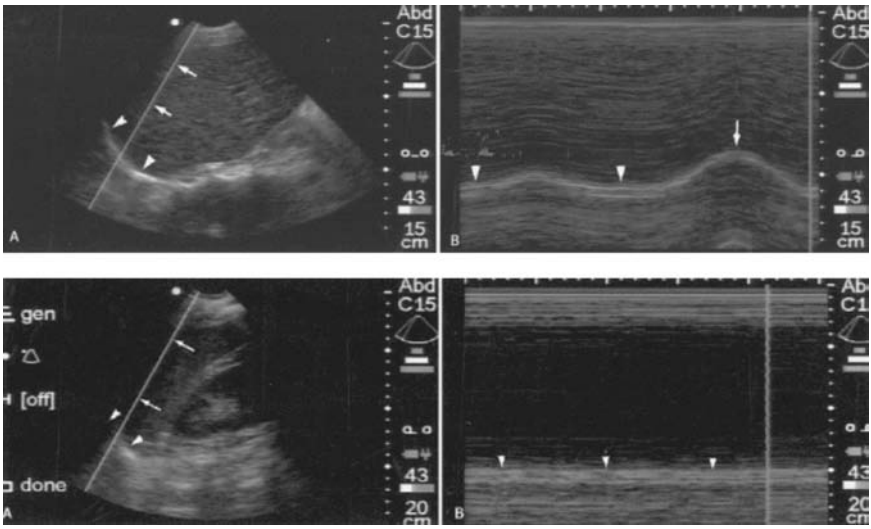



**Figure 2.49**

The top image demonstrates normal diaphragmatic movement in M-mode during the respiratory cycle. The bottom image illustrates the loss of movement in the setting of diaphragmatic injury. From Blaivas et al (30). Reprinted with permission from Dr. Michael Blaivas, Professor of Emergency Medicine, Northside Hospital Forsyth, Atlanta, Georgia.

## New Directions

As promised, each chapter will try to stimulate creative thinking about new diagnostic applications for bedside ultrasound among our readers. One interesting idea is the concept of using M mode to diagnose diaphragmatic injury. Diaphragmatic injuries are notoriously difficult to diagnose; even CT scans are often fooled. The gold standard is usually laparoscopy or laparotomy to directly visualize the diaphragm. Blaivas et al (33). describe using M mode to show whether the diaphragm maintains its respiratory movement/contraction or whether it becomes fixed after injury. Cases where fixed M mode images correlate with diaphragmatic injury are reported (Figure 2.49) (33).

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# 3 Echocardiography

## Introduction

One of the most exciting applications for bedside ultrasound is echocardiography. Differentiating between pulseless electrical activity (PEA) and asystole in patients with no pulse, identifying pericardial effusions in hypotensive patients, and estimating volume status or global cardiac function in hypotensive patients are all applications for bedside echocardiography that can make a difference in patient treatment and outcome. However, it is important to note that this manual is not meant to teach a noncardiologist to be an echocardiographer. Bedside echocardiography is a tool to be used by clinical practitioners who need quick answers to specific questions about cardiac function in critically ill patients. Any good physician must recognize the limitations of his or her knowledge and skill; in cases where ambiguity remains after bedside ultrasonography, follow-up testing should be consistent with normal practice patterns (1).

This chapter also reviews how to make estimations of global cardiac function and how to perform estimations of volume status by evaluating inferior vena cava (IVC) respiratory variation and collapse. Finally, images of a dilated right ventricle are reviewed so that in appropriate clinical settings, support for the diagnosis of pulmonary embolus can be made.

Echocardiography is essential in looking for wall motion abnormalities in ischemic heart disease and in evaluating valvular cardiac disease, but these applications can be complicated and require more extensive training. Again, knowing the limitations of bedside ultrasonography is essential for practicing safely.

## Focused Questions for Echocardiography

Two distinct applications are considered primary indications for emergency department echocardiography and also have a role in other areas of critical care medicine:

1. Is there a pericardial effusion?
2. Is cardiac activity present?

For the novice sonographer, assessing for cardiac activity and pericardial effusion can alter management and impact patient care. These should be the foundation on which further cardiac assessment is built.

## Anatomy

Because the heart lies obliquely in the chest, standard positional nomenclature (e.g., sagittal and coronal) is not useful. Instead, there are standard planes commonly used to visualize key cardiac structures, and these provide the basis for a complete exam. Commonly used planes include (1) the long axis, which "cuts" the heart along its long axis from the atria to the apex; and (2) the short axis, which cuts a cross-section from anterior to posterior.

There are common probe positions used to view these planes. These positions have been selected to avoid artifacts from rib shadows or lung:

- Parasternal position
- Subxiphoid position
- Apical position

By using these positions (or windows), one can obtain common views (or planes) of the heart that are comparable to those used by echocardiographers.

Most clinical applications can be supported by using four basic sonographic views of the heart:

- Subcostal or subxiphoid four-chamber view
- Parasternal long axis view
- Parasternal short axis view
- Apical four-chamber view

When learning bedside echocardiography (Figure 3.1), the most important concept to remember is that the heart lies in the chest at somewhat of an

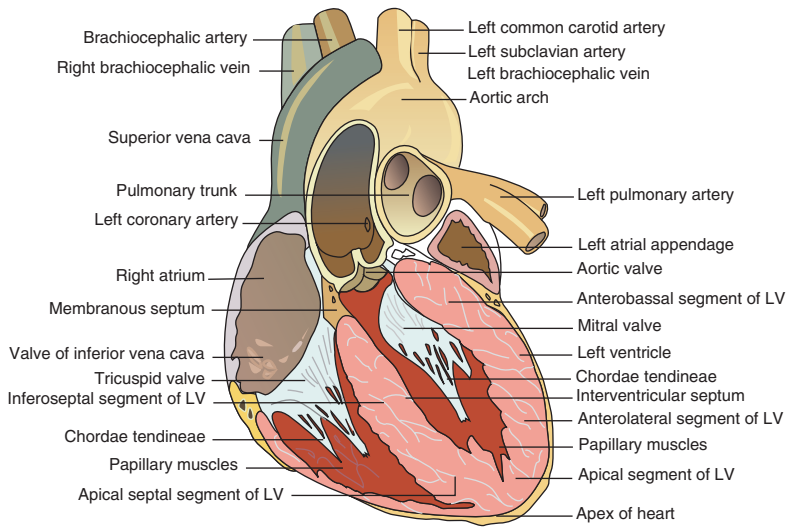


**Figure 3.1**
Anatomy of the heart.

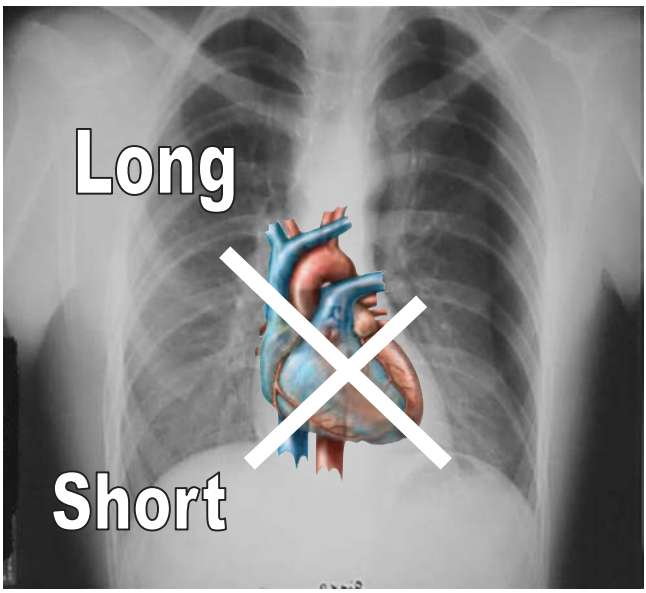


**Figure 3.2**
Position of the heart in the thoracic cavity. Courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

oblique angle, with the apex pointing toward the left hip (Figure 3.2). The right ventricle in the majority of patients will be more anterior (closer to the anterior chest wall) than the left ventricle because of the normal anatomic rotation of the heart. This means that for most imaging, the right ventricle will be more anterior or closer to the probe than the left ventricle. The other obvious anatomic difference between the left and right ventricle is that the left ventricle is a high-pressure system with thicker myocardium, while the right ventricle is a lower pressure system and thus in normal physiology the walls of the right ventricle are much thinner. Of course, this normal appearance is changed with certain types of cardiac pathology, but it is a good place to begin.

## Technique

Historically, echocardiography adopted standard views where the left side of the heart was portrayed on the right side of the ultrasound screen. Although this is reversed from the orientation for abdominal imaging, it is in common use and is described here. There are two ways in which such cardiac-oriented images may be obtained. First, continue to place the probe marker toward the patient's *right* side, but image in "cardiac mode" on the ultrasound machine or flip the screen image 180 degrees (which button to press depends on the machine manufacturer). Alternately, when imaging the heart, hold the probe with the marker facing the patient's *left* side (this option is preferred by the authors because it is faster).

The second technique is described here. This allows the sonographer to keep the settings on the machine the same to avoid confusion. However, if

the first option is preferred, just invert the probe positions described here by 180 degrees.

## Probe Selection

The probe used for echocardiography is a curvilinear probe – ideally with the smallest possible footprint, useful in imaging between ribs. It is usually a lower-frequency probe with ranges between 2 and 5 MHz. Some machines also have cardiac presets in their setup menus that help the machine optimize digital image processing for cardiac imaging.

## Views

Multiple ultrasound views are used to assess the heart at the bedside. The two views most commonly used by the noncardiologist to look for contractility and evaluate for pericardial effusion are the subxiphoid four-chamber view and the left parasternal view. We review these two positions first, and then supplement with parasternal short and apical four-chamber views to give the bedside ultrasonographer multiple options for evaluating the heart. Only the subxiphoid and apical views allow for four-chamber visualization and comparison of right and left ventricular cavity size, however.

### *Subcostal/Subxiphoid View*

The subxiphoid probe position uses the liver as an acoustic window through which the heart is well visualized. The transducer probe should be placed in the subxiphoid position (Figure 3.3). Aim toward the left shoulder and place the probe at a 15-degree angle to the chest wall. The probe indicator should be pointing toward the patient's right (Figure 3.4). Many novices place the probe at too steep an angle, and thus the ultrasound beam being generated is too steep – that is, it is not projecting toward the left chest cavity where the heart lies. In some people, the probe is almost flat against the abdominal wall. Because the beam is transmitted over a fairly long distance (usually 7–10 cm), it is best to start with the screen at maximum depth so the longest distance is visualized on the screen. Once the heart is identified, the depth can be adjusted to enlarge the image as appropriate.

The right ventricle is closest to the probe and so will be most superior on the ultrasound screen. The bright white pericardium is seen here and is flush up against the gray myocardium, indicating no effusion is present (Figure 3.5).

The subxiphoid four-chamber view gives a good view of the right ventricle, which is often used to look for a pericardial effusion. It is also the standard view for cardiac evaluation during the FAST exam.

### *Left Parasternal Long Axis View*

Assuming the long axis of the heart to be from the patient's right shoulder to the left hip, the transducer probe should be placed in the third or fourth intercostal space, immediately left of the sternum (Figure 3.6). The probe

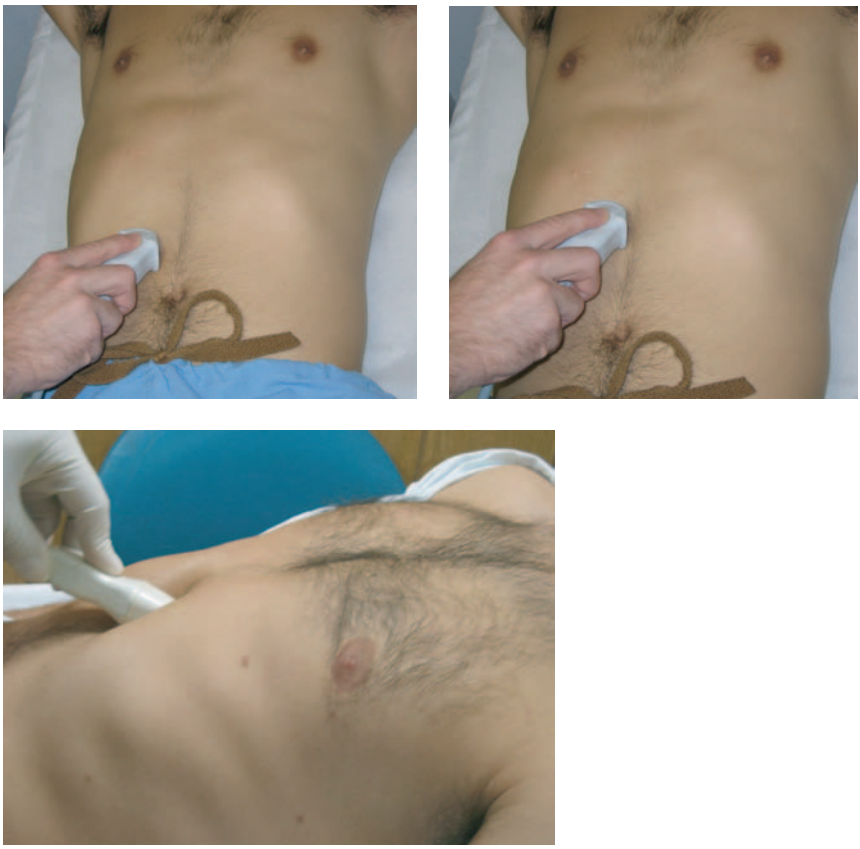

**Figure 3.3**

Probe positioning for subxiphoid view. Begin with the probe several centimeters inferior to the xiphoid process (*left*) and slide the probe cephalad until it "nestles" in the subxiphoid area (*right*).

indicator should be pointing toward the 5 o'clock position or toward the patient's left hip (Figure 3.7). In this position, the depth adjuster on the machine does not need to be as great because the structures of interest should be fairly close to the probe.

The parasternal view is often easier in obese patients, although it can be challenging in patients with significant pulmonary disease. Again, the right ventricle will be the chamber closest to the top of the screen because it is closest to the probe (Figure 3.8).

Most important, the parasternal long view is the primary view that can help distinguish pleural from pericardial effusions. Large pleural effusions can appear to surround the heart, but they will taper to the descending aorta, which you can often see in the parasternal view; pericardial effusions will cross anterior to the descending aorta. This is because the pleura will insert where the descending aorta travels through the thoracic cavity. The pericardium is

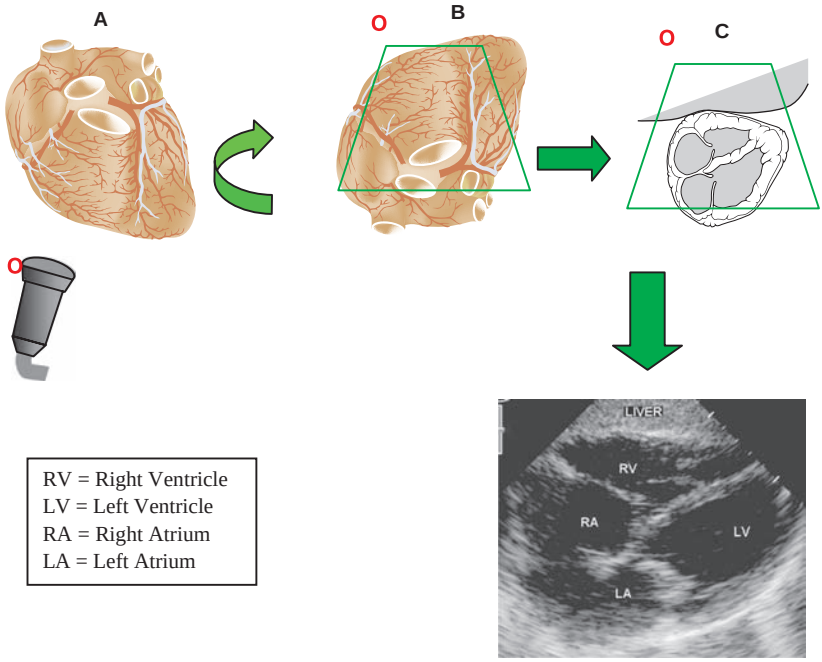


**Figure 3.4**
Orientation of probe and image (probe marker noted with a circle).

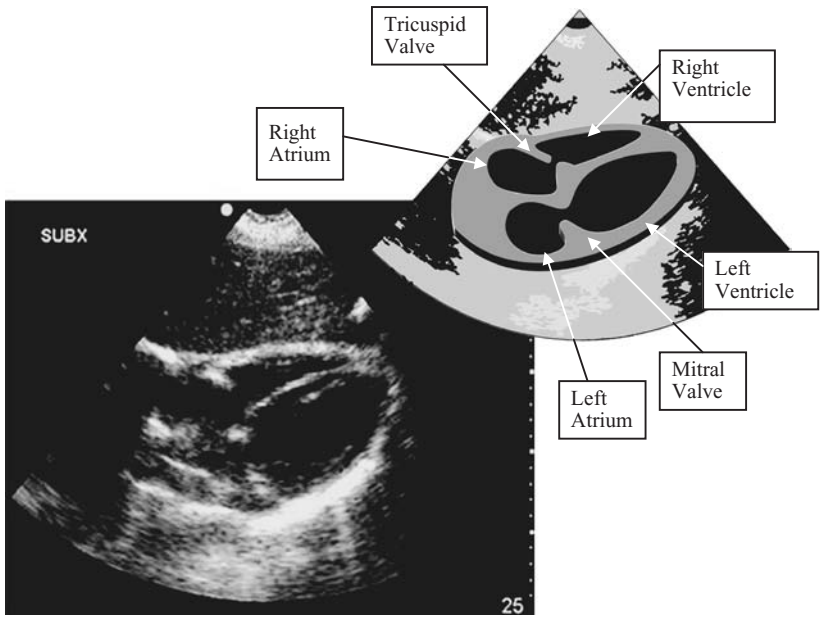


**Figure 3.5**
Cartoon of subxiphoid view with corresponding anatomy as visualized by ultrasound.

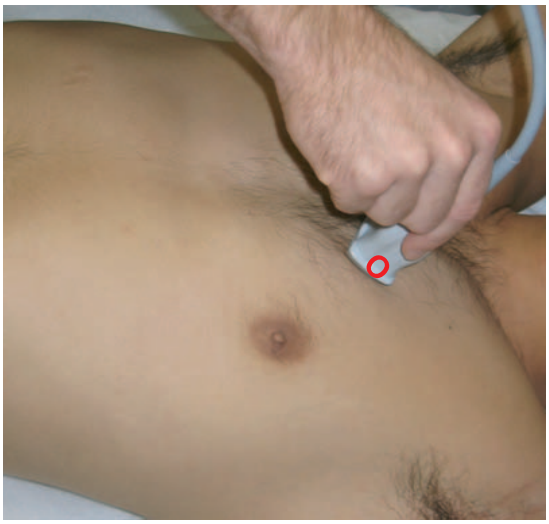

**Figure 3.6**
Probe positioning for parasternal long view.

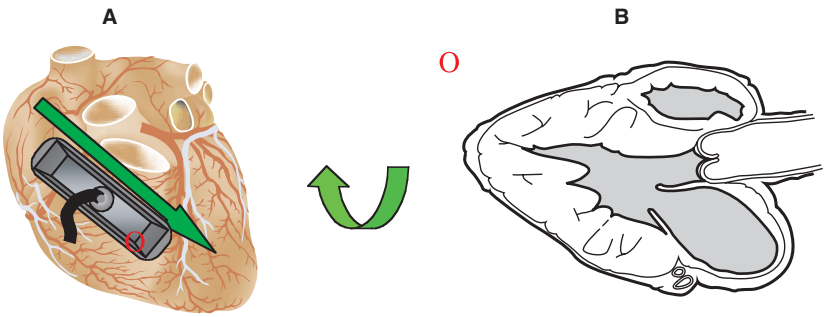


**Figure 3.7**
Orientation of probe (probe marker direction shown by red circle) and corresponding image orientation in parasternal long view.

a self-contained space that will cross the midline. In both Figure 3.9 and Figure 3.10, the pericardium is flush up against the myocardium, and there is no effusion.

### *Left Parasternal Short Axis View*

Assuming the short axis to be from the patient's left shoulder to the right hip, the transducer probe should be placed in the third or fourth intercostal space, immediately left of the sternum (Figure 3.11). If the parasternal long axis view has already been obtained, you can simply rotate the transducer 90 degrees clockwise toward the patient's right hip to gain the short axis view (Figure 3.12). By sliding the probe toward the right shoulder or toward the left hip, the ultrasonographer can slice the short axis at different cross-sections – usually, this view visualizes the mitral valve in cross section, but by sliding

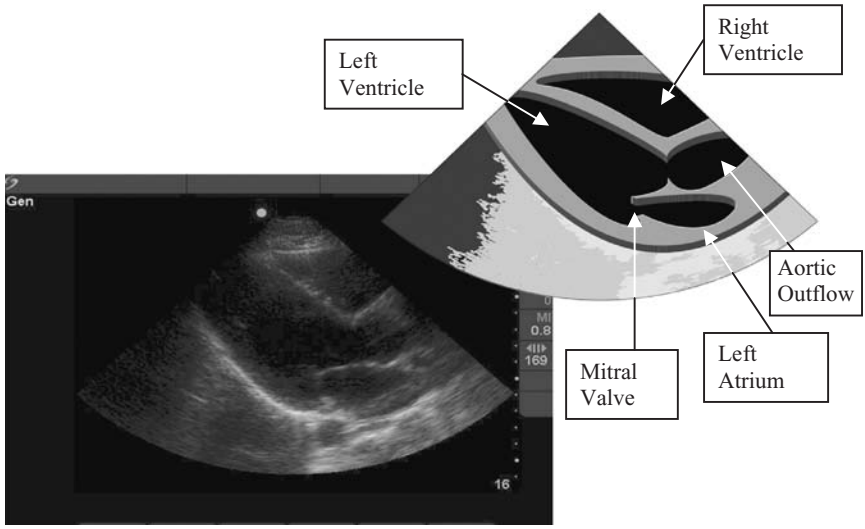


**Figure 3.8**

Cartoon of parasternal long view with corresponding anatomy as visualized by ultrasound.

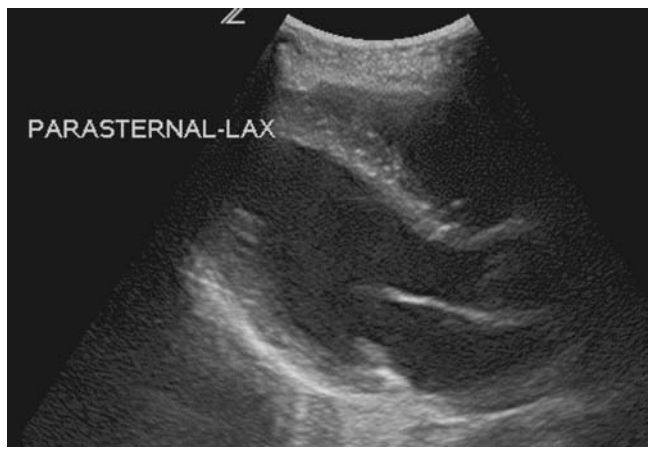


**Figure 3.9**

Normal parasternal long view with no pericardial effusion and open mitral valve leaflets.

toward the right shoulder the aortic valve can be seen, or by sliding to the left hip, more focused images of the heart's apex can be seen (Figure 3.13).

### *Apical Four-Chamber View*

This window is obtained at the apex of the heart, which is usually located along the T4–5 level or nipple line. If possible, rotate the patient onto his or her left side to reduce any lung artifact and to bring the heart closer to the anterior chest wall. Position the transducer probe at the patient's point of maximal impulse (PMI) – or about the fifth intercostal space – aiming toward the patient's right shoulder (Figure 3.14). The probe indicator should be pointed toward the patient's right (Figure 3.15).

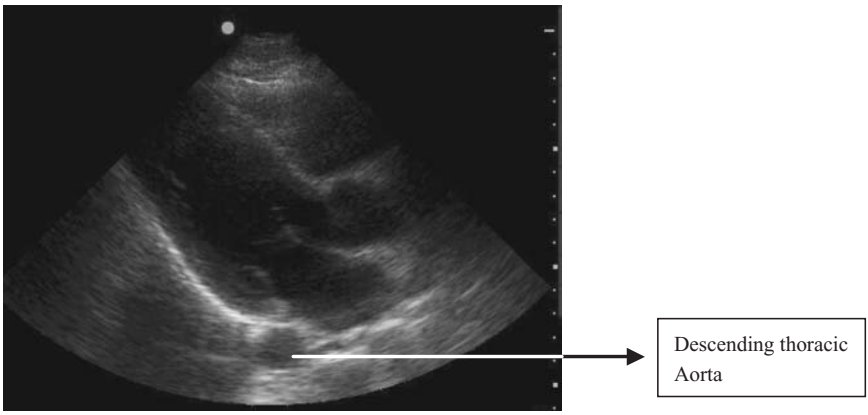


**Figure 3.10**
Normal parasternal long view with view of descending thoracic aorta and no pericardial effusion.

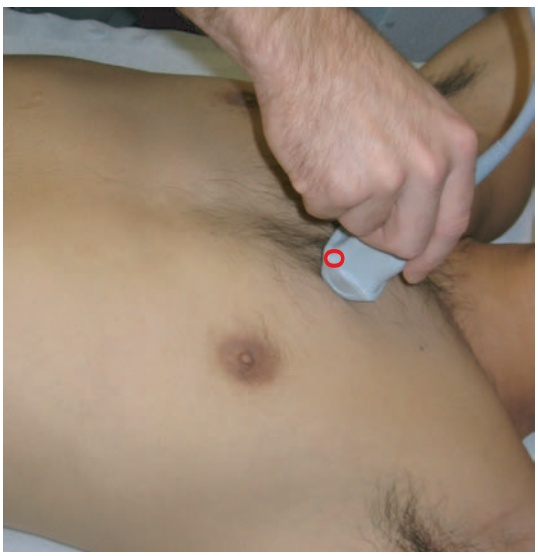

**Figure 3.11**
Probe position for short axis view.

This is an important view because it gives you information about the relative dimensions of the left and right ventricle (Figure 3.16). An important rule of thumb is that the ventricular diameter ratio of the right ventricle to left ventricle is <0.7 – that is, the width from myocardial inner wall to septal inner wall of the right ventricle is about half that of the left ventricle. Although a RV/LV ratio of >0.7 indicates a dilated right ventricle, many authors use a ratio of >1:1 to indicate a pathologically dilated RV (2). Abnormal movement

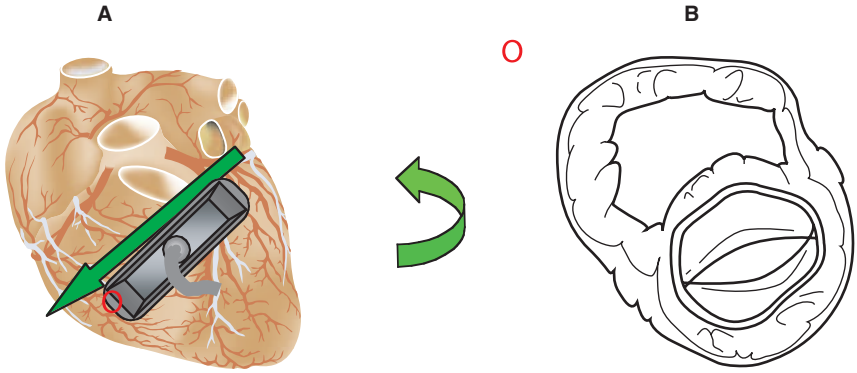


**Figure 3.12**

Orientation of probe (probe marker direction shown by red circle) and corresponding image orientation in parasternal short view.

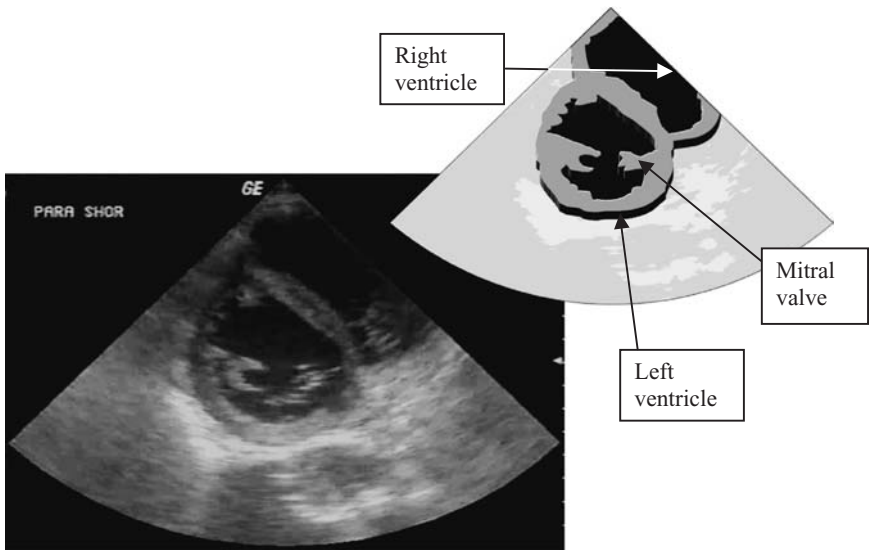


**Figure 3.13**

Cartoon of parasternal short view and corresponding anatomy as visualized by ultrasound.

of the septum away from the right ventricle during diastole indicates increased right ventricular pressures. Normally the right ventricle is a low-pressure system, and therefore, relaxation would mean the septum would bow away from the higher-pressure left ventricle. Both this abnormal septal movement and increased right ventricular size are evidence of right ventricular dysfunction (2). For the bedside echocardiographer, these findings are only helpful in the right clinical setting, i.e., critically ill patients. However, if the clinical suspicion for pulmonary embolus is high and these findings are seen, this may help support the decision for lysis in critical patients in the right clinical setting (3).

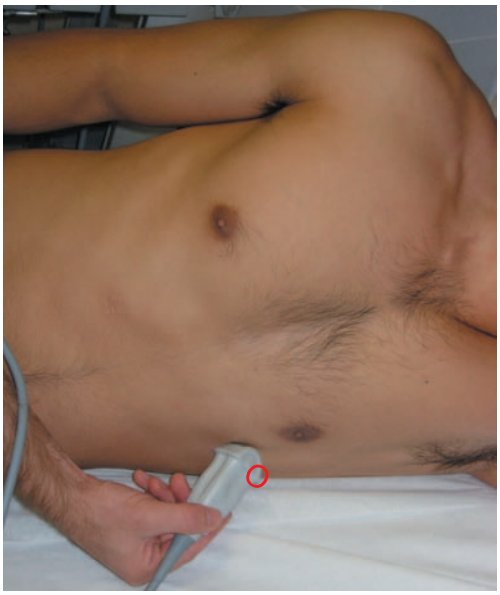

**Figure 3.14**

Probe positioning in apical four-chamber view. Note that the patient is placed in the left lateral decubitus position whenever possible. This improves the quality of all cardiac views but is often the *only* position in which an adequate apical four-chamber view can be obtained.

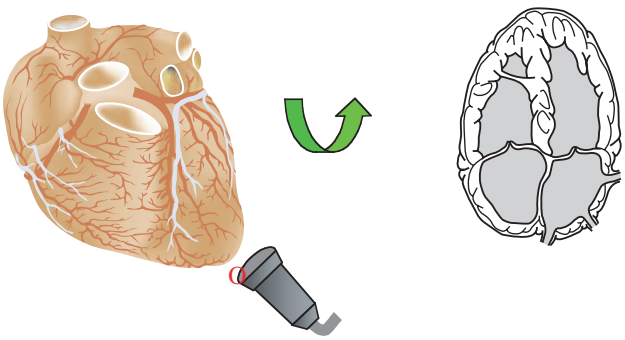

**Figure 3.15**

Orientation of probe (probe marker direction shown by red circle) and corresponding image orientation in apical four-chamber view.

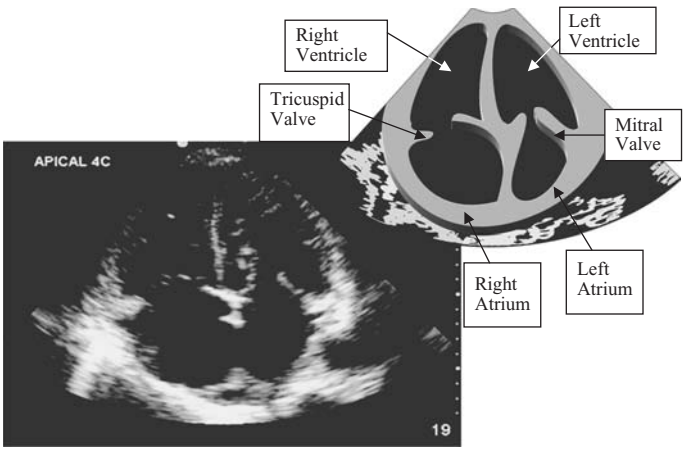


**Figure 3.16**

Cartoon of apical four-chamber view and corresponding anatomy as visualized by ultrasound.

# Scanning Tips

## Trouble with the Subcostal Four-Chamber View

*Can't see anything recognizable?*

- Try increasing the depth to its maximal level to make sure the beam is reaching the part of the thoracic cavity containing the heart.
- Flatten the probe on the abdominal wall to make sure the beam is angling toward the left thoracic cavity.
- Slide the probe over to the right to try using the liver as an acoustic window and to get away from the stomach, which may be scattering the sound waves.
- Have the patient bend his or her knees if possible. This helps relax the abdominal wall muscles and can sometimes make visualization easier.

## Trouble with the Parasternal Long Axis View

*Rib shadow in the way?*

- Try angling the probe obliquely to sneak through the intercostal space.

*Can't see a recognizable image?*

- Try sliding the probe along the third or fourth intercostal space toward and away from the sternum. Occasionally, the long axis view is not adjacent to the sternum but more in the middle of the thoracic cavity.

## Trouble with the Parasternal Short Axis View

*Can't find the heart?*

- Try sliding the probe in the intercostal space toward and away from the sternum. Try angling the probe obliquely as well.
- If the patient can sit forward or be positioned in the left lateral decubitus position, the heart will be brought forward in the chest and will be closer to the probe to make for easier scanning.

## Trouble with the Apical Four-Chamber View

*Can't find the heart?*

- This can be the trickiest view to find, and sometimes sliding the probe around where you think the PMI might be will result in a recognizable image popping into view.
- If the patient can sit forward or be positioned in the left lateral decubitus position, the heart will be brought forward in the chest and will be closer to the probe to make for easier scanning.

## Normal Images

The following images are examples of normal cardiac ultrasound scans.

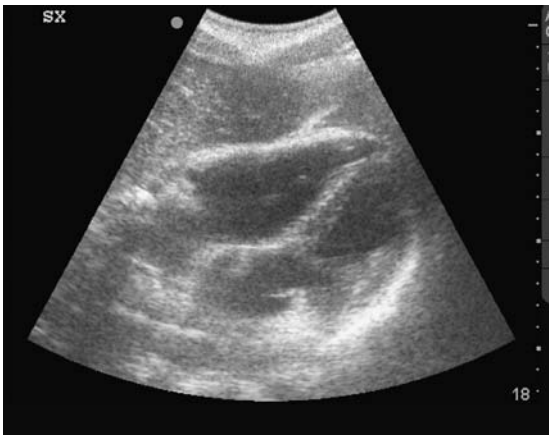


**Figure 3.17**
Normal subxiphoid four-chamber view.

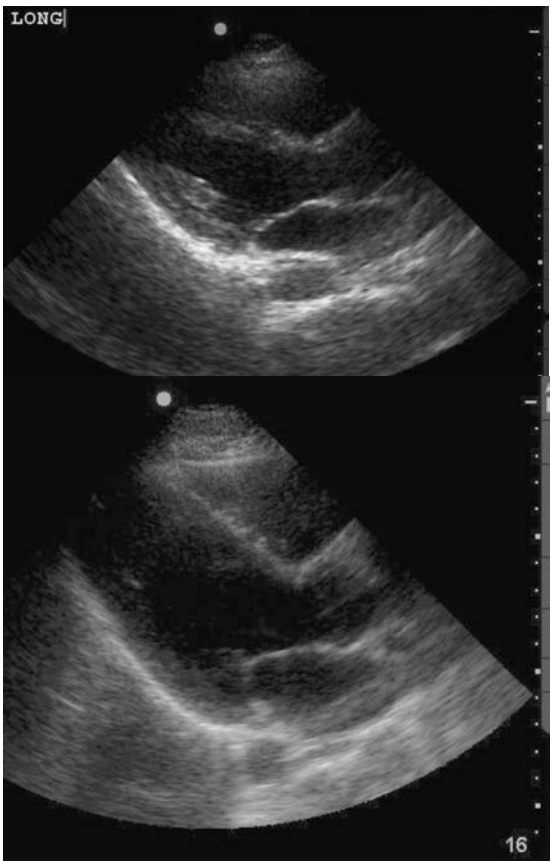


**Figure 3.18**
Two normal parasternal long axis views.

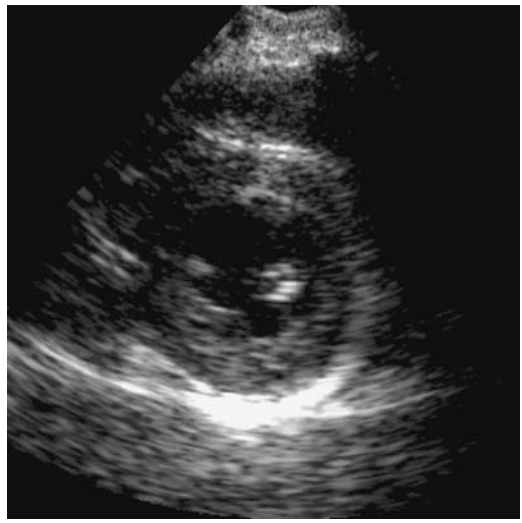

**Figure 3.19**
Normal parasternal short axis view.

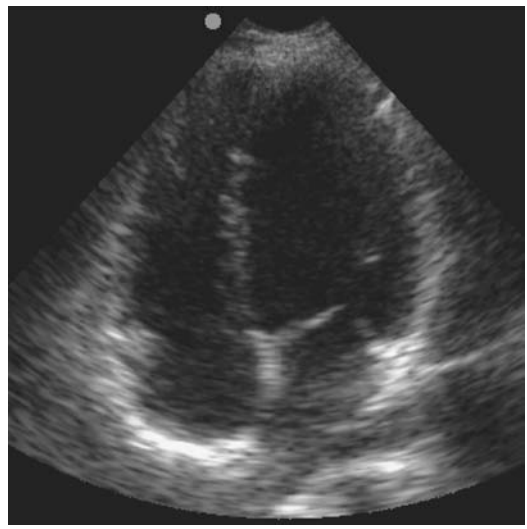

**Figure 3.20**
Normal apical four-chamber view. Note that the right ventricle diameter is smaller than the left, which is normal.

# Abnormal Images

## Pericardial Fluid

Pericardial effusions are defined as the presence of fluid in the pericardial space. They can be caused by a variety of local and systemic disorders or trauma, or they can be idiopathic. They can be acute or chronic, and the time course of development has a great impact on the patient's symptoms.

The pericardium itself is a dense, fibrous sac that completely encircles the heart and a few centimeters of the aorta and pulmonary artery. The dense

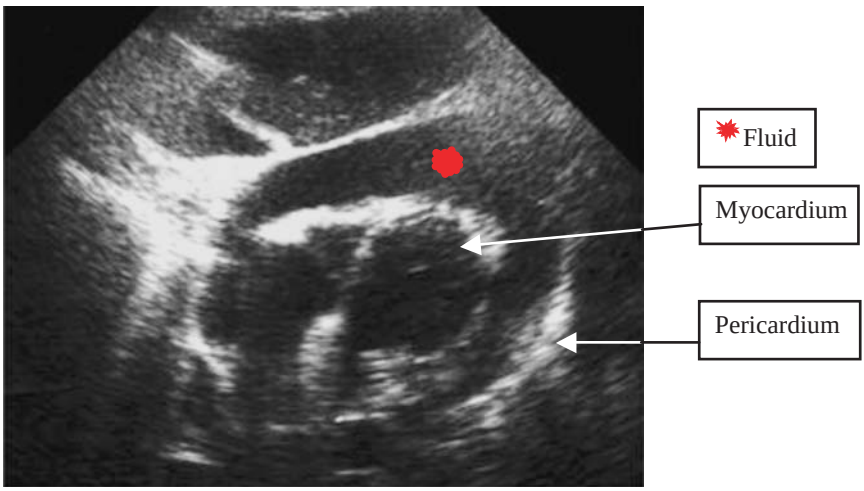


**Figure 3.21**

The black stripe separating the pericardium from the myocardium is the surrounding pericardial effusion.

parietal pericardial tissue is highly echogenic (looks white on ultrasound) and is recognized both anteriorly and posteriorly as the sonographic border of the cardiac image. A pericardial effusion is characterized on ultrasound by an anechoic (black) fluid collection between the visceral pericardium and the parietal pericardium (Figure 3.21) – keeping in mind that the visceral pericardium is not seen by transthoracic echocardiography. Therefore, a pericardial effusion appears as a fluid collection that separates the bright white, highly reflective parietal pericardium from the heterogenous gray myocardium.

If the fluid has pus, blood mixed with fibrin, or is malignant, it can appear echogenic or have a gray appearance. Although this can make the diagnosis more challenging, in real time this "gray" appearance is swirling in a pocket of black fluid that separates the parietal pericardium from the myocardium.

In certain clinical scenarios, pericardial fluid volumes of up to 50 cc can be physiologic. Small effusions are usually located posterior and inferior to the left ventricle. Moderate effusions extend toward the apex of the heart, and large effusions circumscribe the heart. Most textbooks define a moderate effusion as an echofree pericardial space (anterior plus posterior) of 10 to 20 mm during diastole and a large effusion as an echofree space more than 20 mm (4).

Occasionally, either intraabdominal fluid or pleural effusions may be confused with pericardial effusions. Therefore, it is absolutely necessary to visualize the hyperechoic image of the pericardium to ensure that the anechoic fluid is indeed intrapericardial. In addition, when visualizing the descending thoracic aorta via a parasternal long axis window, one will observe that pleural effusions do not cross the aorta, whereas pericardial effusions will. This

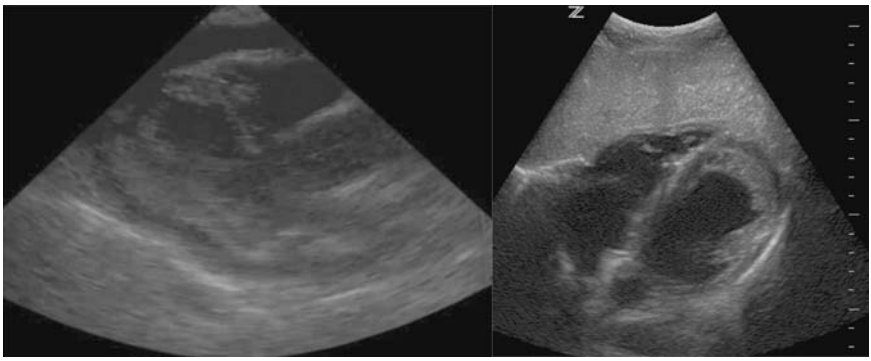

**Figure 3.22**

Two examples of pericardial fluid – the image on the left is a parasternal long axis view, and the image on the right is a subcostal four-chamber view.

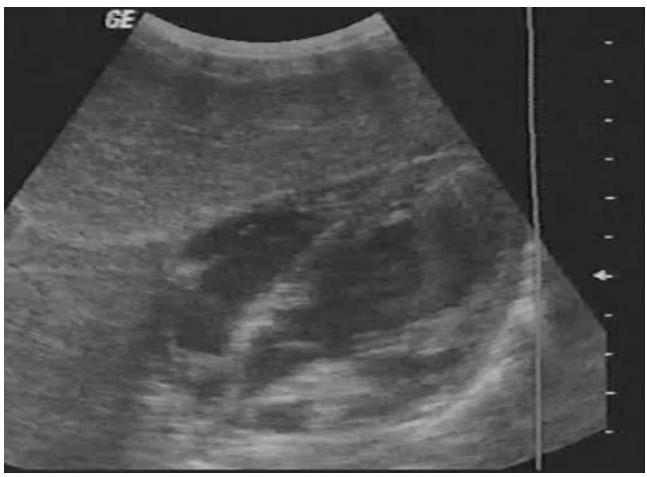


**Figure 3.23**

This is a normal subxiphoid view of the heart, the pericardium is flush up against the myocardium, and there is no black fluid stripe seen around the heart. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

makes anatomic sense because pleural effusions will stop at the insertion of the pleura, whereas pericardial effusions will cross the midline (Figure 3.22).

Another pitfall can be the mistaken impression that an echofree collection anterior to the right ventricle is fluid. Many patients have a "pericardial fat pad" that will appear as anechoic area anterior to the heart. Because most patients have their ultrasounds in a relatively supine position, you would expect fluid to collect posteriorly and thus fluid seen ONLY anteriorly should be suspect. A fat pad will not exert pressure on the right ventricle causing deformation (Figure 3.23).

## Cardiac Tamponade

Cardiac tamponade is the compression of the heart caused by blood or fluid accumulation in the space between the myocardium and the pericardium. It

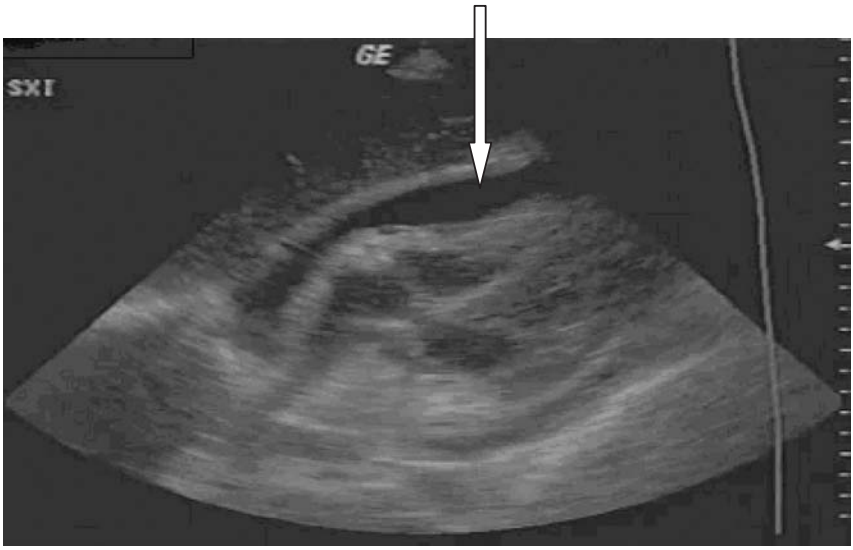


**Figure 3.24**

Subxiphoid view of the heart that shows pericardial fluid with RV scalloping (block arrow). Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

is less dependent on the amount of fluid, but rather on the rate of fluid collection within the pericardial sac. It is important to remember that although pericardial effusions are a diagnosis made by ultrasound, tamponade is a *clinical* diagnosis based on a patient's hemodynamics and clinical picture. Ultrasound may be useful in confirming the diagnosis in a patient with the classic triad of muffled heart tones, hypotension, and jugular venous distension. More important, ultrasound may demonstrate early warning signs of tamponade before the patient becomes hemodynamically unstable.

Several sonographic signs suggestive of tamponade physiology have been described, although appreciation of these may be subtle (4). *The most important finding is a circumferential pericardial effusion with hyperdynamic heart that demonstrates diastolic collapse of the right ventricle or right atrium – also referred to as "scalloping" of the right ventricle* (Figure 3.24 and Figure 3.25). Additional features may include visualization of a swinging heart. This is characterized as counterclockwise rotational movement producing a dancelike motion. Left atrial or left ventricular collapse can occur in localized left-sided compressions. Finally, a dilated IVC without inspiratory collapse (plethora) is highly suggestive of tamponade (4). Remember that these findings should be taken in light of the patient's overall clinical picture.

## Hemopericardium

Identification of any pericardial fluid in the setting of penetrating injury to the thorax or upper abdomen requires aggressive resuscitation.

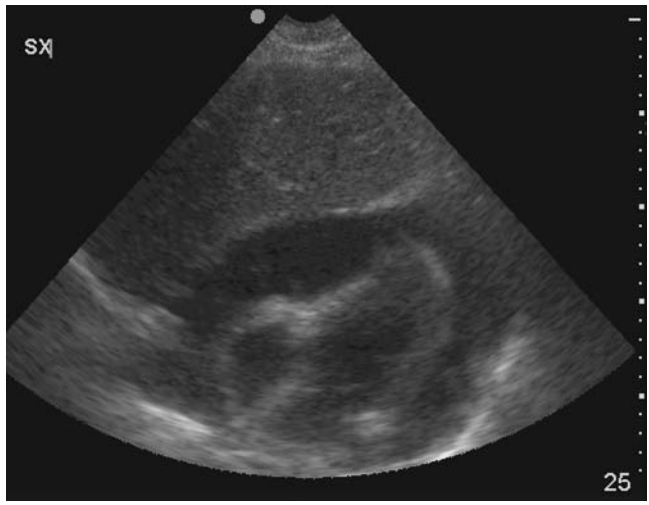


**Figure 3.25**
Circumferential effusion seen on subxiphoid four-chamber view with right ventricle almost fully collapsed. Courtesy of Dr. Andrew Liteplo, Massachusetts General Hospital, Boston, Massachusetts.

Hemopericardium is the most common feature of penetrating cardiac injuries. In acute massive hemopericardium, there is insufficient time for defibrination to occur. The hemopericardium organizes and may partially clot, resulting in a pericardial hematoma. The hematoma may appear echogenic (gray) instead of echofree (black) and thus be more challenging to identify, but deformation of the right ventricle when hemopericardium is suspected is a pertinent clue to the diagnosis. The use of bedside echocardiography in the trauma setting has been shown to be lifesaving because the time to mobilization of the operating room for thoracotomy or the time to initiation of emergency department (ED) thoracotomy are both dramatically decreased with the ability of the ED physician or trauma surgeon to make the diagnosis at the bedside (5,6).

Other potential sources of cardiac perforation include central line placement, pacemaker insertion, cardiac catheterization, sternal bone marrow biopsies, and pericardiocentesis. The right atrium is the most common site of perforation from catheter placement. Perforation, as well as direct catheter infusion of fluids, can also cause tamponade.

# Advanced Applications

## Hypotension/IVC Evaluation

The use of echocardiography for diagnosing undifferentiated hypotension can be invaluable in the emergency setting. The previous discussion noted the example of how early visualization of a pericardial effusion allows the emergency or critical care physician to initiate appropriate maneuvers for resuscitation and toward definitive therapy.

There are several additional sonographic views that may be helpful in the hypotensive patient whose volume status is uncertain. For example, right atrial pressures, representing central venous pressure, can be estimated by

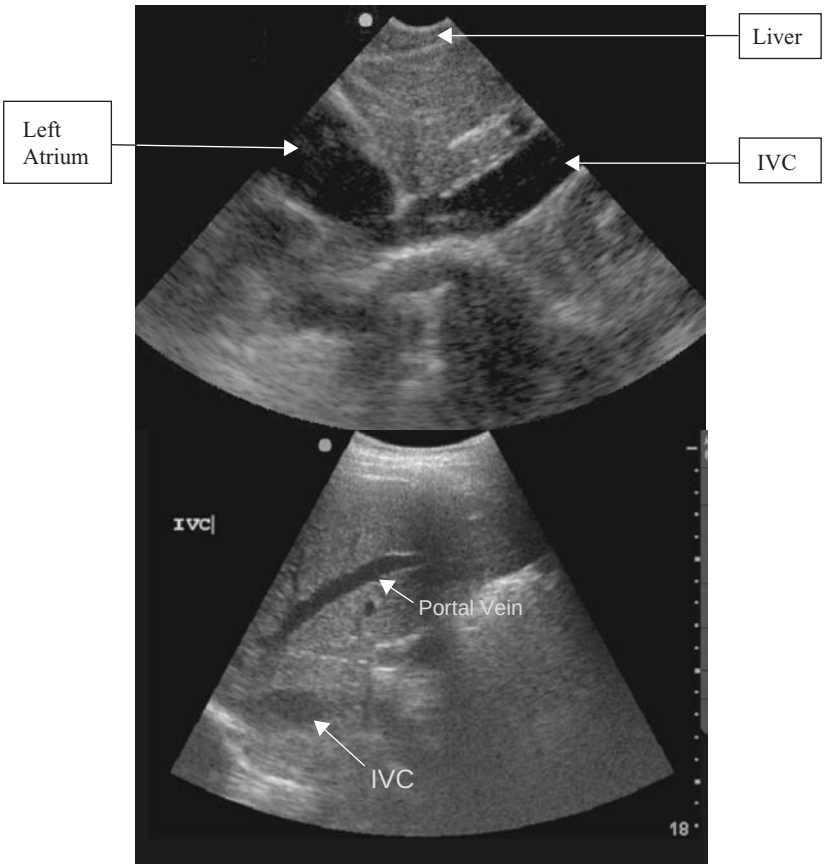


**Figure 3.26**

Image of the IVC. (*Top*) Image shows the IVC as it enters the right atrium. (*Bottom*) Image shows the IVC as it meets the portal venous system. Images Courtesy of Dr. Ruth Lamm, Massachusetts General Hospital, Boston, Massachusetts.

viewing the respiratory change in the diameter of the inferior vena cava (7–9).

Figure 3.26 shows the vena cava and can be obtained by sliding the probe toward the liver from the subxiphoid position and tracing the IVC as it travels behind the liver.

During inspiration, negative intrapleural pressure causes negative intraluminal pressure and increases venous return to the heart, speeding blood through the extrathoracic IVC. Given that the extrathoracic IVC is such a compliant vessel, this causes the diameter of the IVC to decrease with normal inspiration (Figure 3.27). Therefore, in patients who have low intravascular volume, the inspiration to expiration diameter ratios change much more than those patients who have normal or high intravascular volume. Table 3.1 is a summation of the IVC diameter to central venous pressure measurement correlations (10).

**Table 3.1** Ultrasound visualized IVC diameter and RA pressure

| IVC size (cm) | Respiratory Change | RA Pressure (cm) |
|---|---|---|
| <1.5 | Total collapse | 0–5 |
| 1.5–2.5 | >50% collapse | 5–10 |
| 1.5–2.5 | <50% collapse | 11–15 |
| >2.5 | <50% collapse | 16–20 |
| >2.5 | No change | >20 |

From Wong SP, et al. Echocardiographic findings in acute and chronic pulmonary disease. In Otto CM (ed.), *Textbook of Clinical Echocardiography*. 2nd ed. Philadelphia: WB Saunders; 2000:747 (10).

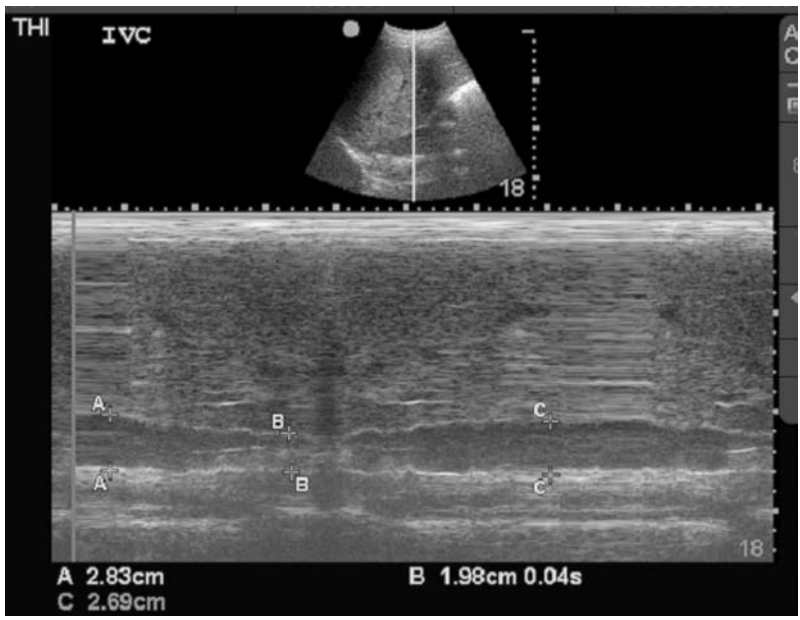


**Figure 3.27**
IVC during inspiration and expiration using M mode. Measurement B shows the inspiratory IVC diameter as compared to expiratory diameters A and C. Courtesy of Dr. Ruth Lamm, Massachusetts General Hospital, Boston, Massachusetts.

## Global Cardiac Function

There have been multiple studies evaluating the ability of nonechocardiologists to use bedside transthoracic echocardiography to estimate left ventricular ejection fraction (EF) or global cardiac function (11–18). Formal EF calculations can be performed using several different methods and range from simple observation to a variety of two-plane calculation formulas to measurements

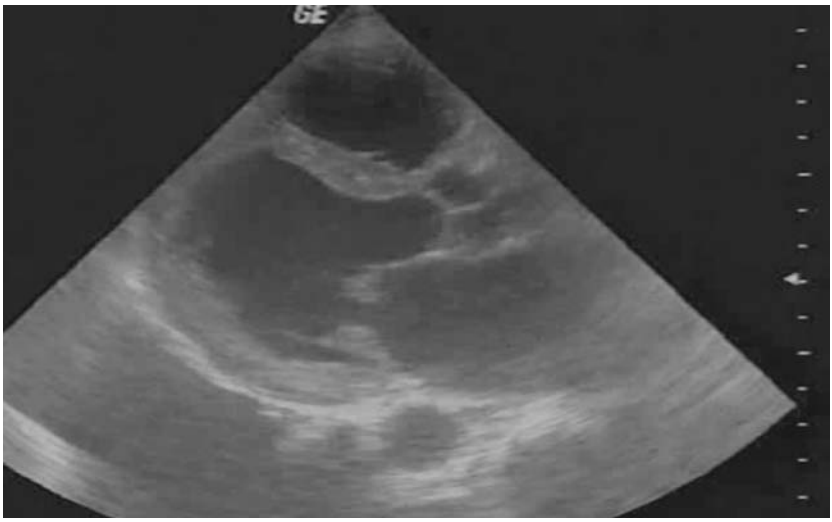

**Figure 3.28**

This parasternal long axis image shows a dilated left ventricle. The moving image would show a minimally contracting left ventricle and stiff septal wall. In the setting of hypotension, this image may help guide a physician's method of resuscitation. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

using M-mode. In addition, there are software packages that machines have to estimate EF by tracing the borders of ventricular cavities in diastole and systole. There are also studies, however, that have shown that visual estimation of EF is as good or better than calculated EF (19–21). When faced with caring for a critically ill patient who is hypotensive, decisions must be made regarding the use of volume or inotropic support. In these patients, global cardiac function assessments can be particularly beneficial (22–25). Kaul et al. even demonstrated that transthoracic echocardiography can provide information that is comparable to a pulmonary artery catheter in 86% of patients (25).

For the noncardiologist looking to estimate ejection fraction, global assessments of contractility should evaluate the shortening of left and right ventricular walls and septal wall contractility during systole. Again, this assessment is not meant to be a formal echocardiographic evaluation, but rather attempts to generalize cardiac function as low or hyperdynamic in the setting of a hypotensive patient (Figure 3.28). If minimal contractility or shortening is visible with enlarged chamber sizes, a "low" EF state can be assumed (Figure 3.29 and Figure 3.30). If contractility is hyperdynamic and the IVC is shown to have severe respiratory variation, a hypovolemic or intravascularly deplete state can be assumed.

## Cardiac Arrest

In the emergency setting, the palpation and/or auscultation of peripheral pulses can be difficult to assess in cardiac arrest or hypotensive patients (26).

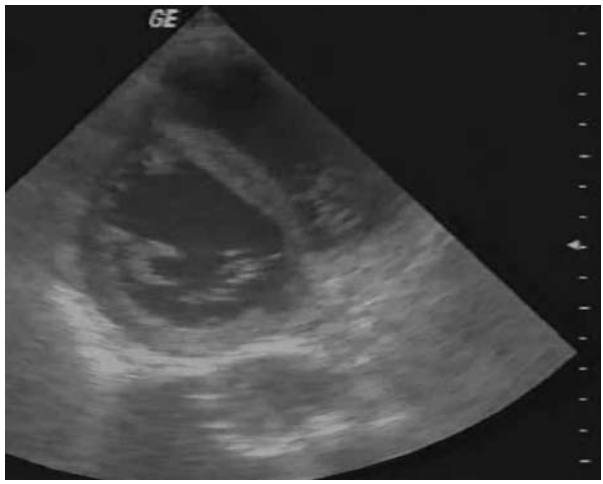


**Figure 3.29**

Parasternal short view of a patient with a low ejection fraction. Again, the moving image would reveal a stiff septal wall and minimal shortening of muscle during systole. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

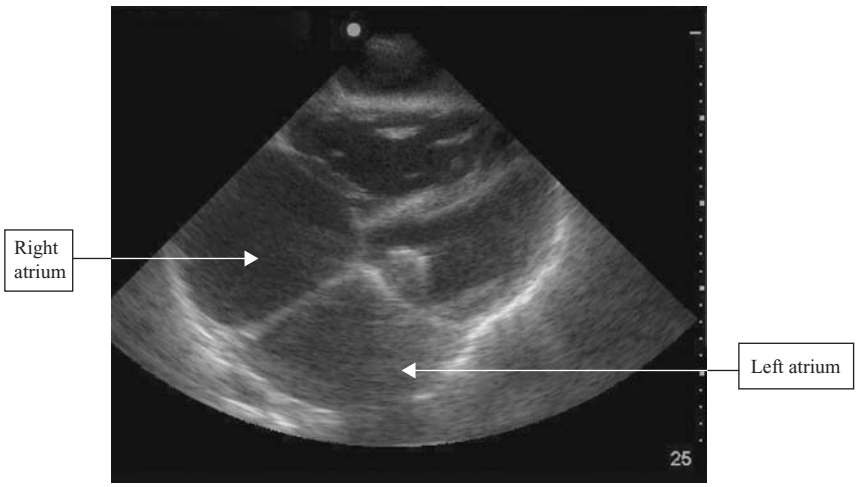


**Figure 3.30**

This subxiphoid four-chamber view shows enlarged right and left atria suggestive of high intravascular volume states.

Although asystole, ventricular fibrillation, and ventricular tachycardia are usually evident on the cardiac monitor, the diagnosis of pulseless electrical activity or PEA depends on the determination of a pulse. Echocardiography is helpful not only because it can detect cardiac motion, but also because it can detect a pericardial effusion or evidence of a dilated right ventricle consistent with pulmonary embolism – two possible causes of PEA (27).

Sonographic asystole will show an absence of ventricular contraction. Absence of cardiac contractions despite resuscitative efforts can help the clinician formulate a prognosis and determine when resuscitative efforts should be stopped. However, rare contractions of the atria and/or mitral valve may continue despite a terminal event, so it is important to base prognosis on

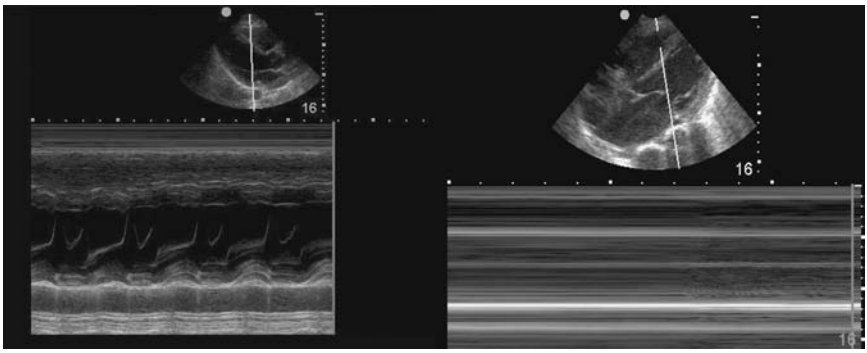

**Figure 3.31**

The heart on the right has M-mode waveforms indicating contractility. The heart on the left has flat M-mode lines, indicating asystole and no contractions.

ventricular contractions. One other important point is to ensure that artificial respirations and compressions are held during the ultrasound because respiratory effort can occasionally appear as ventricular movement. Blaivas and Fox, in their study of ultrasound in cardiac arrest, suggest that patients who arrive in emergency departments with cardiac standstill confirmed on ultrasound have little to no chance of survival (28). Given the prognosis for asystole compared with PEA during cardiac arrest is so disparate, differentiating between the two with bedside ultrasonography can be quite useful.

M-mode can assist in documenting the absence of cardiac activity. The M-mode line should be placed across the ventricular wall of the left ventricle in the parasternal long axis or subxiphoid position. When the graph of motion over time shows a flat line, this can be a still image representation of asystole (Figure 3.31).

## Pulmonary Embolism

Bedside echocardiography is not sufficiently accurate for the diagnosis of pulmonary embolism by itself, but there are sonographic findings that may help expedite intervention. Remember that in the normal heart, pressures in the right ventricle are lower than the left. This is why the right ventricular wall is thinner and more responsive to sudden increases in pressure. The normal right ventricle, therefore, looks triangular (see previous normal subxiphoid images) and is smaller than the left ventricle because of this lower pressure. When the pressure in the right ventricle rises, the RV wall will bow outward, and the RV will appear to be the same size or larger than the LV (Figure 3.32) (see discussion of ventricle size ratios in apical four-chamber section of Chapter 2) (2,29). If a patient has a massive pulmonary embolism (PE) and is hemodynamically unstable, there may not be time to obtain tests such as computed tomography scanning or transesophageal echocardiography. Therefore, in the right clinical setting, the detection of a dilated, stiff right ventricle may lend evidence for consideration of lysis (3,30–33).

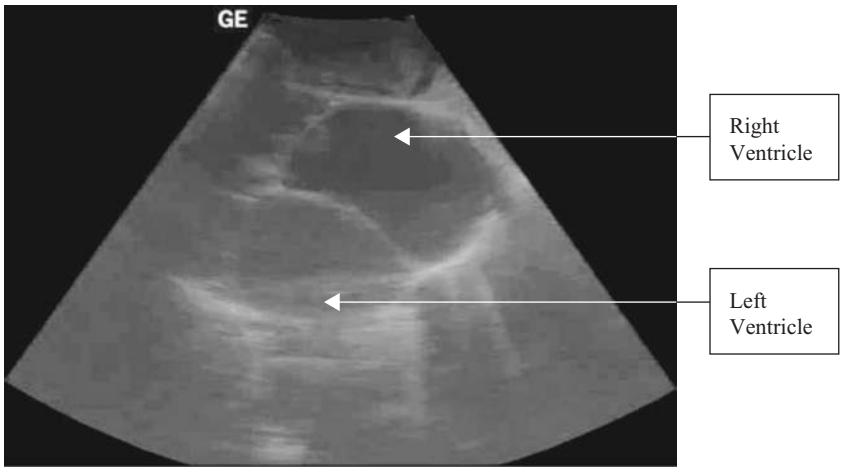


**Figure 3.32**

This subxiphoid view shows a very enlarged right ventricle – in fact, it is difficult to tell the right from left ventricle because they are both the same size. This is abnormal, and this is a patient with a saddle pulmonary embolus that required lysis. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

# Guidance for Procedures

## Pericardiocentesis

Pericardiocentesis is the aspiration of fluid from the pericardial sac. Typically, it is performed in a blind fashion by directing the needle from the subxiphoid region toward the left nipple until blood is aspirated. This method necessitates needle placement through the liver. Echocardiography has been shown to help guide pericardiocentesis in a subxiphoid, parasternal, or apical approach (34,35). When ultrasound is used to guide the procedure, a parasternal approach may be used, which involves a more direct anatomic approach to the heart than the subxiphoid approach. Visualization of the needle entering the pericardial space or visualization of agitated sterile saline injections in the pericardial space help confirm correct placement of the cardiac needle. Also, the depth markers on the ultrasound display screen (typically, each hatch mark = 1 cm) can aid in determining how deep the cardiac needle must be advanced to be in the pericardial space. Use of echocardiography in this manner may help prevent cardiac lacerations, pneumothorax, pneumopericardium, and liver laceration (34,35).

## Detection of Pacing Capture

In transcutaneous and transvenous pacing, visualization of ventricular contraction by echocardiography subsequent to the pacing spikes indicates that capture has been obtained. In addition, proper placement of transvenous pacing wires can be confirmed using bedside echocardiography. Transvenous

wires will appear bright or hyperechoic and can be seen within the right ventricle. Ultrasound can ensure that the wire is against the right ventricular wall and in good position (and also that perforation and hemopericardium has not occurred!) (36,37).

## Sample Clinical Protocols

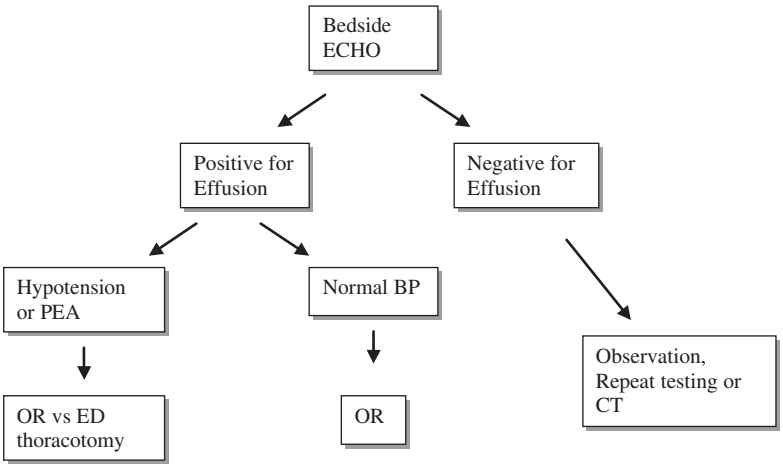


**Figure 3.33**
Sample Cardiac trauma protocol.

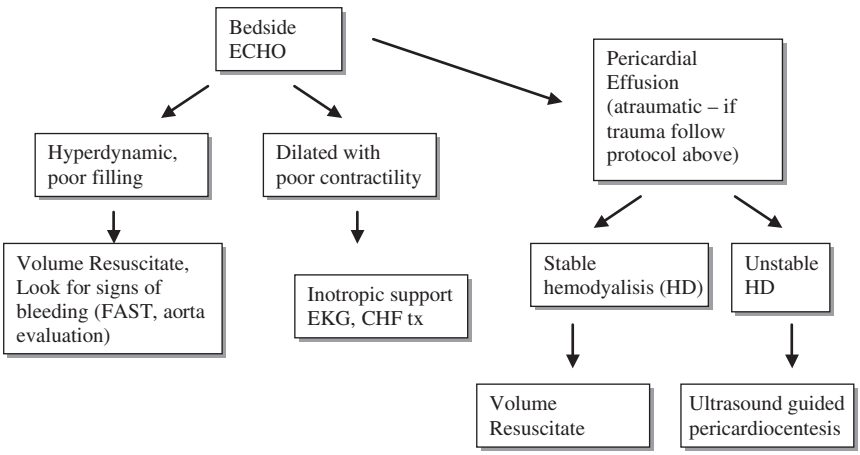


**Figure 3.34**
Sample Hypotension protocol.

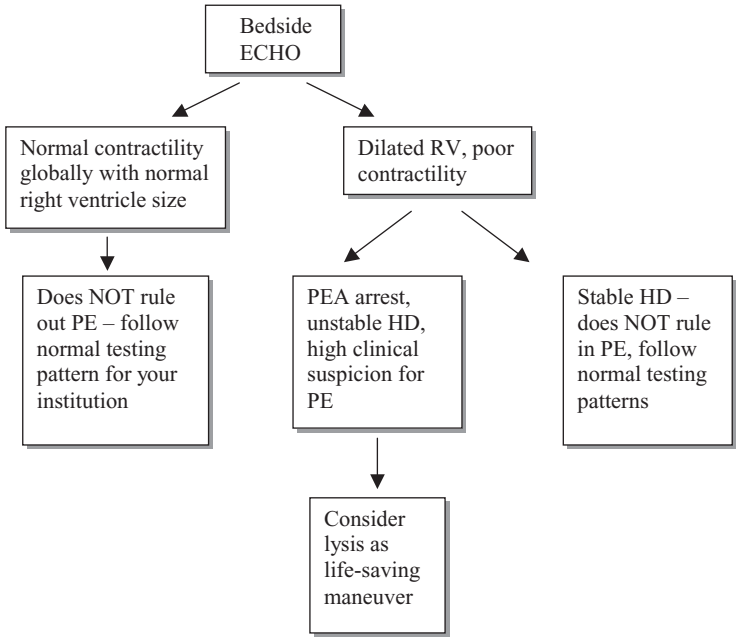


**Figure 3.35**
Sample High suspicion for PE protocol.

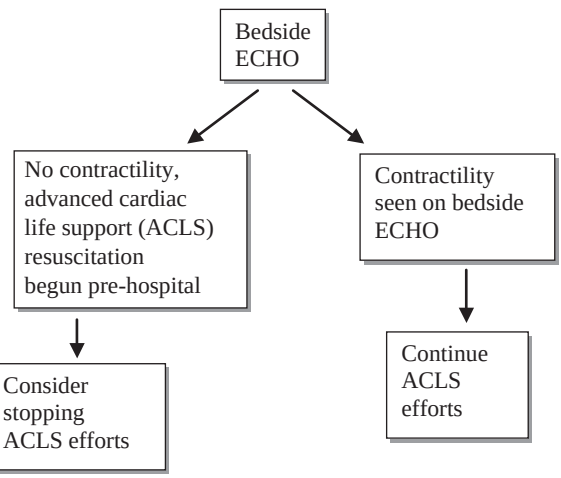


**Figure 3.36**
Sample Cardiac arrest protocol.

## Literature Review

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Blaivas and Fox (28) | 169 ED patients undergoing ACLS resuscitation, bedside ECHO during code by EPs. | 169 patients. Cardiac standstill on initial echocardiogram in patients with ongoing CPR had 100% PPV for death. | Provided data for bedside ECHO findings indicative of poor outcomes and of when to stop ACLS resuscitation. |
| Plummer et al. (5) | Penetrating trauma patients randomized to ED ECHO vs. "standard of care" evaluation (ECHO called in). | Diagnosis and disposition expedited in ED ECHO group, also noted survival benefit if patients had ED ECHO. | Mortality benefit of ED ECHO in penetrating cardiac injury. |
| Kaul et al. (25) | Blinded interpreters evaluated cause (cardiac vs. noncardiac) of hypotension in critical ICU patients receiving both 2-D ECHO and pulmonary artery (PA) catheters. | ECHO and PA catheter evaluations agreed on cause of hypotension in 86% (36/42) patients evaluated. Fewer complications with ECHO, and it was performed faster. | Prove the utility of bedside ECHO in more rapidly evaluating etiology of hypotension with fewer complications. |
| Amico et al. (20) | Comparison of multiple methods for calculating the ejection fraction with subjective visual estimation. | Best correlation of methods studied between expert observers was with visual estimate. | Support for estimation of left ventricular ejection fraction with visual estimation among experts. |
| Moore et al. (12) | Comparison of visual estimations of ejection fraction grouped as normal, depressed, and severely depressed by echocardiographers and trained emergency physicians (EPs). | Cardiology and EP ventricular function estimation had similar interobserver correlation ($R = 0.86$) to two cardiology estimations ($R = 0.84$). | Showed that nonechocardiologists and cardiologists make similar estimates of global cardiac function. |
| Randazzo et al. (11) | Comparison of EP estimated ejection fraction (poor, moderate, normal) and central venous pressure (low, moderate, high) with formal ECHO. EPs were American College of Emergency Physicians (ACEP) level III trained (3-h formal course). | 86% overall agreement in ejection fraction estimation. 70.2% agreement in central venous pressure. | With minimal training, overall agreement in broad categorical ejection fraction (EF) and CVP assessment is still good. |

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Alexander et al. (15) | Comparison of medical house staff ECHO interpretations after 3-h training course with that of formal ECHO. | Agreement was 75% for LV dysfunction and 98% for pericardial effusions. | Medical house staff with very limited training can diagnose LV dysfunction and pericardial effusions on bedside ECHO. |
| Kobal et al. (17) | Comparison of medical students' ultrasound cardiac evaluation after 18 h of training with physical exam of the heart performed by board-certified cardiologists. | Students correctly identified 75% of the pathologies vs. 49% found by cardiologists. Diagnostic accuracy of students vs. cardiologists was superior in detecting valvular disease, left ventricular dysfunction, enlargement and hypertrophy. | If medical students can do it . . . |

## New Directions

There are many new directions that bedside ECHO could take in the next few years. As three-dimensional ECHO technology becomes more widespread and as the cost of three-dimensional ECHO machines decreases, it is easy to imagine that ejection fraction calculations could be made much more accurately. ECHO machine automated protocols for estimating global cardiac function could even become standard. Estimations of volume status and central venous pressure could likewise be accurately generated by three-dimensional ECHO and could finally replace invasive monitoring (38,39).

As this technology spreads throughout critical care medicine, it is likely that ultrasound-guided protocols for evaluating critically ill hypotensive patients could be helpful in many critical care settings, and it is expected that with the diffusion of this technology, research in this area will continue.

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# 4 First Trimester Ultrasound

## Introduction

Ectopic pregnancy (EP) is the leading cause of maternal mortality in the United States and is estimated to have a prevalence of 8% in pregnant patients presenting to the ED for any complaint (1,2). Indeed, the incidence of ectopic pregnancy has been rising since the mid-1980s (3). Therefore, any female of child-bearing age who comes to the emergency room with abdominal pain, vaginal bleeding, near-syncope, or syncope has ectopic pregnancy on the differential. This is a "can't miss" diagnosis. Given the volume of female patients presenting with these complaints, an algorithm incorporating first trimester ultrasound can be timesaving for the physician and patient but must increase efficiency without compromising safety.

The evaluation for ectopic pregnancy differs from other indications for bedside ultrasound. Evaluation of the uterus seeks to confirm an intrauterine pregnancy (IUP), ruling out ectopic gestation by exclusion. Visualization of the actual ectopic pregnancy is not the goal. In contrast, evaluation of the aorta, heart, and other organs typically confirms pathology (aneurysm, asystole, hydronephrosis) via direct visualization.

There are instances where an extrauterine gestation will be seen on bedside ultrasound or free fluid will be seen in a hypotensive pregnant female and ectopic pregnancy will be diagnosed or inferred. This will be the exception, however, to how bedside ultrasound is used for this application. Bedside ultrasonography instead will be used to increase the number of IUP cases that can be definitively diagnosed and discharged in the ED without further imaging.

One other important subgroup of patients that should be mentioned is those women who are undergoing in vitro fertilization (IVF) or assisted reproduction and who present to the ED with pain or vaginal bleeding. Because the risk of heterotopic pregnancy in these women is so high, it is the view of the authors that these patients should *always* have formal ultrasonography done by gynecology or radiology and should always have a formal gynecology consultation (4–7). Others have suggested that there are other subgroups of patients (history of ectopic pregnancy, known fallopian tube scarring) with unacceptably high rates of heterotopic pregnancy that should also always undergo formal sonography and consultation, but this recommendation is not universally practiced.

## Focused Questions for First Trimester Ultrasound

The focused questions for first trimester ultrasound are as follows:

1. Is there an intrauterine pregnancy?
   a. Is there an intrauterine yolk sac, fetal pole, or fetal heartbeat?

b. Anything else (including an intrauterine gestational sac) is NOT an intrauterine pregnancy and a formal study or a formal consultation should be performed.

## Terminology

Terminology used when describing first trimester pregnancy can be confusing, and it is important that emergency physicians are precise when describing their findings. Miscommunication can lead to emotional distress and unsafe assumptions. The following list defines terms commonly used in first trimester pregnancy:

- **Spontaneous Abortion and Miscarriage** – synonymous terms in early pregnancy that refer to spontaneous passage of the products of conception (POC) through the cervical os.
- **Threatened Abortion** – a pregnancy prior to 20 weeks of gestation accompanied by cramping and vaginal bleeding.
- **Incomplete Abortion** – a condition in which some POC remain with the uterus after miscarriage.
- **Complete Abortion** – a condition in which all products of conception have passed through the os and none remain in the uterus.
- **Inevitable Abortion** – a condition in which the patient's cervix is dilated and POC are often seen exiting the cervical os.
- **Missed Abortion** – refers to the clinical situation in which an intrauterine pregnancy is present but no longer developing normally. The gestation is termed a missed abortion only if the diagnosis of incomplete abortion or inevitable abortion is excluded. Patients with this condition may present with an anembryonic gestation (empty sac or blighted ovum) or with fetal demise prior to 20 weeks' gestation.
- **Blighted Ovum** – an ambiguous term that formerly indicated that no embryo ever developed. This term was synonymous with the term *anembryonic gestation*. Recent advances in ultrasound scanning have shown that a very early embryo usually develops. Therefore, *embryonic resorption* has become the more modern and appropriate term.
- **Embryonic Demise** – refers to a pregnancy in which no fetal heartbeat or motion is seen despite a clearly visible embryo of a gestational size where a fetal heartbeat would be expected.

Again, these terms are important to the emergency physician only in terms of clear communication. The purpose of performing bedside emergency first trimester ultrasound is to diagnose an intrauterine pregnancy in patients with an acceptably low risk of heterotopic pregnancy (non-IVF, no history of ectopic pregnancy) so they can be discharged and followed up as outpatients safely. If an intrauterine pregnancy is not diagnosed, most emergency department patients should be referred for formal sonography and gynecology consultation.

## hCG Levels

Another area of much confusion and debate is correlation of serum human chorionic gonadotropin (hCG) levels with ultrasound findings. The first important rule for the emergency physician is there is no hCG level at which a patient can be ruled out for ectopic pregnancy. Ectopic pregnancies have been described with levels <30 IU/mL, and very frequently <1,000 IU/mL (8,9). Therefore, pelvic sonography should be done for any patient who is pregnant regardless of beta-hCG (8–10). The concept of a discriminatory zone becomes more significant after pelvic sonography is complete. The discriminatory zone is the level of beta-hCG at which an intrauterine pregnancy should be seen 100% of the time. Transvaginal ultrasound is able to visualize intrauterine pregnancies earlier, and the discriminatory zone is usually accepted as 1,500 IU/mL. The discriminatory zone for transabdominal ultrasound is usually believed to be between 4,000 and 6,500 IU/mL because it uses a lower-frequency probe and thus has images with less resolution (11). Therefore, if an ultrasound is indeterminate and the serum hCG is greater than the discriminatory zone, the suspicion for ectopic pregnancy should be increased (12). However, serum quantitative hCG levels are mostly helpful in following a patient over time, and there is no level at which a patient will not require an ultrasound (except zero).

## Anatomy

There are several anatomic relationships that can help guide the sonographic evaluation of the female pelvis (Figure 4.1). The bladder is always anterior to the uterus. The ovaries are usually found at the end of the fallopian tubes and

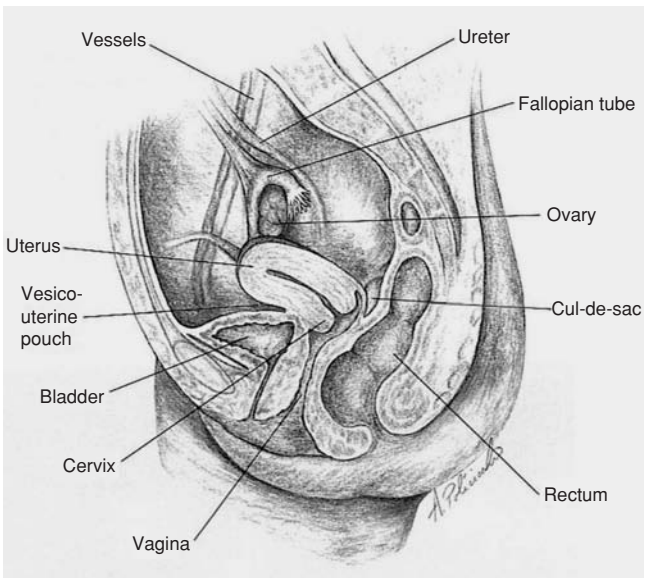


**Figure 4.1**
Normal female anatomy. Image from *Gray's Anatomy* textbook; courtesy of Elsevier.

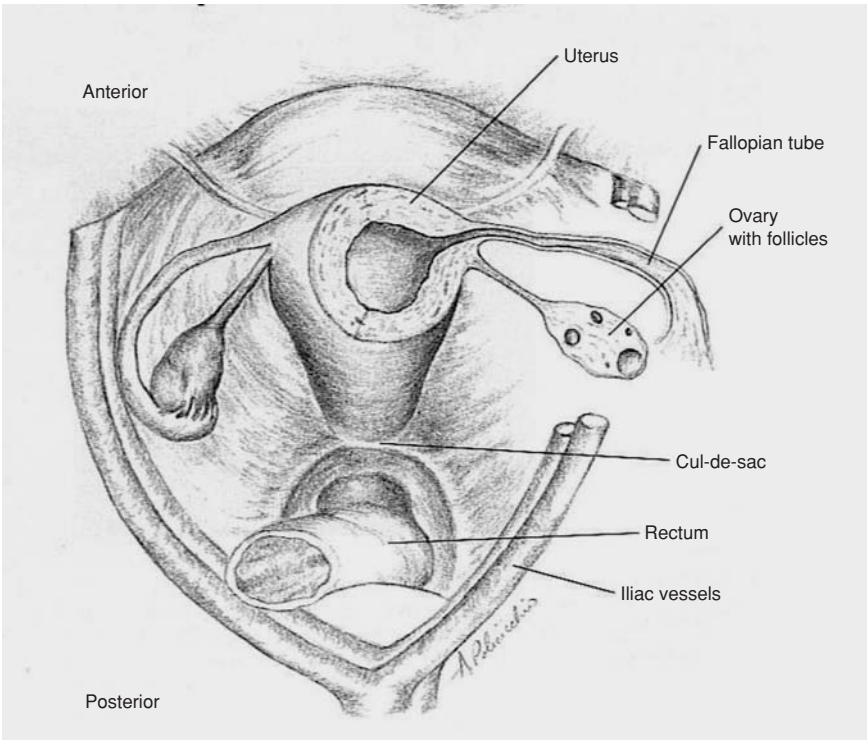


**Figure 4.2**

Normal female anatomy. Note the relation between the ovaries and the iliac vessels; ovaries are found superior and medial to vessels on ultrasound imaging. Image from *Gray's Anatomy*; courtesy of Elsevier.

are anterior and medial to the ileac vessels (Figure 4.2). If the bladder is full, it is a good acoustic window for visualizing the uterus transabdominally. However, it is easier to visualize the uterus transvaginally with an empty bladder because then the uterus will be anteroflexed in most cases over the vaginal introitus.

## Technique

There are two approaches to performing the sonographic exam of an early pregnancy: transabdominal and transvaginal approaches. Usually, a transabdominal scan is done first while the patient still has a full bladder. The patient then can empty her bladder prior to the transvaginal scan if the transabdominal scan was nondiagnostic for intrauterine pregnancy. In patients with unclear gestational age, it is even more important to perform an abdominal scan first. Occasionally, a second trimester fetus will be visualized transabdominally, and a nonsterile pelvic exam (which would increase the risk of infection) can be avoided.

## Transabdominal Scanning Technique

### *Probe Selection*

Use a 3.5-MHz curvilinear transducer for the transabdominal scan.

### *Views*

At least two views are necessary for complete evaluation of the uterus: a transverse view and a longitudinal view both demonstrating the endometrial stripe (and uterine contents, if any).

Like the suprapubic window used in the FAST and renal exams, the transabdominal ultrasound of the patient with an early pregnancy requires a full urinary bladder. An inadequately filled bladder is one of the most common causes of a technically inadequate transabdominal exam.

Begin by placing the probe above the pubic symphysis (Figure 4.3). Start in the midline, and use both the sagittal/longitudinal and the transverse orientations. Again, careful angulation and movement off the midline may be necessary to obtain optimal views of the structure being evaluated (and to see the endometrial stripe). Remember when scanning longitudinally that the probe marker is to the patient's head, and when scanning transversely, the probe marker is to the patient's right (Figure 4.4).

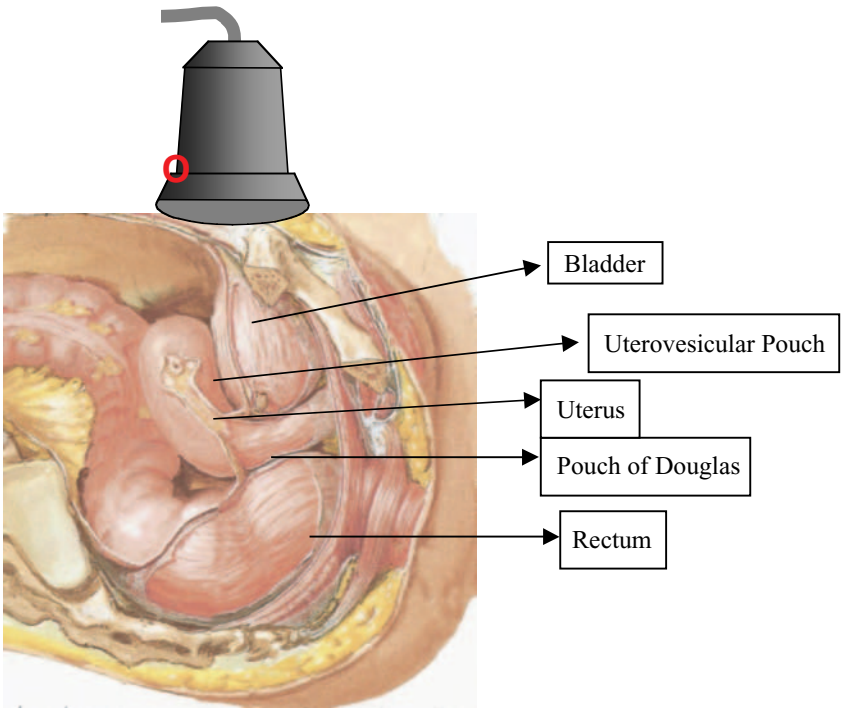


**Figure 4.3**

Probe positioning and anatomy in transabdominal scanning. Drawing from *Netters Atlas of Human Anatomy*, 2nd ed. 1997, plate 363.

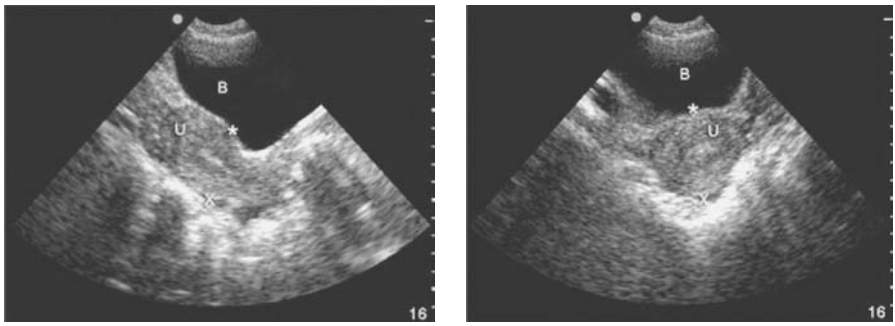


**Figure 4.4**

Transabdominal images of non-pregnant female pelvis-longitudinal (left) and transverse (right). Images of a normal uterus. B = bladder, U = uterus, ∗ = uterovesicular space, X = pouch of Douglas.

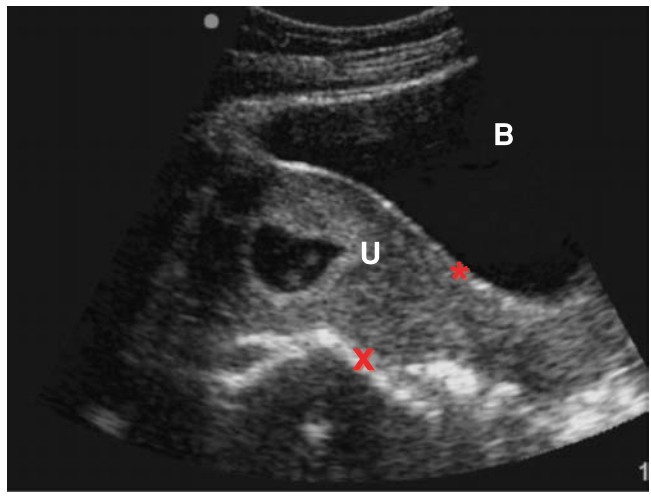


**Figure 4.5**

Transabdominal imaging of pregnant female pelvis – longitudinal (*left*) and transverse (*right*) images of a normal uterus. B, bladder; U, uterus; *, uterovesicular space; X, pouch of Douglas.

In this transabdominal longitudinal image of uterus with IUP, the bladder (B) is noted anteriorly, with the uterus (U) and then rectum (R) noted posteriorly. The uterovesicular pouch is noted with an asterisk (*) anterior to the uterus, and the pouch of Douglas is noted with an (X) posterior to the uterus (Figure 4.5).

## Transvaginal Scanning Technique

### *Probe Selection*

Most manufacturers have a high-frequency intracavitary or transvaginal probe that is specifically made for transvaginal scanning. The frequency ranges are usually from 5 to 9 MHz.

### *Views*

Again, at least two views are necessary for complete evaluation of the uterus: one transverse view and one longitudinal view, both demonstrating the endometrial stripe (and uterine contents, if any).

After performing a transabdominal scan, the patient should empty her bladder to facilitate the transvaginal scan. As with all invasive procedures, before proceeding to the transvaginal exam, the physician should counsel the patient about the exam and obtain consent. The probe must be cleaned and sterilized, and the probe tip covered with a small amount of conductive gel; a sterile condom or cover is then placed over the probe and sterile gel is placed on the outer condom tip. Holding the probe with the indicator or marker to the ceiling, the probe is inserted into the vaginal canal (Figure 4.6).

The first view with the marker pointing to the ceiling should give the image in Figure 4.7. It is important to fan through the entire body of the uterus; in

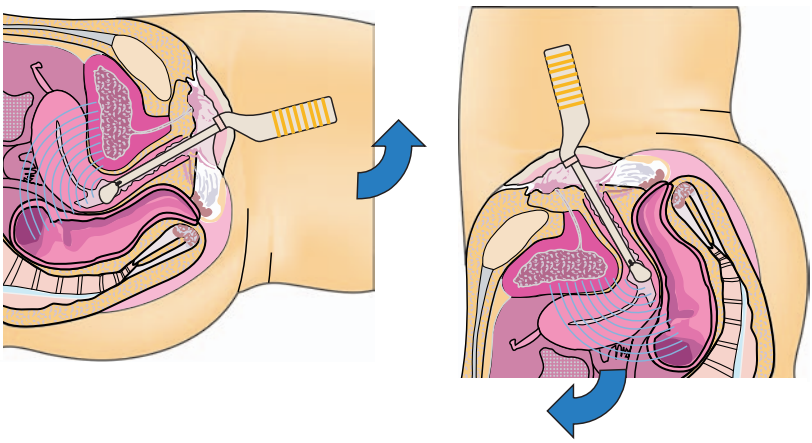

**Figure 4.6**
Probe positioning in transvaginal scanning.

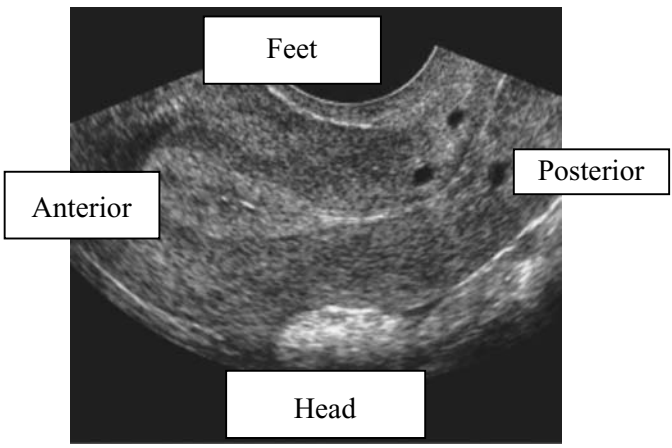


**Figure 4.7**
Transvaginal sagittal or longitudinal view of a nonpregnant uterus. Hyperechoic stripe represents the endometrium. Labels show probe orientation.

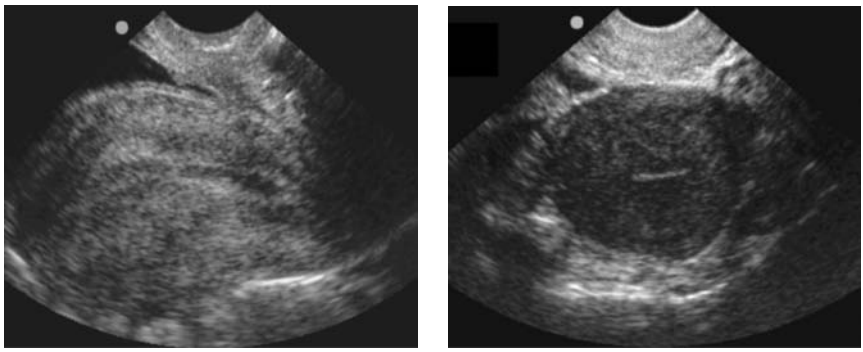

**Figure 4.8**

Longitudinal and transverse transvaginal view of the uterus – anechoic fluid in the left-hand corner of the longitudinal image is the bladder. To image the cervix on the longitudinal image, the handle of the probe would be brought up and the probe tip angled toward the posterior fornix.

the longitudinal plane, make sure to fan the probe side to side and see the entire uterus (the endometrial stripe should disappear and reappear as you fan). To bring the cervix into the viewing window, bring the transducer handle toward the ceiling. This will angle the tip toward the posterior fornix of the vaginal canal, which is where the cervix is located in most women (Figure 4.8).

After scanning in the longitudinal plane, turn the probe marker to the patient's right. You will then see the uterus in a transverse plane (Figure 4.8). Again, it is important to fan through the entire uterus, so fan the probe anteriorly and posteriorly to see the entire fundus. The endometrial stripe should again disappear and reappear as you fan. At this point, the fallopian tubes can be traced out to visualize the ovaries. If you see the ileac vessels, then the ovaries should be anterior and medial. The ovaries will often have multiple follicles (F) that look like multiple cysts (Figure 4.9). This can help identify them. However, the emergency physician should remember that he or she is doing this scan to identify an intrauterine pregnancy. Performing a complete ovarian ultrasound is beyond the scope of this text.

## Normal Images in Early Pregnancy

As mentioned previously, to be conservative and to practice with the greatest safety, only an intrauterine yolk sac, fetal pole, or intrauterine fetal heartbeat should be identified as an intrauterine pregnancy on bedside ultrasound scans. The reason for this is that although a gestational sac can be an early marker of a normal gestation, it can also be the result of hormonal stimulation caused by an ectopic pregnancy, also known as "pseudogestational sac of ectopic pregnancy" (3,13). This finding is seen in up to 10% to 20% of all ectopic pregnancies (13). Therefore, it is not recommended to use this finding as a sign

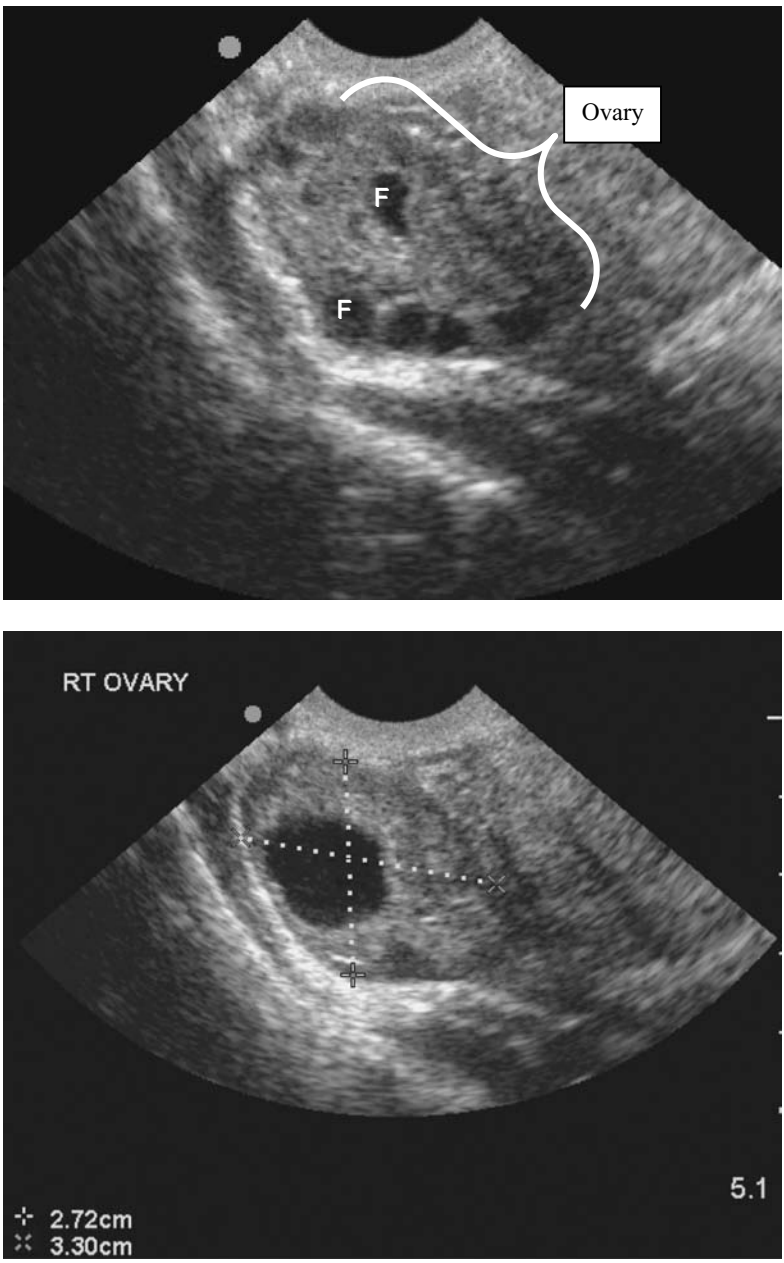


**Figure 4.9**

Two normal transvaginal views of the ovary. Most women will have multiple visualized follicles – some may be quite prominent, depending on luteal stage.

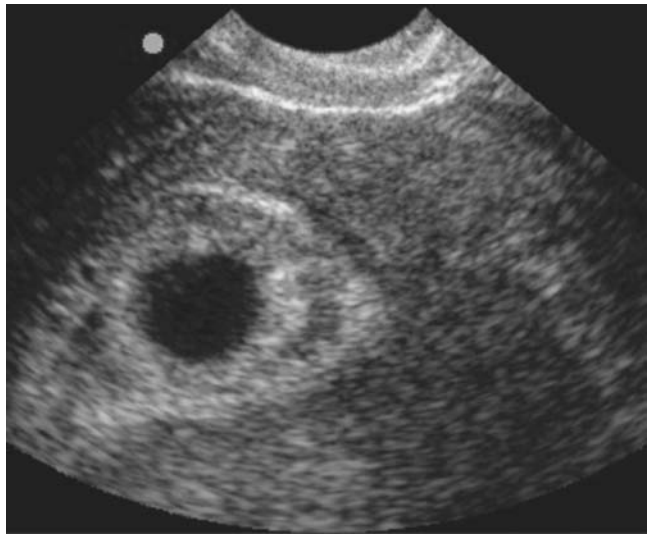

**Figure 4.10**
Double decidual sign. The hypocholic layer surrounding the gestational sac can be seen; however, because there is no yolk sac visualized within the gestational sac, this cannot be definitively called an intrauterine pregnancy.

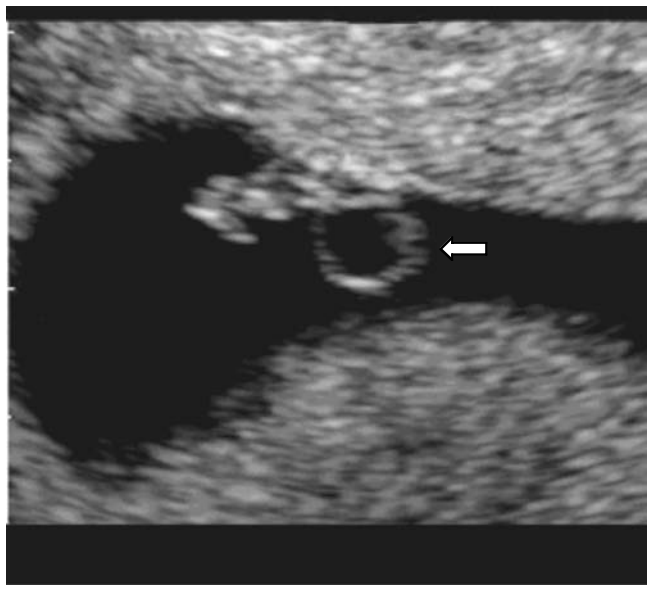

**Figure 4.11**
Using the zoom function present on most bedside ultrasound machines, the "sac within the sac," or the yolk sac (block arrow), can be seen. This is the first definitive sign of an intrauterine pregnancy.

of normal gestation. The "double decidual sign" has also been described as a reliable marker for early intrauterine pregnancy (Figure 4.10). This is a sac with echogenic and hypoechoic rings surrounding it. However, even in the radiology and obstetric literature, there is debate as to the accuracy of this finding, and it is not present in all cases. Thus, before the appearance of a yolk sac, an IUP cannot be definitively diagnosed in the ED.

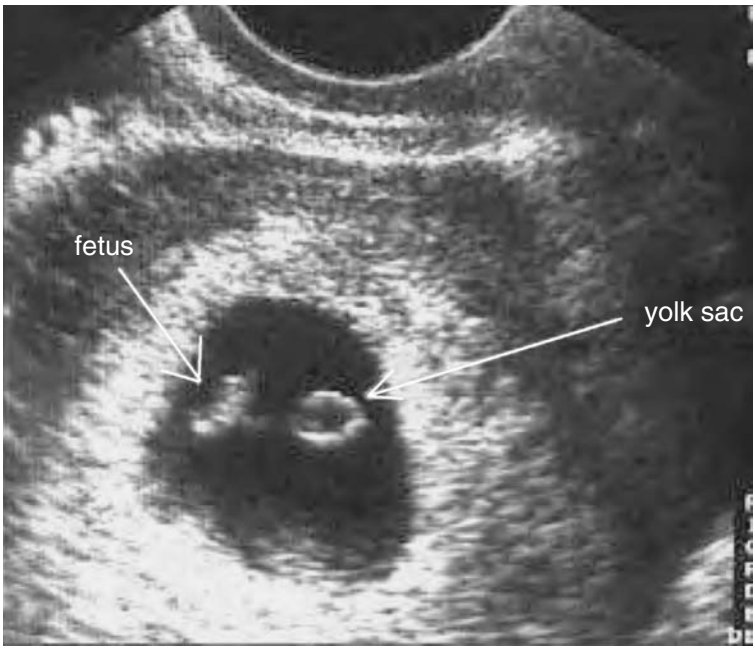


**Figure 4.12**
Transvaginal image of the yolk sac and the fetal pole.

When first visible, the gestational sac contains no identifiable structures. By the time its diameter reaches 5 to 8 mm, the yolk sac ("sac within the sac") should be detectable (Figure 4.11).

By the end of the sixth menstrual week, the mean diameter of the gestational sac grows by 1 mm/day, the yolk sac appears, and embryonic cardiac activity may be seen between the yolk sac and the wall of the chorionic sac even before the embryo is measurable. At this point, the tiny embryo is surrounded by a small amniotic membrane. This complex, located between the yolk sac and the chorionic wall, is termed the fetal pole (Figure 4.12).

The embryo grows by about 1 mm/day in crown–rump length, and by the end of the seventh menstrual week, the embryo measures 5 to 10 mm (Figure 4.13 and Figure 4.14) and should exhibit cardiac motion on both *transvaginal* and *transabdominal* scanning.

The gold standard for the diagnosis of a living intrauterine pregnancy is the visualization of embryonic cardiac activity. This may be seen as early as 41 to 43 menstrual days (6 weeks) or when the mean sac diameter is 12 to 16 mm. Physicians should use M mode to highlight cardiac motion (Figure 4.15) because it uses less acoustic power than Doppler and thus theoretically transmits less acoustic energy to the fetus (see Chapter 1). The alternating black and gray bands represent chamber movement. Heart rate is

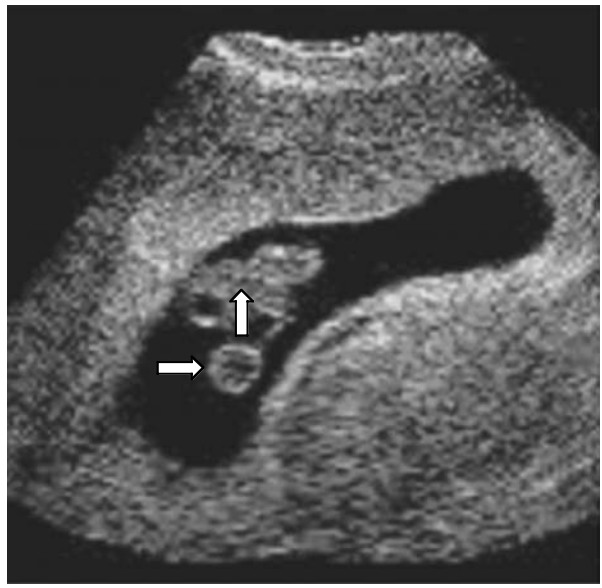

**Figure 4.13**
Seven-week-old embryo *(up arrow)* and yolk sac *(side arrow)* on a transvaginal sagittal window.

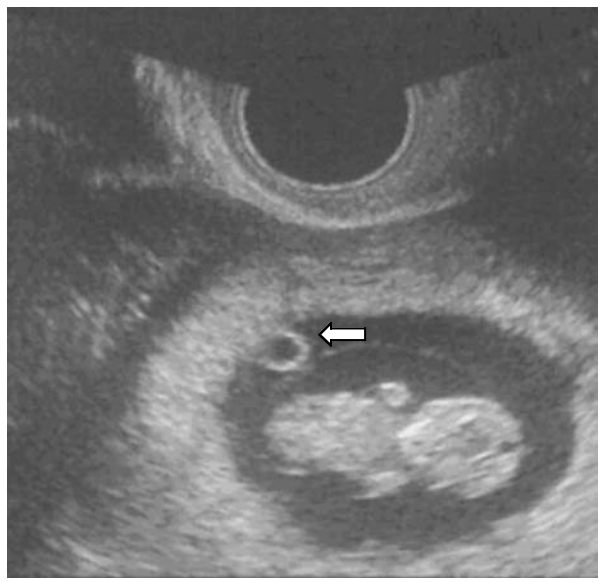

**Figure 4.14**
Ten-week-old fetus and yolk sac *(arrow)* on transvaginal window.

calculated by measuring one cycle length and determining the cycles per second based on that measurement. In addition, many bedside ultrasound machines will have an automatic fetal heart calculation function in their M mode menu.

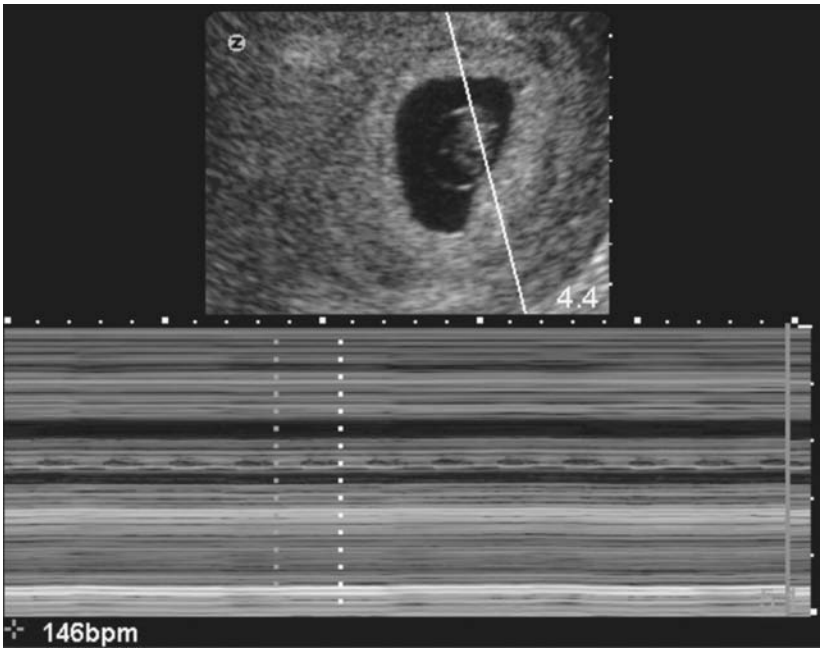


**Figure 4.15**
Fetal heart rate (FHR) by M mode (FHR 146 seen on bottom of screen).

## Ectopic Pregnancy

Ectopic pregnancy occurs in about 2% of all pregnancies in the United States. However, some studies have reported an incidence of 7.5% to 13% among symptomatic patients who present to the emergency department (1–3).

Transvaginal ultrasound can detect the embryo in ectopic pregnancies. The presence of an adnexal mass and/or cul-de-sac fluid in a patient with no intrauterine gestation and measurable circulating hCG is highly specific for the diagnosis of ectopic pregnancy. Absence of these sonographic findings does not exclude the diagnosis because up to 30% of women with extrauterine gestations have no sonographic evidence of an adnexal mass or pelvic intraperitoneal fluid (1–3,12,17,19). The majority (95%) of ectopic pregnancies occur in the fallopian tubes. Ovarian, abdominal, cervical, and interligamentary ectopics are rare. However, these non-fallopian ectopics carry a higher mortality because they rupture at a later gestational age and, thus, hemorrhage is more rapid. To prevent mistaking a cervical or corneal ectopic for an intrauterine pregnancy, one must determine that a thick enough "myometrial mantle" exists to sustain the gestation within the uterus. Thus, the thinnest stripe of myometrium seen surrounding the gestation should be measured (Figure 4.16). Anything <8 mm is concerning for a cervical or corneal/interstitial ectopic pregnancy, and proper consultation should be arranged (1–3).

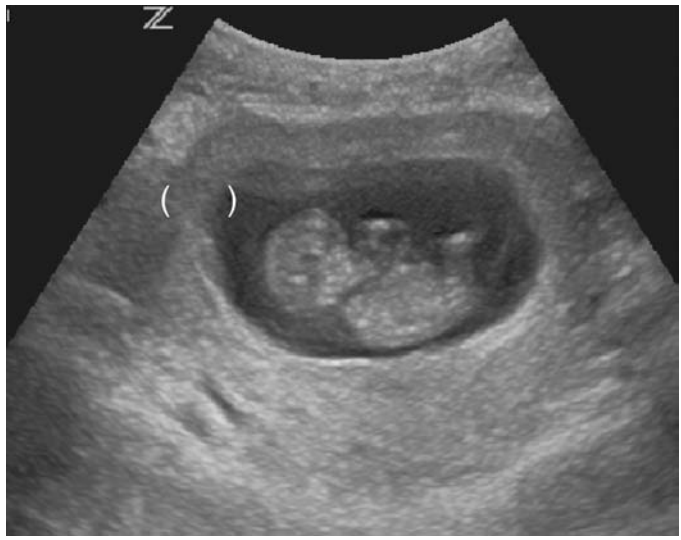

**Figure 4.16**
Image showing where to measure the myometrial mantle. Image courtesy of Dr. Greg Press, University of Texas – Houston, Hermann Memorial Hospital, Houston, Texas.

## Abnormal Images

The following images of abnormal pelvic ultrasound scans.

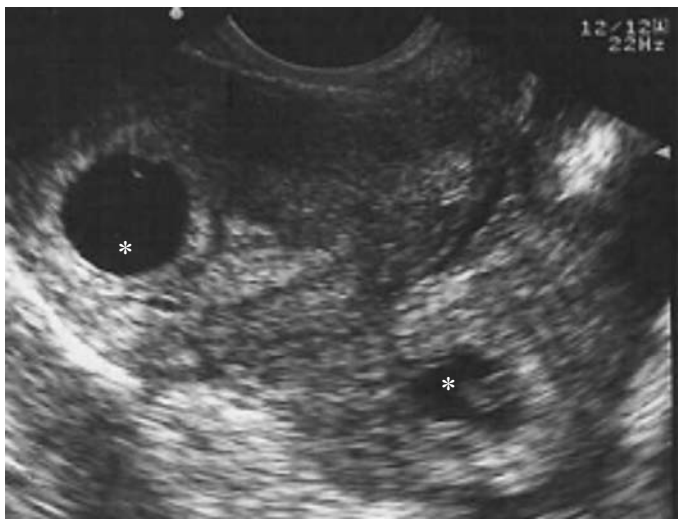


**Figure 4.17**
Heterotopic pregnancy. Two gestational sacs are seen (∗). The sac in the lower right-hand corner of the screen is outside the uterine cavity. Courtesy of Dr. Greg Press, University of Texas – Houston, Hermann Memorial Hospital, Houston, Texas.

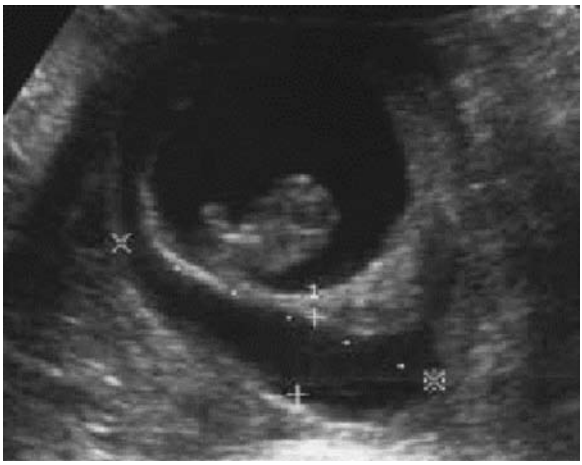

**Figure 4.18**

Subchorionic hemorrhage. The anechoic fluid separating the gestational sac from the myometrium is clearly seen. These patients should pursue formal consultation because they are at a higher risk of hemorrhage and miscarriage.

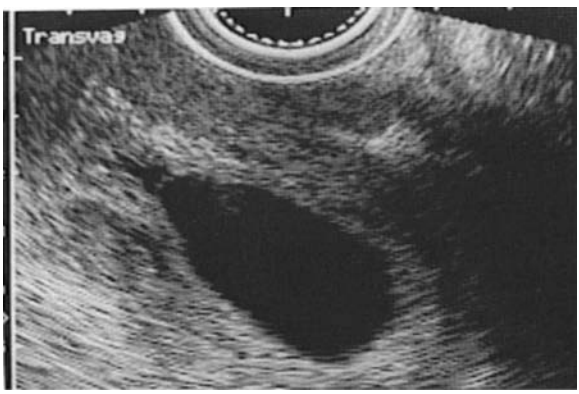


**Figure 4.19**

Large, irregularly shaped gestational sac. Because no yolk sac or fetal pole is seen, this is likely embryonic resorption and a missed abortion. However, pseudogestational sac of ectopic pregnancy cannot be ruled out on this image alone, and proper consultation should be obtained.

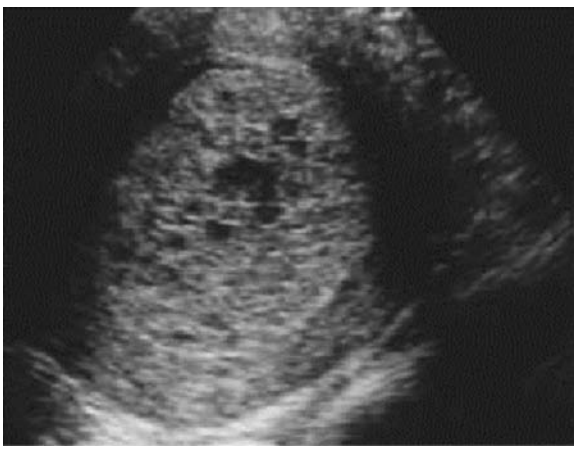

**Figure 4.20**

Molar pregnancy. The large uterus appears filled with heterogenous material in the form of hundreds of tiny follicles. Because a significant number of such patients have high hCG levels and undergo malignant transformation of this tissue, they should pursue formal consultation.

## Sample Clinical Protocol

Algorithms using transvaginal sonography and a beta-hCG discriminatory zone have been developed to improve diagnostic accuracy and clinical consistency. There are several variations of this algorithm, although the recommendations are generally similar (1–3,12).

The protocol below (Figure 4.21) describes a typical algorithm incorporating several key decisions point (pelvic ultrasound, Rh type, hCG level, etc.) into a care plan for patients with possible ectopic pregnancy.

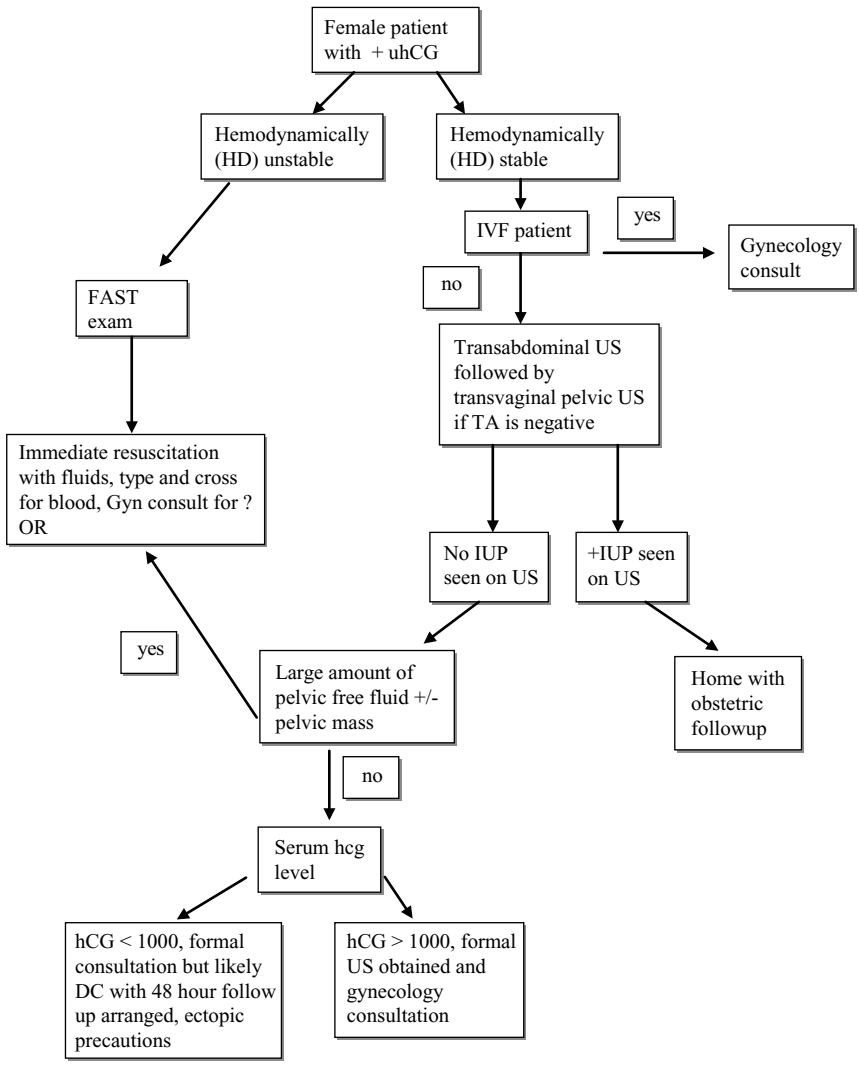


**Figure 4.21**
Sample Clinical Protocol.

## Literature Review

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Blaivas et al. (14) | Retrospective chart review of 1,419 ED patients undergoing US for r/o ectopic. | For patients with IUP, length of stay 21% (daytime) to 28% (evening) shorter when EPs perform US vs. radiology. | Time saving with EP-performed bedside US. |
| Burgher et al. (20) | Retrospective review of 84 patients undergoing evaluation for ectopic pregnancy by EPs and ob/gyn. | Shorter length of stay, no missed ectopics in group evaluated by EPs. | Time saving with EP-performed bedside US, low risk of missed ectopic. |
| Durston et al. (16) | Retrospective study evaluating test ordering practices after introduction of EP-performed pelvic sonography. | Specificity of EP-performed sonography ruling in IUP was 95%. Increased availability of US improves quality of ectopic pregnancy detection at expense of number of US done. | Proposed that EP physicians screen all patients with first trimester cramping or bleeding and immediately refer for formal study all indeterminate scans for best results. |

## New Directions

As emergency physicians have become more proficient with first trimester scanning, new protocols have been proposed to address the large number of patients with indeterminate scans who are clinically and hemodynamically stable. Patients with indeterminate first trimester scans have three possible outcomes: (1) the pregnancy is too early and is below the discriminatory zone level for ultrasound detection, (2) the pregnancy is an ectopic pregnancy, or (3) the pregnancy is a missed or incomplete abortion (18). Often, patients with indeterminate scans and hemodynamic stability are sent home to be followed up in 48 hours for a repeat serum quantitative hCG level to assess the viability of the pregnancy.

Tayal et al. (21) proposed an algorithm that would decrease the number of patients that require formal gynecology consultation before discharge in the indeterminate ultrasound group. They suggested that patients with indeterminate bedside ultrasound scans who (1) have no adnexal tenderness, (2) have no pelvic free fluid seen on US, (3) are hemodynamically stable, and (4) have an hCG level <1,500 are safe for discharge without gynecology consultation but with a plan for follow-up in 48 hours for repeat evaluation.

**Table 4.1** Discriminatory zone findings on transabdominal (TA) and transvaginal (TV) scanning

| | TA | TV | hCG level |
|---|---|---|---|
| Gestational sac | 5.5–6 weeks | 4.5–5 weeks | 1,700–6,000 |
| Yolk sac | 6–0.5 weeks | 5–5.5 weeks | 8,000–15,000 |
| Fetal pole | 7 weeks | 5.5–6 weeks | 13,000–15,000 |
| Cardiac activity | 7 weeks | 6 weeks | 16,000–25,000 |
| Fetal parts | >8 weeks | 8 weeks | 29,000–39,000 |

Although this is not recommended for departments that are new to bedside scanning, this protocol further highlights the progress of ultrasound. As technology becomes more routine and techniques are mastered, the diagnostic envelope continues to be pushed forward.

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# 5 Abdominal Aortic Aneurysm

## Introduction

With the possible exception of pericardial tamponade, there is no other condition in which the special capabilities of bedside sonography are of such striking benefit (1,2). Emergency bedside ultrasonography enables the emergency physician to confirm a high-risk diagnosis – decreasing the time needed to mobilize resources – or even transfer the patient to a referral center if necessary. This one exam will save lives if incorporated into the regular practice of emergency physicians and other critical care physicians involved in the evaluation of acutely ill patients (1).

Part of the reason for this is because abdominal aortic aneurysms (AAAs) can present with such varied symptoms. Patients can have back pain, flank pain that sounds like ureteral colic, syncope, abdominal pain, gastrointestinal bleeding, or any variety of these. Because of this and because of the ease of a screening abdominal aortic ultrasound, it is recommended that all patients with the aforementioned presenting symptoms and risk factors for AAA undergo an ultrasound screening exam. This is particularly true if a patient with flank pain is found to have unilateral hydronephrosis. An expanding abdominal aneurysm can compress the ureter so hydronephrosis results. It is far better to do extra screening exams in at-risk patients with flank pain, than to miss this life-threatening diagnosis.

## Focused Questions for Aortic Ultrasound

The focused questions for aorta ultrasound are as follows:

1. Is the abdominal aorta >3 cm in diameter?
2. Are the ileac arteries >1.5 cm in diameter?

If the answers to these questions are no, then the aortic ultrasound evaluation is normal. However, one must be careful to exam the entire length of the abdominal aorta and to evaluate in two planes as described in this chapter.

If the answers to these questions are yes, then an aneurysm has been diagnosed, and the physician's next step depends on the clinical picture of the patient. A vascular surgeon should be called immediately for unstable patients and operative repair expedited. For stable but symptomatic patients, further evaluation with a CT scan can be arranged to better define anatomy and facilitate operative repair. Outpatient referral for vascular surgery evaluation can be arranged if the aneurysm is asymptomatic and the diameter is <5 cm (3–5).

# Anatomy

Normal abdominal aortas (Figure 5.1) have a proximal-to-distal taper, and a loss of that taper with a diameter >3 cm indicates the presence of an AAA. An iliac diameter >1.5 cm is indicative of an iliac aneurysm. All measurements are from outer wall to outer wall (it is better to overestimate in this case than underestimate!). Significant abdominal aneurysms (i.e., high risk of rupture) are ordinarily ≥5 cm in diameter, with a fusiform shape (5). Much research has been done to correlate diameter with risk of rupture: AAAs <4 cm have a 2% per year risk of rupture, AAAs 4 to 5 cm have a 3% to 12% per year risk of rupture, and AAAs >5 cm have a 25% to 41% risk of rupture (2).

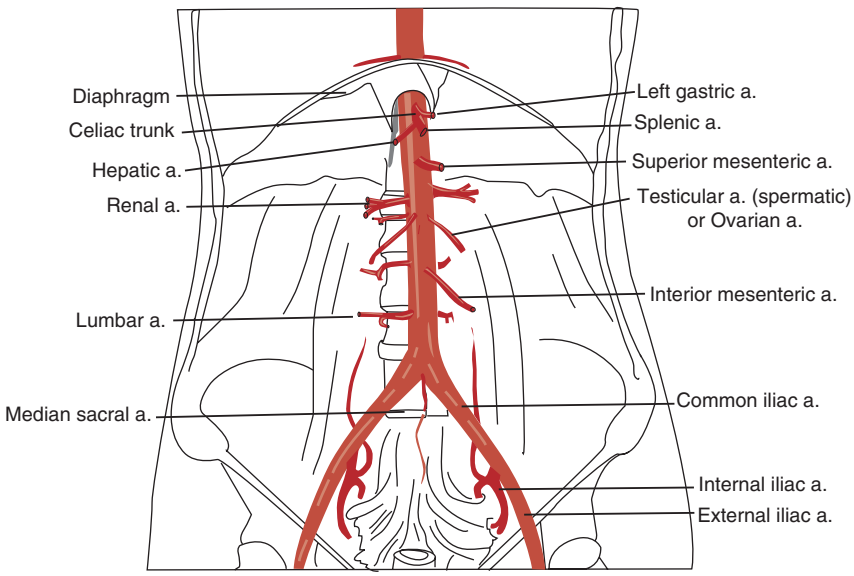


**Figure 5.1**
Normal anatomy.

# Technique

## Probe Selection

Using a standard 3.5-MHz transducer, the abdominal aorta can usually be visualized in its entirety – down to the iliacs. Ideally, a curvilinear array probe will give the best penetration, especially in patients with a larger habitus.

## Views

We recommend that at least five distinct views are obtained when recording still images of the aorta:

1. Transverse view of the proximal aorta
2. Transverse view of the mid aorta
3. Transverse view of the distal aorta
4. Transverse view of the distal aorta showing the bifurcation into both iliacs
5. Longitudinal/sagittal view of the aorta

Of course the entire length of the aorta should be imaged in real-time for a complete exam even if only the five still images listed above are documented.

The most helpful landmark for aorta scanning is the vertebral shadow – remember that both the aorta and the vena cava will be just anterior to the vertebrae. One common mistake is to set the depth on the ultrasound machine too shallow to find the vertebrae. It is recommended to set the depth as deep as the machine will allow until the vertebral shadow is found. The depth can then be decreased to get a better picture. Onscreen, the vena cava is usually noted to be just to the left of the aorta. This corresponds to the patient's right side when the probe marker faces the patient's right. Because it is a low-pressure system, the vena cava often appears triangular or teardrop shaped. The vena cava may pulsate because it is adjacent to the pulsatile aorta (or because of brisk venous return), so do not use visually observed pulsations to distinguish the two. The best way to distinguish between the vena cava and the aorta is to show the compressibility of the vena cava. The walls of the vena cava are also much thinner and less echogenic. If your machine has spectral Doppler, the waveforms of each vessel can also help to distinguish artery from vein.

### *Proximal Aorta*

Starting proximally, position the probe in the transverse orientation with the probe marker to the patient's right (Figure 5.2). The probe should be in the epigastric area just distal to the subxiphoid process and perpendicular to the patient's abdominal wall.

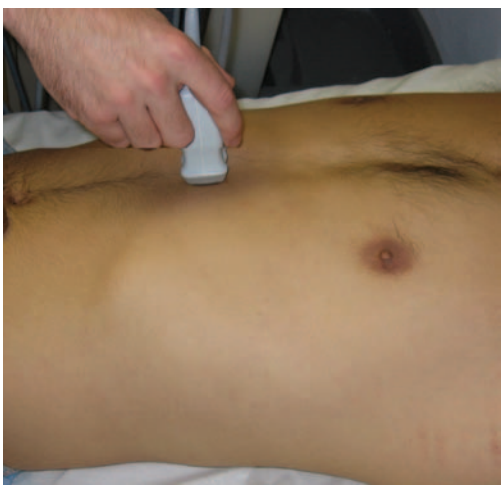

**Figure 5.2**
Probe positioning.

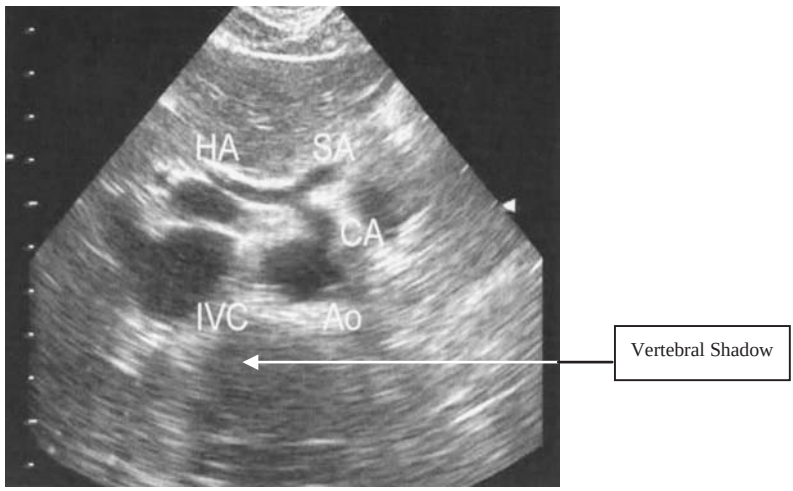


**Figure 5.3**

Most proximal abdominal aorta view including the celiac trunk. This view is rarely seen. (HA, hepatic artery; SA, splenic artery; CA, celiac artery; IVC, interior vena cava; AO, aorta).

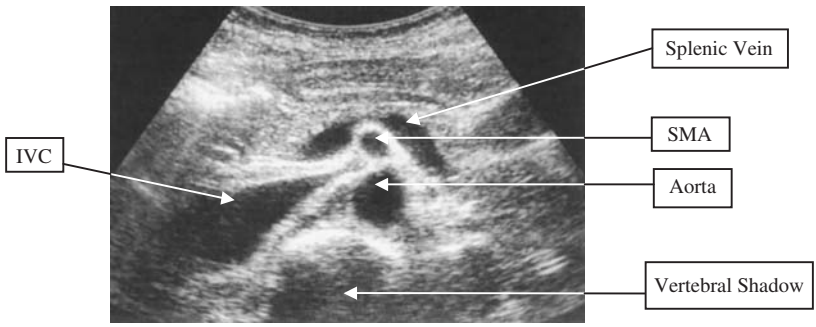


**Figure 5.4**

Standard proximal view of the abdominal aorta visualizing the superior mesenteric artery, splenic vein and left renal vein.

When scanning the proximal aorta, the left lobe of the liver is often included in the field. The most proximal level of the abdominal aorta includes the celiac trunk (Figure 5.3). However, it can often be difficult to get a view this proximal and to visualize the celiac artery. Clinically, it is exceedingly rare to have an isolated AAA that only involves the abdominal aorta from the celiac trunk to the superior mesenteric artery so it is not essential that this branch is visualized for screening purposes. If it is seen as shown in Figure 5.3, it looks like a seagull and thus, this view is called "the seagull sign." The branches of the hepatic and splenic artery from the celiac trunk can be seen. The gastric arterial branch is rarely seen in AAA screening images.

Figure 5.4 shows the more commonly seen proximal view with the bright echogenic superior mesenteric artery (SMA) just anterior to the aorta. The

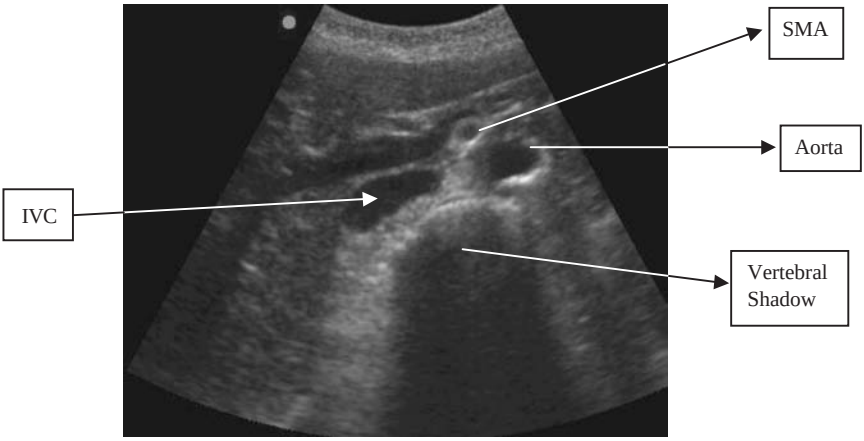


**Figure 5.5**
Standard proximal view of the normal aorta.

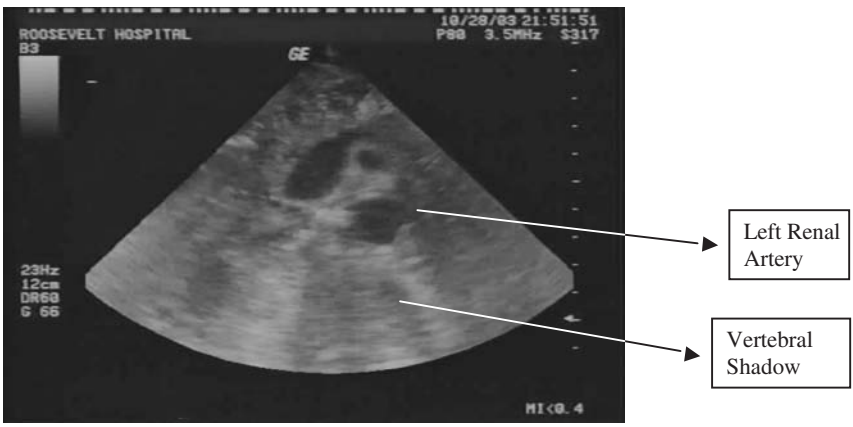


**Figure 5.6**
Abdominal aorta with renal artery visualized. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

splenic vein is seen traveling anterior to the SMA. It is even possible to see a glimpse of the renal vein as it travels under the SMA to fuse with the IVC.

Figure 5.5 shows another view of the proximal aorta with the SMA (the bright echogenic surrounded vessel). The IVC can be seen on the left, along with a good view of the vertebral shadow.

Figure 5.6 shows the view just distal to Figure 5.5. Here, the splenic vein is seen as it travels anterior to the SMA. In addition, the left renal artery can be seen as it merges with the aorta. Most of the time, however, it is difficult to visualize the renal arteries with bedside ultrasound, which is why surgeons appreciate the anatomic detail provided by a CT scan for operative planning if possible.

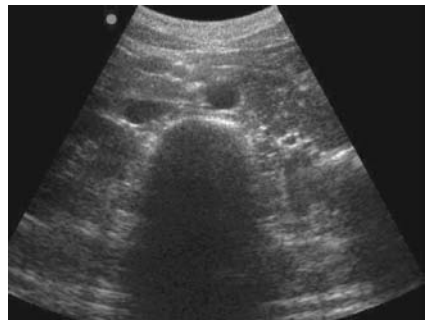

**Figure 5.7**
Midaorta.

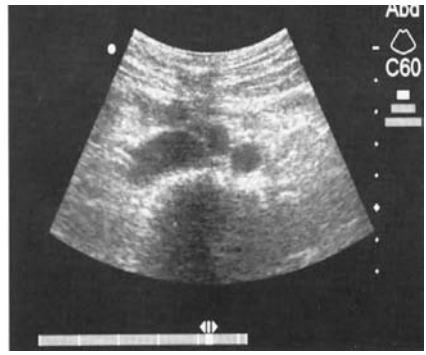


**Figure 5.8**
Distal bifurcation.

### *Midaorta*

A transverse view of the midaorta (Figure 5.7) is obtained by moving the probe caudally along the midline while maintaining a transverse orientation (probe marker to patient's right). This view lacks unique landmarks. Remember that most AAAs are infrarenal, and this portion of the aorta should be thoroughly imaged.

### *Distal Aorta*

As the probe approaches the umbilicus, the distal aorta is imaged (Figure 5.8). In most cases, the bifurcation of the aorta is located at the level of the umbilicus, or the L4 level. Careful adjustment of the angle of the probe with regard to the abdominal wall will often reveal where the aorta splits into the iliac arteries. Often, a small rocking motion angling toward the feet will be all that is required to image the split.

### *Longitudinal View*

Obtaining a long axis/sagittal plane view of the aorta is usually best obtained from the proximal to midaortic view positions. Begin by locating the aorta in the short axis/transverse plane first; then slowly rotate the probe 90 degrees with the marker toward the patient's head to obtain the longitudinal view. Again, careful side-to-side adjustment of the angle of the probe with regard to the abdominal wall will ensure that the aorta's greatest diameter is visualized (Figures 5.9 and 5.10).

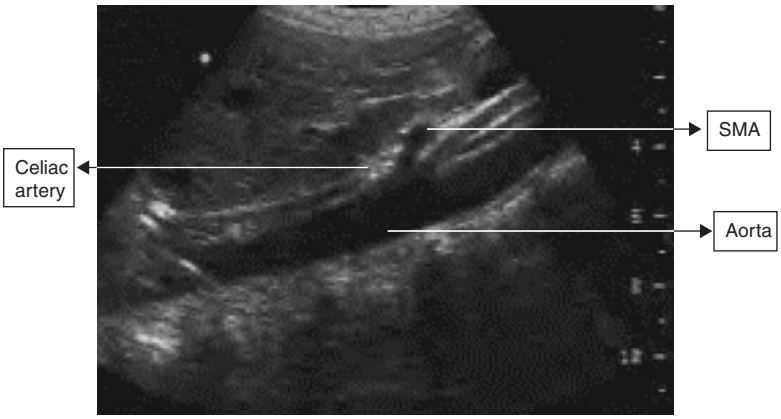


**Figure 5.9**
Longitudinal aorta with branches.

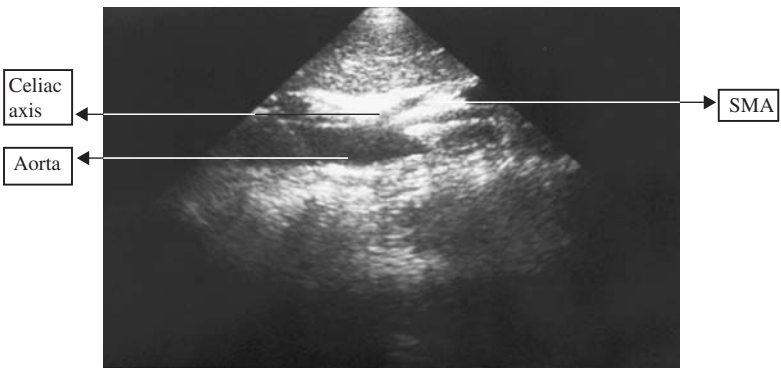


**Figure 5.10**
Longitudinal aorta.

It is also important to remember that a tubular structure is being imaged by a plane; thus, the transverse view is more accurate in terms of ensuring that the true cross section of the aorta is visualized. When imaging longitudinally, it is easy to see how a falsely low cross section of the aorta could be measured if the plane of the beam is just off midline (Figure 5.11). The reason to image in two planes is to ensure that saccular outpouchings of the aortic wall are not missed.

### *Aorta versus Vena Cava*

Differentiating between the inferior vena cava and the aorta may seem straightforward, but a few points are worth remembering. Of course, if you have the probe marker to the patient's right in most patients, then the aorta will be on right of the screen (the side without the screen marker, thus indicating the patient's left). In addition, the aorta is a thicker-walled structure than the vena cava and often develops calcifications as sequelae of

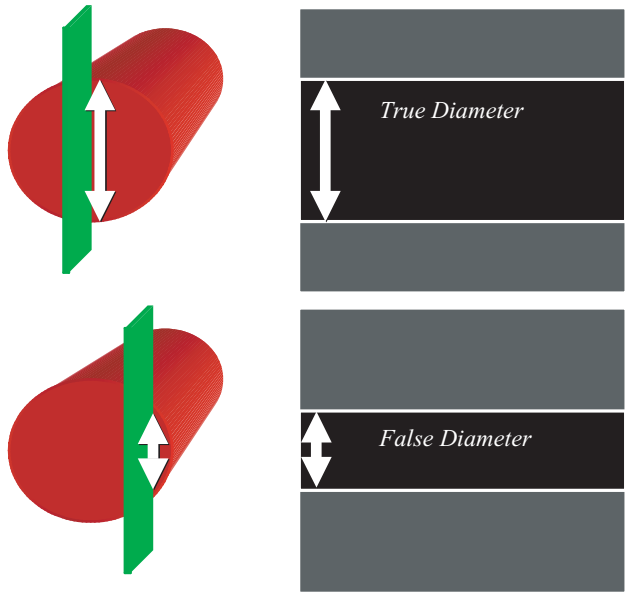


**Figure 5.11**
Longitudinal imaging.

atherosclerotic plaque; thus, it may appear to have brightly echogenic walls. The aorta is actively pulsatile; however, as mentioned, transmission of pulsations to the IVC from the aorta and the right ventricle can make this distinction difficult. The aorta is not compressible with probe pressure, whereas the vena cava is. The normal aorta tapers as it progresses distally, whereas the vena cava gets somewhat larger as it approaches the renal vessels. Finally, with deep inspirations (sniff test) the IVC will change caliber, whereas the aorta will not.

*Adequate visualization of the entire length of the aorta is required to exclude AAA.* If the diameter of the aorta (from outer wall to outer wall) appears normal over this length, then this excludes a ruptured AAA with an essentially 100% negative predictive value (6–9). Again, remember that an aortic diameter >3 cm and an iliac artery diameter >1.5 cm are considered abnormal. Do not forget to evaluate the iliac arteries – aneurysmal dilatation and rupture of the iliacs can carry significant morbidity and mortality.

# Scanning Tips

## Trouble with Aorta Scanning

*Bowel gas in the way?*

- Apply pressure to minimize artifact caused by bowel gas interposed between the probe and the aorta. Occasionally, it will be necessary to hold constant pressure to force peristalsis of the overlying bowel out of the field of view. If obesity and/or bowel gas still degrade the quality of

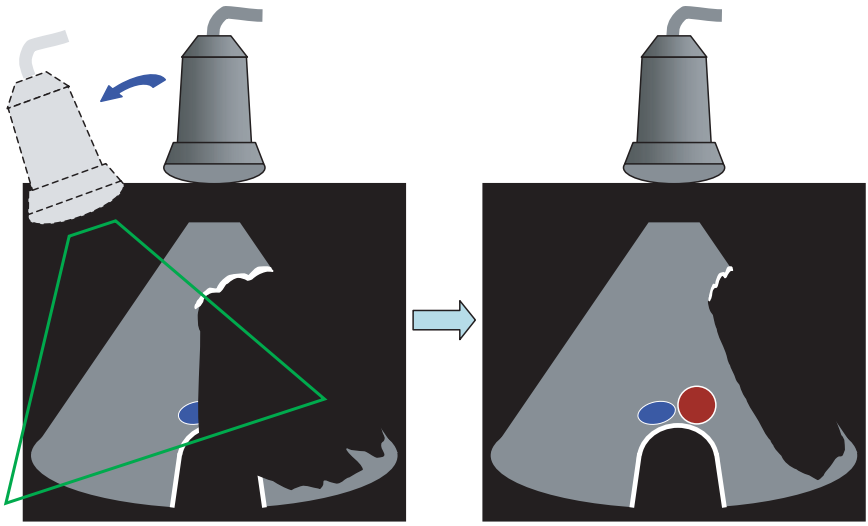

**Figure 5.12**
Probe angles to avoid bowel gas when imaging the abdominal aorta.

the images, rolling the patient into a left lateral decubitus position may help mechanically shift the bowel out of the way of the ultrasound beam.

- Jiggle the probe with gentle pressure over the offending bowel to encourage peristalsis and afford a clearer view of the aorta.
- Try imaging the transverse aorta from an angle. If bowel gas obscures the right side of your screen, move the probe to your left and angle the beam toward the aorta to visualize it from an angle. As long as the beam remains transverse, this should not alter the size of the aorta as it appears on the screen (Figure 5.12).

*Can't see the aorta at all?*

- Have the patient roll onto his or her left side, and use the liver as an acoustic window to try and view the aorta this way.
- Increase the depth to the maximum to see if you can find the vertebral shadow.

## Abnormal Images

### AAA

Figure 5.13 is a transverse view of the midabdominal aorta in an elderly patient presenting with back pain. The cursor denotes that the luminal diameter of the aorta is 8.6 cm. Because this is larger than 3.0 cm in diameter, this is an AAA. Note that the blackened center is the only area through which blood flows. The

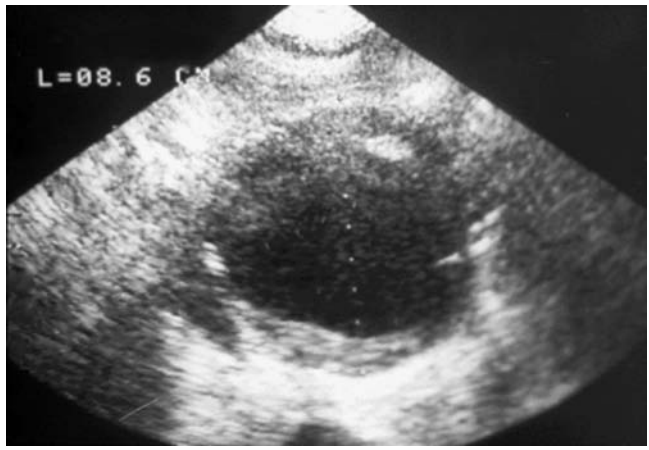


**Figure 5.13**
AAA – abdominal aortic aneurysm.

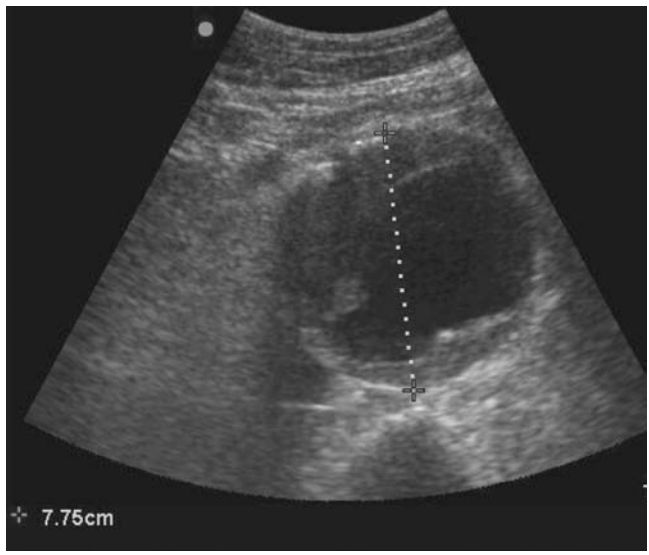


**Figure 5.14**
AAA with intraluminal clot.

thickened outer dimension of the aorta is the result of a clot and atherosclerotic plaque that are adherent to the wall (Figure 5.13 and Figure 5.14).

In this view of an AAA (Figure 5.15), lumen clot is visualized as a somewhat more heterogenous gray lining of the aorta. Caution must be used when measuring the diameter so as not to be fooled into measuring only the patent lumen but to include the luminal clot in the diameter measurement. This diameter is 7.75 cm, and it should be appreciated that the aorta is actually significantly larger than the vertebral shadow, which is a visual clue that the diameter is likely dilated.

Figure 5.15 shows a longitudinal view of an abdominal aortic aneurysm. It is easy to appreciate the fusiform shape in these views.

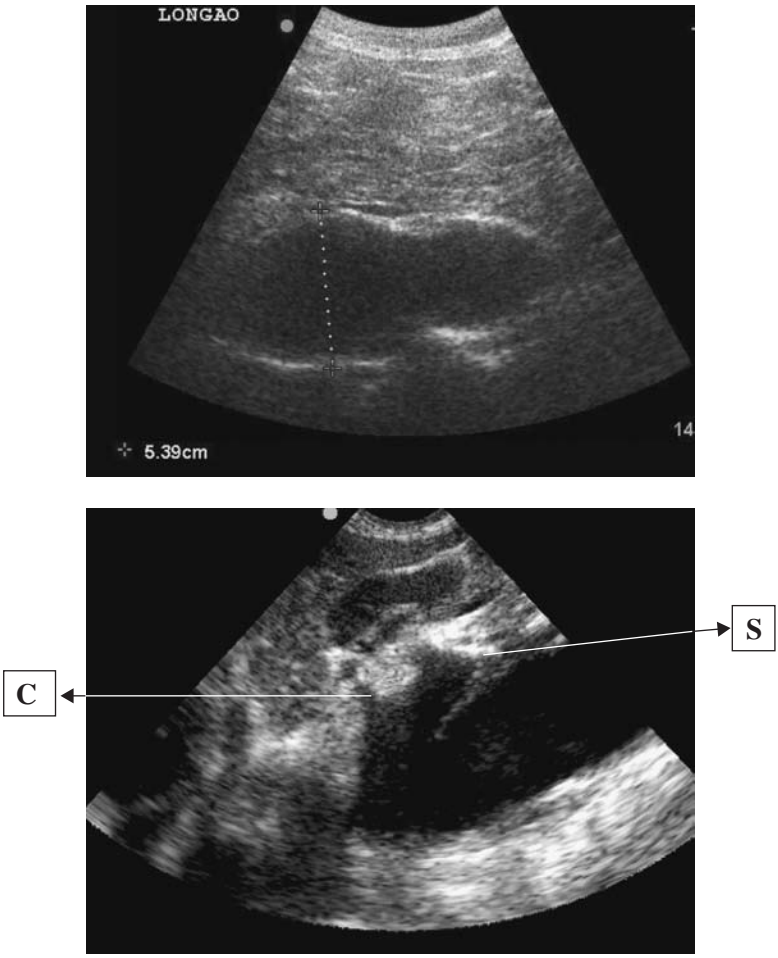


**Figure 5.15**

Two longitudinal views of fusiform AAA (*top*) and proximal AAA with the celiac (C) and superior mesenteric (S) arteries branching off (*bottom*).

## Aortic Dissection

CT is a much more accurate test for dissection and only rarely will bedside ultrasound be able to image the flap of an aortic dissection. However, if images similar to those in Figures 5.16 to 5.18 are seen (in particular, the dilated aortic root as seen in Figure 5.18), the physician should have a very high suspicion for aortic dissection, and immediate consultation should be arranged.

# Sample Clinical Protocol

A sample protocol for incorporating ultrasound into the evaluation for AAA is detailed in Figure 5.19. Note that the test is most useful in a stable patient when AAA is excluded, or in an unstable patient in whom a large AAA is found.

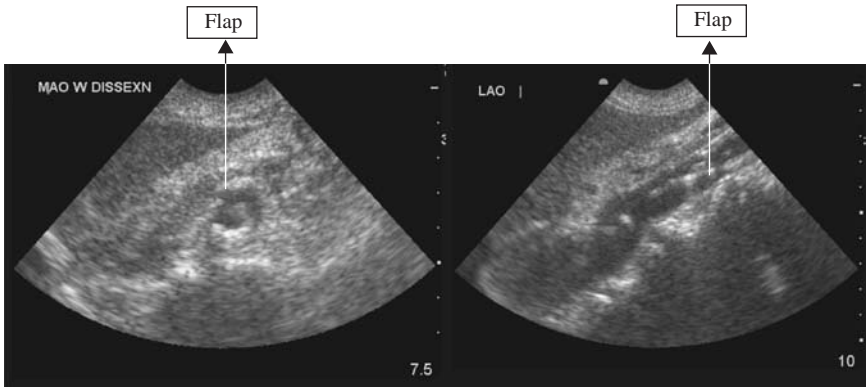


**Figure 5.16**

Transverse and longitudinal view of aorta with visible flap within the lumen.

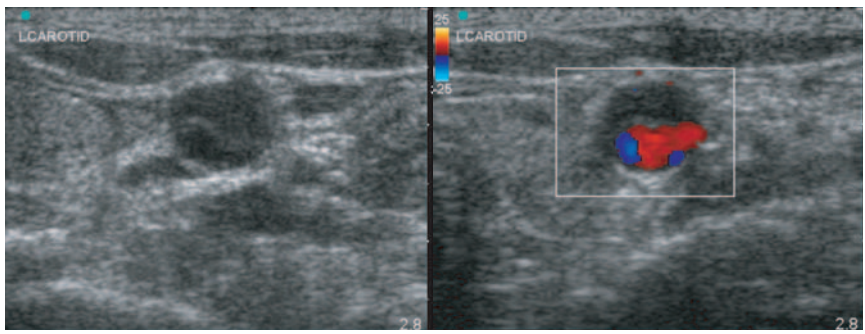


**Figure 5.17**

This dissection also extended into the carotid as a flap is seen in the image on the left and confirmed with Doppler flow.

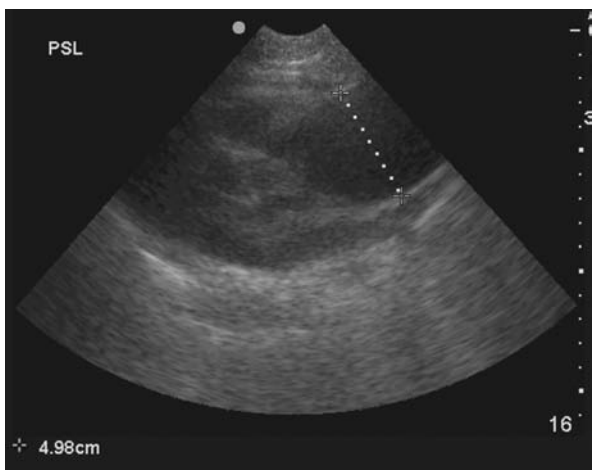


**Figure 5.18**

Parasternal long axis view of the heart reveals a greatly enlarged aortic root/outflow tract, confirming this is a type-A dissection. Courtesy of Dr. Andrew Liteplo, Massachusetts General Hospital, Boston, Massachusetts.

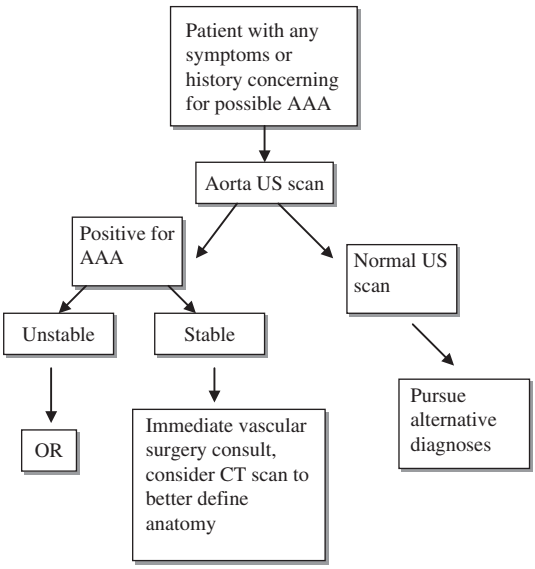


**Figure 5.19**
Sample clinical protocol.

Further imaging is warranted for any technically limited bedside study, or in a stable patient without a clear diagnosis.

## Literature Review

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Plummer et al. (1) | Randomized patients to ultrasound vs. standard of care diagnostics and compared time to diagnosis and OR. | US improved time to diagnosis (5.4 min vs. 83 min) and improved time to disposition for patients requiring operative intervention (90 min vs. 12 min). | Provided support for improved diagnosis and disposition for patients with symptomatic AAA who received bedside US. |
| Tayal et al. (6) | Prospective study of accuracy and outcome of bedside US in diagnosis of AAA. | 29/125 patients diagnosed with AAA over 2 years. PPV 93% (27/29) and NPV 100%. Immediate OR for 10/27 without confirmatory study – all with intraoperative confirmation of AAA. | PPV and NPV numbers provide strong support for ED US as AAA screening test. Additional data for more rapid disposition (10/27 for immediate OR). |
| Limet et al. (4) | Analysis of expansion rate and incidence of rupture in AAA. | AAA $<4$ cm have 2%/year risk of rupture, 4–5 cm with 3%–12%/year risk of rupture and $>5$ cm have 25%–41%/year risk of rupture. | Further defines diameter at which AAA needs urgent vs. emergent treatment. |

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# 6 Renal and Bladder

## Introduction

The kidney and bladder are two of the most sonographically accessible organs. The evidence for using ultrasound to make lifesaving diagnoses in this application is not as apparent as it is for cardiac or aortic ultrasound (except, of course, if flank pain and hydronephrosis are the result of a rapidly expanding AAA – see Chapter 5). Indeed, it is accurate to say that CT is dramatically more sensitive and specific in detecting ureteral stones and that ultrasound has a very low specificity for identifying ureteral stones (1–4). However, despite the advantages of CT for nephrolithiasis, there is still a role for ultrasound in evaluating the urinary tract in the emergency setting. In the most straightforward case, US identification of mild or moderate unilateral hydronephrosis in a patient with known renal colic and normal renal function testing (and a normal aortic screening evaluation) can obviate further radiologic testing. Patients who have relative contraindications to radiation exposure (pregnancy, pediatric patients) can also have ureteral obstruction evaluated by ultrasound. Renal ultrasonography easily and rapidly obtains evidence for or against high-grade obstruction, thereby expediting decisions regarding management and disposition (5,6).

In addition, determination of bladder volume is another important indication for urinary tract ultrasound. Before catheterizing a patient to evaluate for postrenal obstruction or urinary retention secondary to neurologic events, an ultrasound can give an estimation of bladder volume and indicate whether catheterization is even necessary. Pediatric patients can also have bladder volume evaluated with ultrasound. If they have a contracted bladder, catheterization or suprapubic taps should be postponed until after hydration to ensure invasive procedures are done with maximal chance of success (7). Finally, ultrasound-guided suprapubic taps have shown fewer complications and superior outcomes (8).

## Focused Questions for Renal and Bladder Ultrasound

The questions for renal ultrasound are relatively straightforward:

1. Is there hydronephrosis?
2. Is the bladder distended?

## Anatomy

The renal cortex has a homogenous appearance on ultrasound, which is slightly less echogenic (less bright) than the neighboring liver in normal

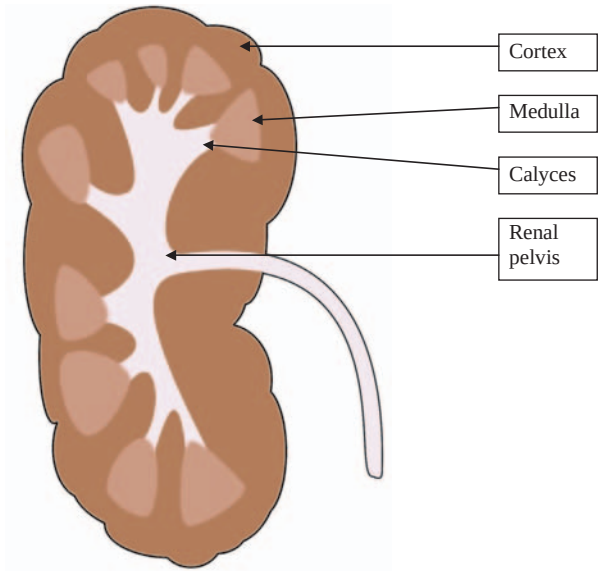



**Figure 6.1**
Renal anatomy. Image courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

physiologic states. The renal medulla, which forms the pyramids that point toward the pelvis of the kidney, is significantly less echogenic than the surrounding cortex. In some patients, the renal pyramids are surprisingly prominent and hypoechoic. Do not mistake such pyramids for renal cysts or hydronephrosis. The pyramids are discreet anechoic spaces that do not connect with each other or the renal pelvis (Figure 6.1). The renal pelvis appears as an echogenic or brighter central complex within the kidney. The hyperechoic stripe surrounding the kidney represents Gerota's fascia. Both kidneys are ordinarily 9 to 12 cm in length, 4 to 5 cm in width, and within 2 cm of each other in terms of size (Figure 6.2). Because the spleen is smaller than the liver, the left kidney will be positioned more superior and posterior than the right kidney.

The normal ureter is not ordinarily visualized in the bedside scan, but when dilated, it can sometimes be visualized.

# Technique

## Probe Selection

The 3.5-MHz transducer is ordinarily used in adults, although very good images can often be obtained in thin subjects using a 5-MHz probe.

## Views

Images of both affected and unaffected kidneys in longitudinal and transverse planes should be obtained. As with other structures, it is absolute necessary to carefully pan through the kidneys in both planes to examine the entire

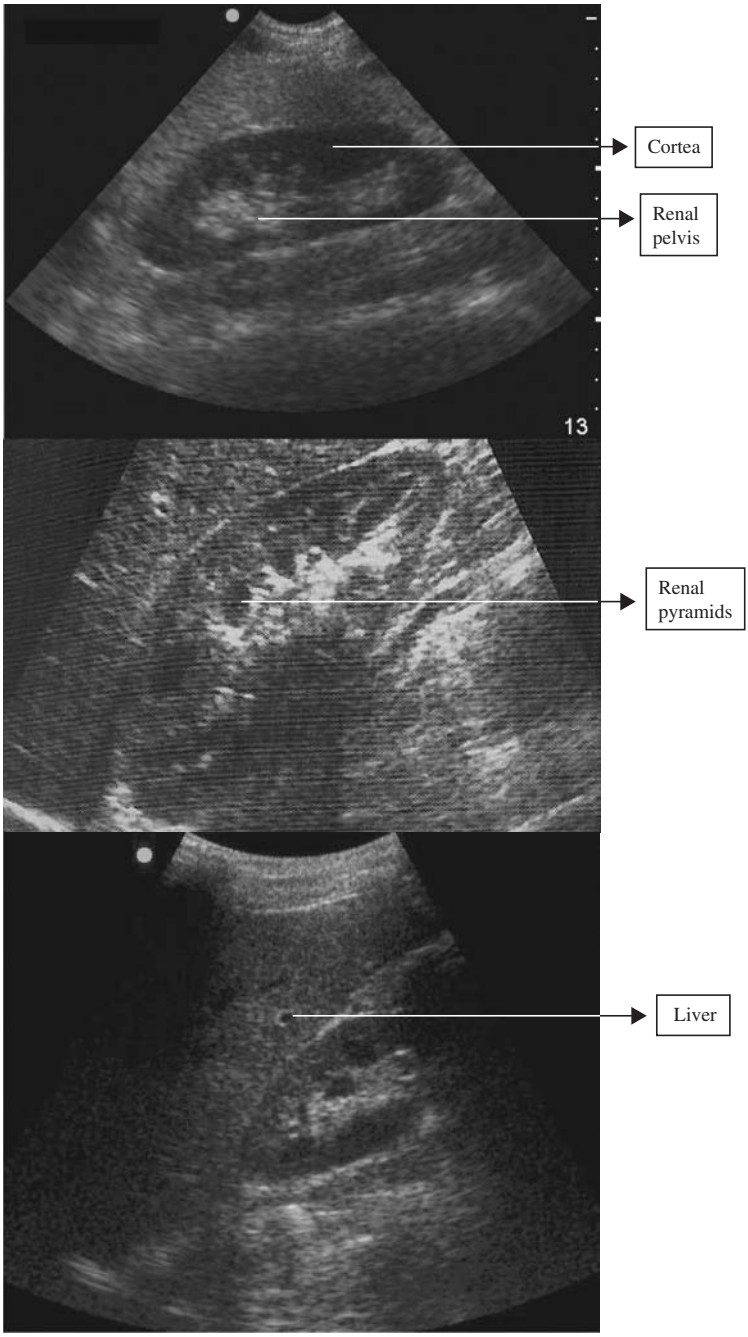



**Figure 6.2**

Three normal longitudinal views of the kidney–prominent pyramids are seen in both the bottom two images but as the collecting system is still echogenic or brighter and thus not dilated, these pictures show no hydronephyosis.

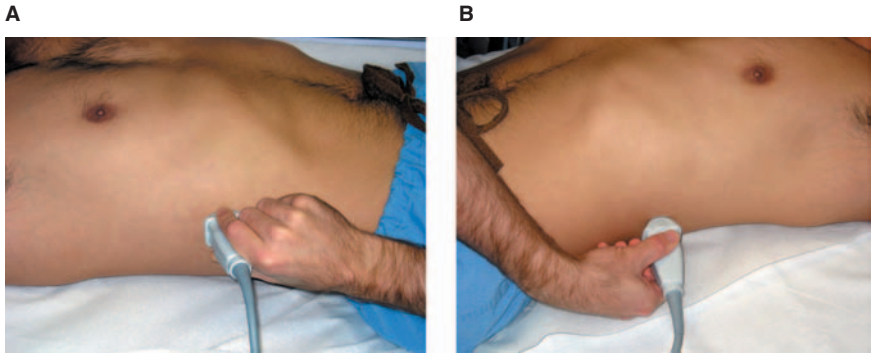



**Figure 6.3**
Probe positions useful in visualizing the right (A) and left (B) kidneys.

parenchyma. Finally, suprapubic views of the bladder complete the urinary tract evaluation.

Although the technique for visualization of the kidneys was discussed in Chapter 2, we review the probe positioning here to reinforce the technique. To visualize the right kidney, begin with the patient in the supine position. Place the transducer along the right midaxillary line, below the costal margin with the marker toward the patient's head (Figure 6.3A). Move the transducer incrementally from the costal margin to the ileac crest along the midaxillary line to find the kidney. It will be necessary to rotate/twist the transducer on its vertical axis to obtain the kidney in its maximal length because of the kidney's oblique lie. Once an adequate longitudinal view is obtained, rotate the transducer on its vertical axis 90 degrees to obtain the transverse view. Again, scan the kidney from superior to inferior poles to completely evaluate the parenchyma. When scanning longitudinally be sure to fan anterior to posterior. When scanning transversely fan from the superior to inferior pole.

To visualize the left kidney, the same technique is employed. However, because of interference from air in the stomach and intestine, it is often easier to obtain images using a more posterior window. Begin by placing the transducer along the left posterior axillary line (Figure 6.3B). Again, move the transducer between the costal margin superiorly and the iliac crest inferiorly to find the kidney. As with the right kidney, rotate/twist the transducer to find the kidney's longest axis before scanning through the entire kidney. Do not forget to obtain a transverse window and to fan throughout the transverse plane.

Scanning the left kidney is more difficult because of the left kidney's relatively cephalad positioning, which results in marked obscuration by rib shadows. Having the patient take a prolonged deep inspiration will bring the diaphragm, spleen, and left kidney down and may allow the sonographer to circumvent interfering rib shadows. You may also try positioning the patient in the right lateral decubitus position.

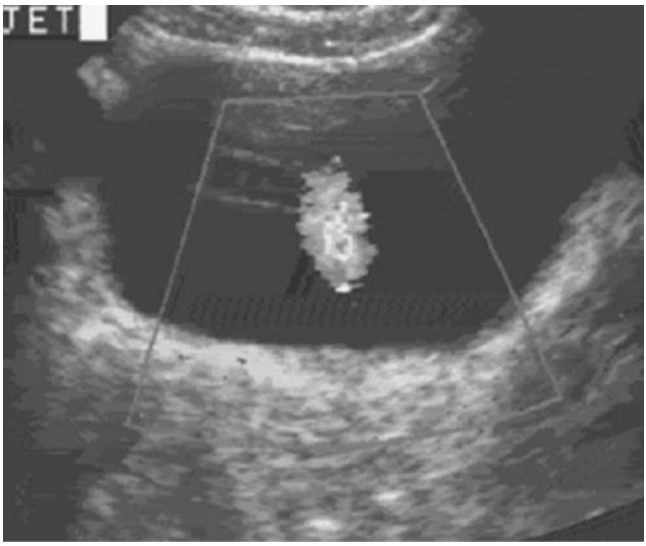



**Figure 6.4**
Transverse view of a filled bladder at the level of the trigone. Hyperechoic image in the center of the color Doppler field represents a ureteral jet. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

The bladder, which is ideally moderately filled at the time of examination, should be imaged with the transducer placed suprapubically. Again, the bladder should be scanned thoroughly in both longitudinal/sagittal and transverse planes. If your ultrasound machine is equipped with color Doppler technology, it is possible to record the presence or absence of ureteral jets. By using color Doppler techniques on the trigone of the bladder, you may observe a jet of urine entering the bladder (Figure 6.4). Observing bilateral ureteral jets *in a patient with normal hydration* provides evidence against the diagnosis of obstructive uropathy.

## Bladder Volume Estimation

Bladder volume estimation can be calculated by simple formulas that approximate the bladder to either an ellipsoid or a cylinder. For the clinical purposes of determining retention and/or postvoid residuals, these methods have good support in the literature and have good correlation with actual catheterization volumes (9–12). The difficulty is that slightly different formulas have been used in different studies and portable ultrasound machines use varying automated volume calculations. Initially, it is instructive to do the calculations by hand to ensure that the automated function is accurate on your machine. The quickest calculation to use (0.75 × width × length × height) is based on research correlating these distance measurements with catheterized volume and seems to have the best correlation factor ($r = 0.983$) (12). However, other studies have used the following formulas and also had good results (Ellipsoid formula: 4/3 PI × R1 × R2 × R3; Cylinder formula: 3.14 × r2 × height) (10,11).

# Scanning Tips

## Trouble with Renal Scanning

*Pyramids versus hydronephrosis?*

- Pyramids will be just below the cortex, and the kidney will still have a collapsed and hyperechoic pelvis and collecting system. They also do not connect one to another. Hydronephrosis should connect to a dilated renal pelvis.

*Renal cyst versus hydronephrosis?*

- Renal cysts are usually located in the cortex or periphery. They are smooth walled and fluid filled but do not connect to the pelvis or collecting system.

*False positives*

- Patients who are pregnant or have BPH can have mild to moderate dilatation of their collecting system because of external compression of the ureters or overdistended bladders, respectively. The hydronephrosis in the cases should resolve after bladder emptying.

*False negatives*

- Patients who are severely dehydrated can have falsely negative renal scans for hydronephrosis. If there is clinical concern, a repeat renal scan should be done after some IV hydration.

# Normal Images

The following images are examples of normal renal ultrasound scans.

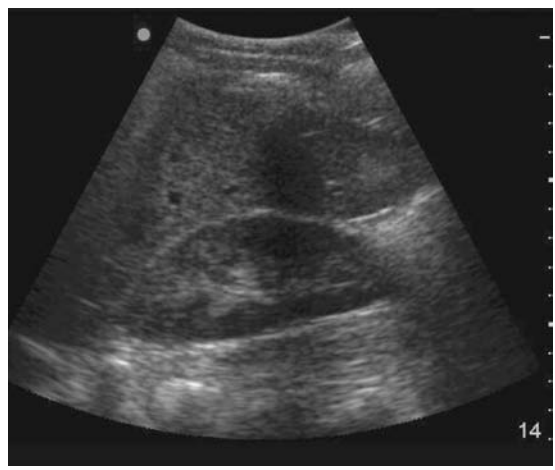



**Figure 6.5**
Normal longitudinal view of the right kidney. Morison's pouch is well visualized here, too.

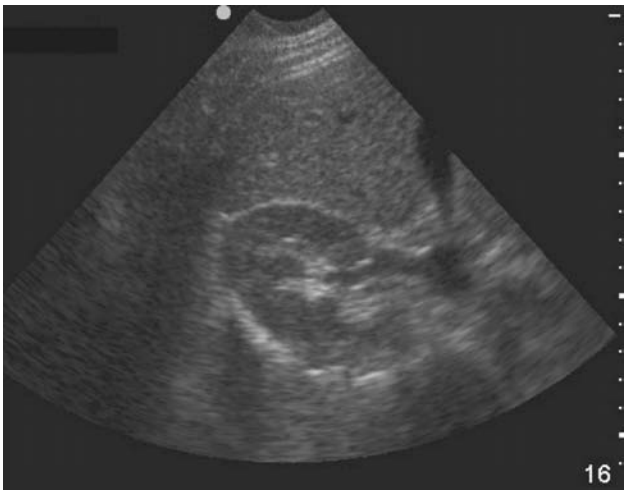



**Figure 6.6**
Normal transverse view of the kidney.

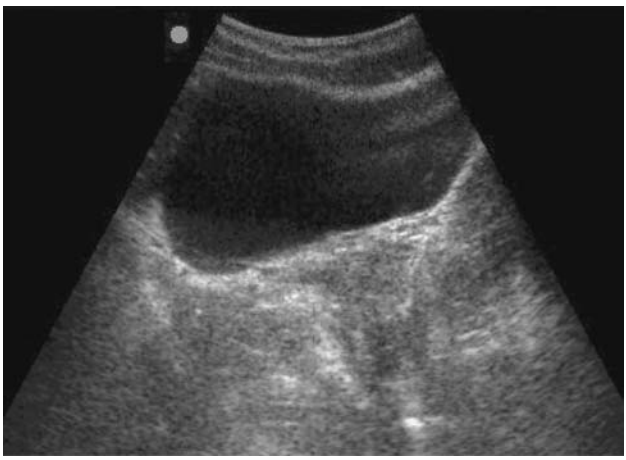


**Figure 6.7**
Transverse view of the bladder with no fluid seen outside the bladder wall.

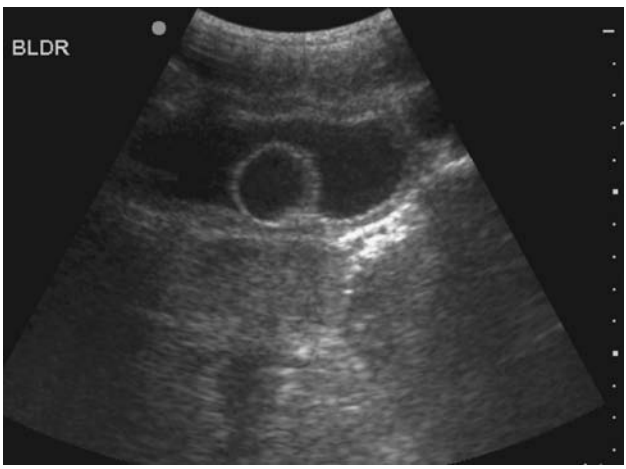



**Figure 6.8**
The bulb of the Foley catheter is visualized on ultrasound with a partially decompressed bladder.

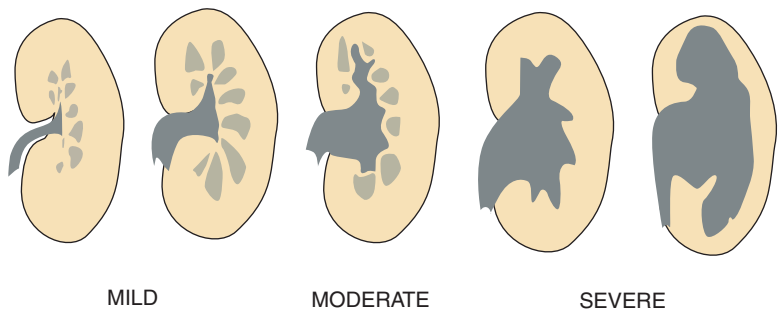
# Abnormal Images

## Hydronephrosis

According to Grainger and Allison's *Diagnostic Radiology* (13), the following grading system is used by radiologists/sonographers:

- Grade I – slight blunting of calyceal fornices
- Grade II – blunting and enlargement of calyceal fornices but easily seen shadows of papillae
- Grade III – rounding of calices with obliteration of papillae
- Grade IV – extreme calyceal ballooning

**Grades of hydronephrosis**



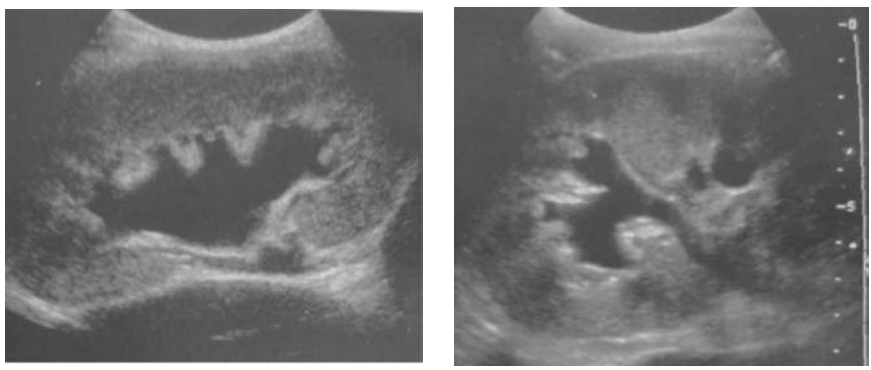



**Figure 6.9**
Longitudinal and transverse views of the kidney with moderate hydronephrosis.

Chronic hydronephrosis can cause thinning of the renal medulla. Such distortion of the renal architecture is only seen in long-standing obstruction.

Bilateral evidence of hydronephrosis is less likely to be caused by two discrete ureteral events than by bladder outlet obstruction.

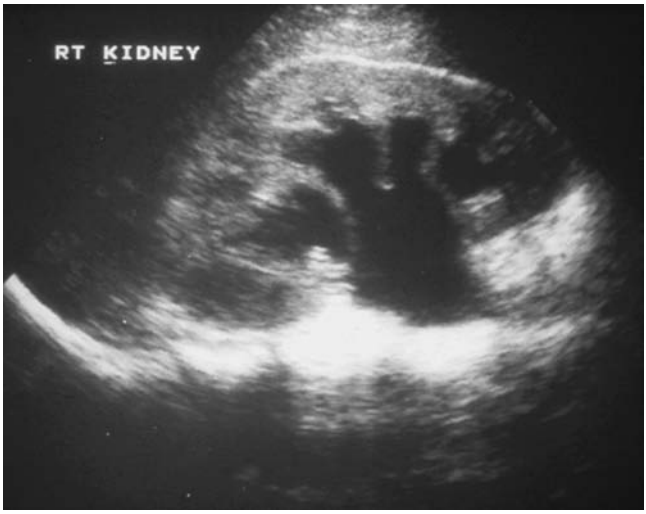



**Figure 6.10**
Dilated right renal pelvis with splaying of the renal calyces indicative of severe hydronephrosis.

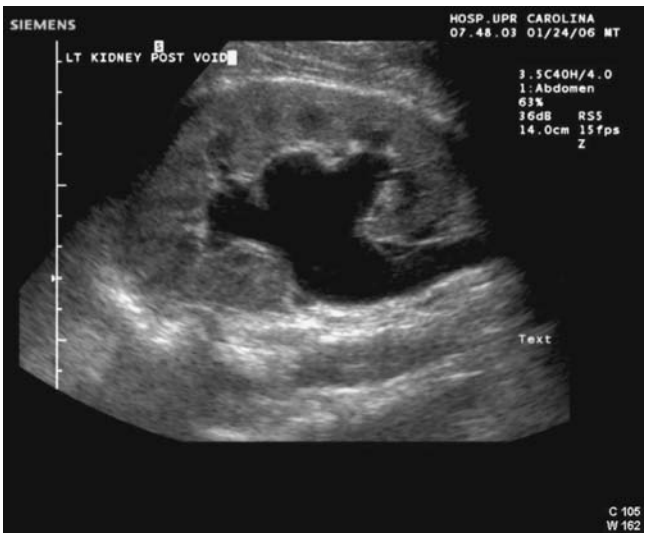



**Figure 6.11**
Another image of severe hydronephrosis. In this image, the pyramids can be seen as distinct from the dilated renal pelvis. Image courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

It is expected that pregnancy and an overdistended bladder cause hydronephrosis – sometimes to a large degree. Another common finding that can be confused with acute obstruction is that of an extrarenal pelvis. This is a developmental variant in which the collecting system lies predominantly outside the kidney.

Generally, in the normally hydrated patient, absence of any evidence of dilatation virtually rules out acute renal colic as the cause of severe pain.

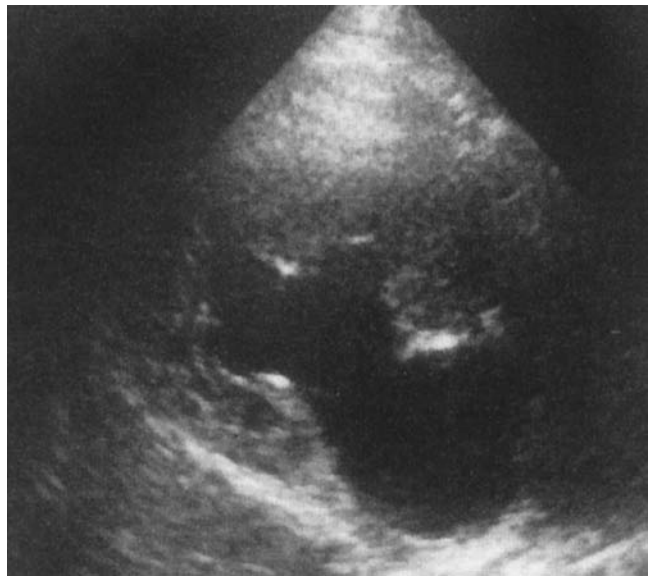


**Figure 6.12**
A very dilated proximal ureter and renal pelvis.

## Other Pathologic Images

To review, the focused question of bedside renal ultrasound is to assess for the presence of hydronephrosis and to look for bladder volume. The following images of renal pathology may be seen during bedside screening, but these diagnoses should be made by formal scanning and if seen, these patients should be referred for further imaging either immediately or as an outpatient based on their clinical status.

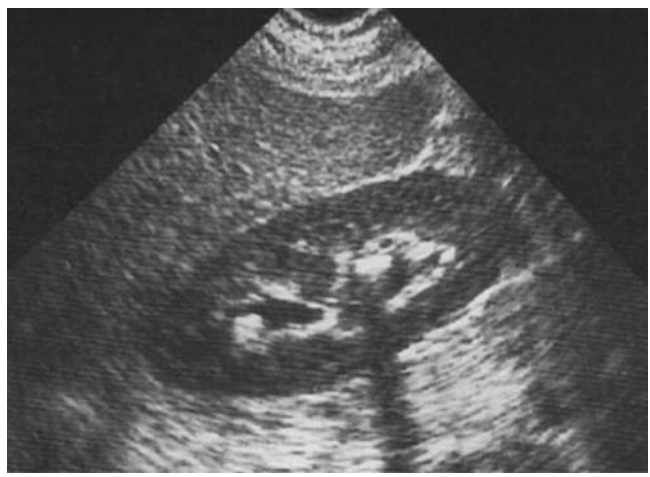


**Figure 6.13**
The unusual image where a renal calculus is actually visualized on ultrasound. However, because there is minimal dilatation of the collecting system, this stone is not likely responsible for renal colic. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

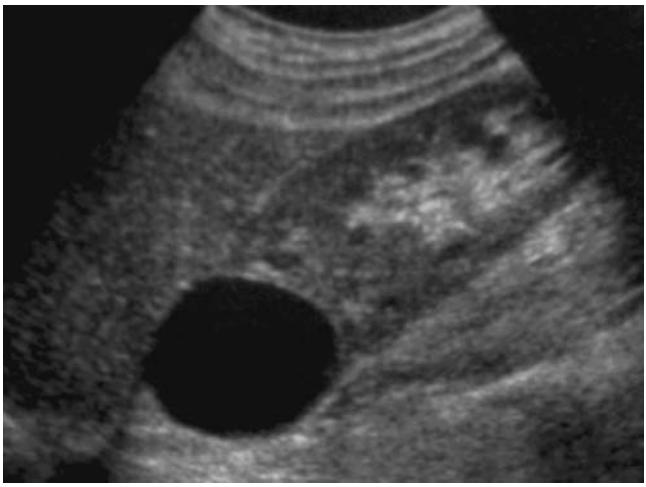


**Figure 6.14**
Renal cyst.

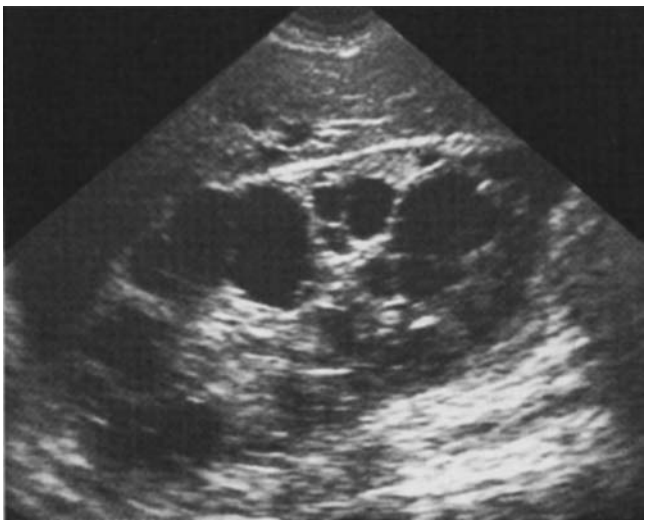


**Figure 6.15**
Polycystic kidney disease.

Figure 6.14 shows a renal cyst. This is a smooth-walled, anechoic, fluid-filled structure far from the collecting system. The regularity of this structure is reassuring for non-malignant etiologies.

The kidney visualized in Figure 6.15 is full of irregular cysts. This is a patient with polycystic kidney disease.

As mentioned previously, most kidneys are darker or less echoic than adjacent live parenchyma. When the kidney is brighter or more echoic, it is most likely inflamed and/or infected; this is a marker for acute renal failure (14) (Figure 6.16).

As more bedside ultrasounds are performed, it is increasingly likely that asymptomatic pathology may be uncovered, including the diagnosis of renal

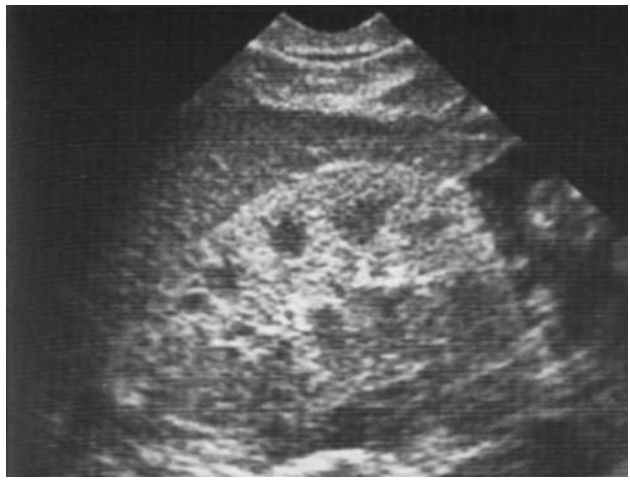


**Figure 6.16**
Acute renal failure.

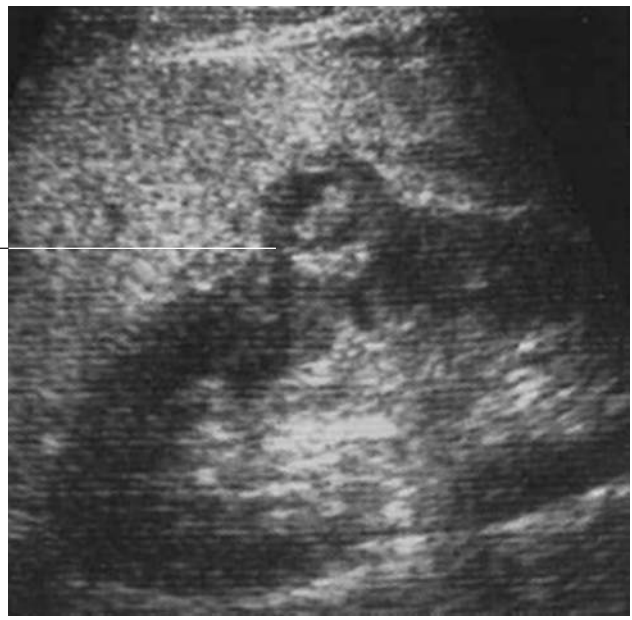



**Figure 6.17**
Renal cell carcinoma.

cell carcinoma (15) (Figure 6.17). The important key to remember is that the renal cortex should always be smooth and regular. Whenever irregular masses or distortions are seen, patients should be informed and should have close follow-up with further radiologic imaging.

As always, important communication between bedside point-of-care sonographers and patients about the limited nature of their test is essential; bedside

ultrasound is designed to answer focused questions. Any abnormality outside this scope of practice should be referred for formal testing.

## Sample Clinical Protocol

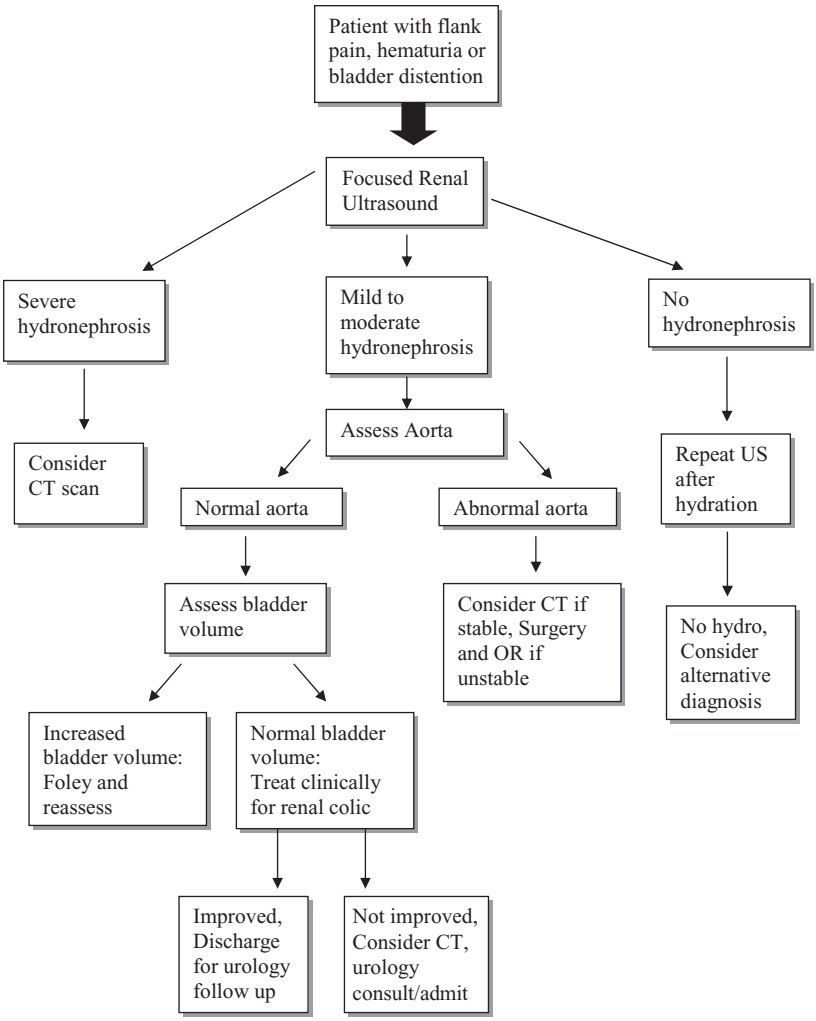



**Figure 6.18**
Sample clinical protocol.

## Literature Review

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Sheafor et al. (2) | Prospective comparison of helical CT and US in patients with renal colic. | CT much more sensitive in identifying stones (96% vs. 61%). Sensitivity for CT and US more comparable in identifying hydronephrosis (100% vs. 92%). | Radiology literature showing advantages of CT but also that US is comparable when looking for hydronephrosis. |
| Chan (12) | Compare bladder volume estimations calculated using US with catheterized bladder volumes. Urinary retention suspected clinically. | Correlation of two measurements highly significant ($r = 0.983$) | Provided data supporting ultrasound use in calculating bladder volume. |
| Gaspari and Horst (6) | Evaluate sensitivity and specificity of renal US in diagnosing renal colic as compared to helical CT. Impact of hematuria on test characteristics was also evaluated. | In patients with hematuria, US was 87.8% sensitive and 84.8% specific for renal colic (86.8% and 82.4% without hematuria). | US shows very good sensitivity and specificity for diagnosing renal colic. |

## New Directions

One area of potential research for renal bedside ultrasound is assessing the outcomes and number of patients identified with renal cell cancer when performing renal scanning in the ED. As Mandavia et al. (15) showed, incidental cancer identification is not unexpected given the volume of ultrasound scanning that is performed in most major trauma centers. In the future, perhaps patients will be screened for both AAAs and renal cell cancer when they come to the ED.

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# 7 Gallbladder

## Introduction

Gallbladder disease is well suited for emergency ultrasound investigations. Use of diagnostic ultrasound frequently leads to either confirmation of a presumptive diagnosis or rapid narrowing of the differential diagnoses. However, if biliary ultrasound findings are equivocal or conflict with initial clinical impressions, the emergency physician should be reminded that formal studies or other imaging modalities may be complementary.

In this section, the application of bedside ultrasonography in the evaluation of the gallbladder is discussed.

## Focused Questions for Gallbladder Ultrasound

As with all emergency bedside ultrasound, it is important to remember the focused questions you are trying to answer with your ultrasound. In gallbladder ultrasound, these questions are as follows:

1. Are there gallstones?
2. Does the patient have a sonographic Murphy sign?

It is also useful to know the following:

1. Is the common bile duct dilated?
2. Is the anterior wall thickened?
3. Is there pericholecystic fluid?

However, the first two questions are far and away the most helpful and diagnostic (1,2).

## Anatomy

It is important to remember that the gallbladder is not a fixed organ, so it can move to a variety of locations in the right upper quadrant (Figure 7.1). The gallbladder neck does have a fixed relationship to the main lobar fissure and the portal vein. The main lobar fissure connects the right portal vein to the gallbladder neck, and the fissure can be traced between the two (Figure 7.2). Another anatomic relationship that is reliable is that the bile duct is always anterior to the portal vein. Moreover, ducts appear to have brighter, more echogenic walls than veins or arteries on ultrasound because they are fibrous and thicker than the thin walls of portal vessels or hepatic veins.

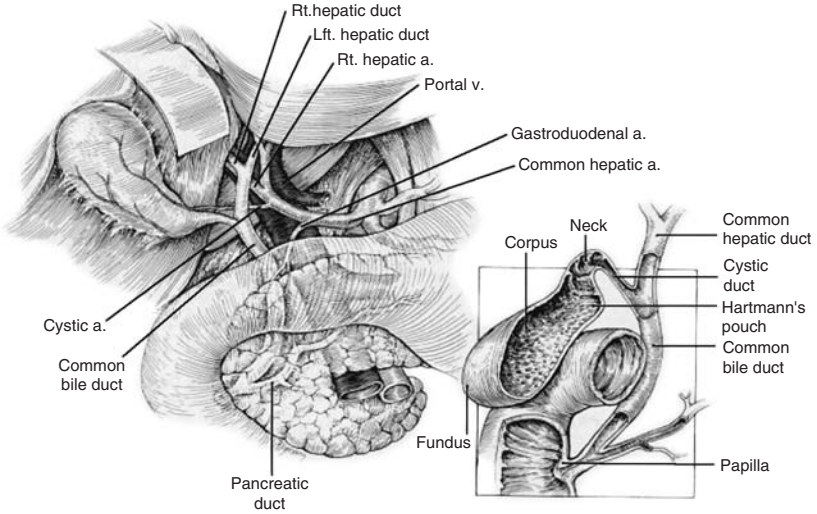


**Figure 7.1**

Gallbladder anatomy. From Townsend CM, Beauchamp DR, Evers MB, Mattox KL and Sabiston DC (ed). In *Sabiston Textbook of Surgery*. 16th ed. Philadelphia: WB Saunders; 2001:1077, Figure 50–1.

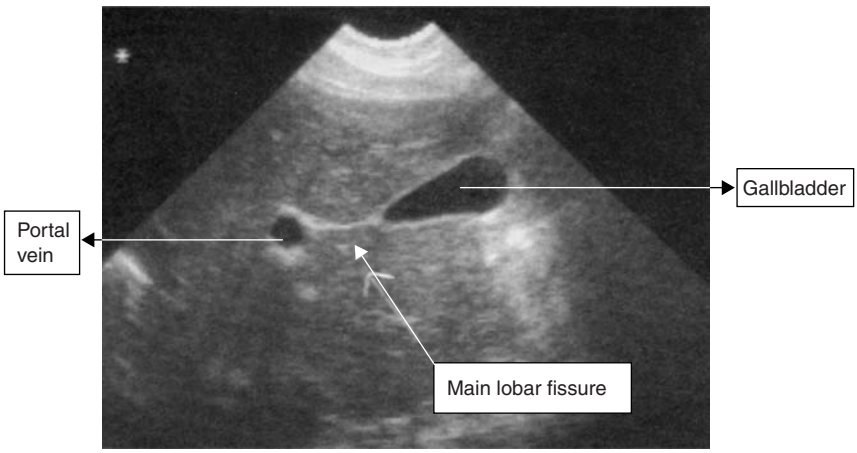


**Figure 7.2**

Relationship of gallbladder and portal vein with main lobar fissure.

# Technique

## Probe Selection

When scanning the gallbladder, the curvilinear or abdominal probe with the curved footprint is most commonly used. Occasionally, the microconvex probe with a smaller footprint is used to image a gallbladder located posterior to the ribs. The frequency range for both probe choices is usually 2.5 to 5.0 MHz.

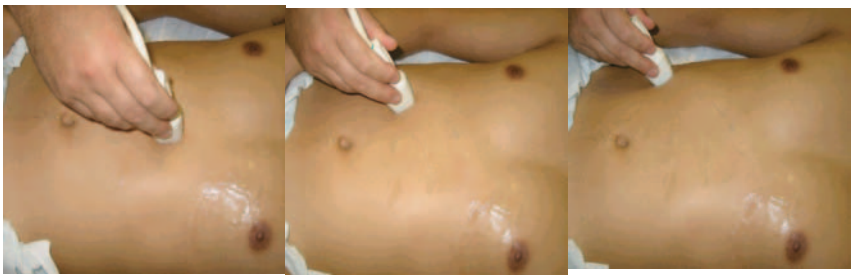

**Figure 7.3**
Probe positioning in gallbladder scanning.

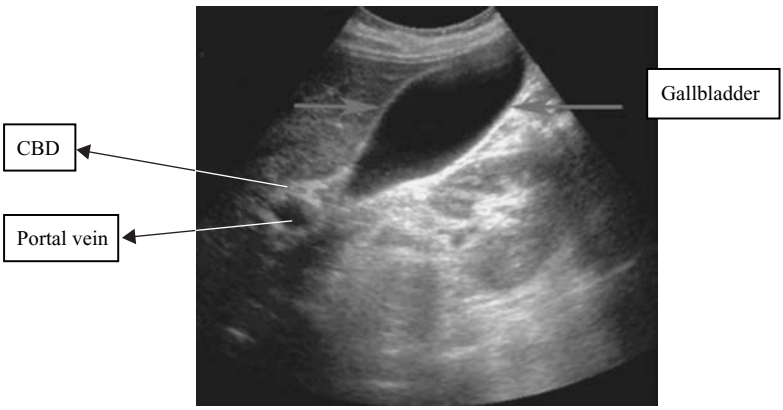


**Figure 7.4**
Exclamation point. Longitudinal view of the gallbladder points to the portal vein. The common bile duct is the small circular structure sitting on top of the portal vein.

## Views

Usually, the patient is in the supine position, but the left lateral decubitus or upright sitting positions can be used in difficult cases.

Place the probe under the right costal margin, directed toward the right shoulder with the probe marker longitudinal (Figure 7.3). Sweep along the costal margin until an image of the gallbladder is obtained. If you are experiencing difficulty, you can have the patient take and hold a deep breath in order to bring the gallbladder down below the rib margin. If you continue to have difficulty, try placing the patient in the left lateral decubitus position.

The next step is to obtain a true longitudinal view of the gallbladder. This is done by rotating the probe on its axis. Once this is done, try to demonstrate the relationship with the portal triad. When you obtain a long axis view of the gallbladder, main lobar fissure, and the right portal vein, it will take on the appearance of an exclamation point (Figures 7.4 and 7.5). This is the way to ensure that the structure you are visualizing is indeed the gallbladder, and not a loop of bowel or the IVC.

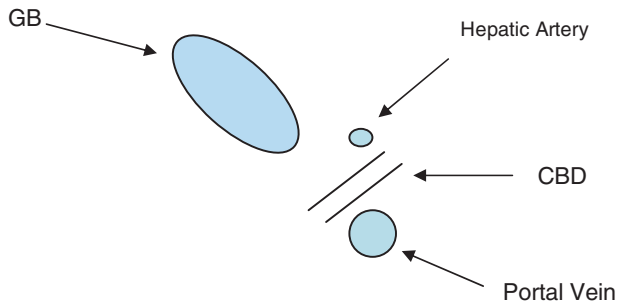


**Figure 7.5**
Exclamation point schematic.

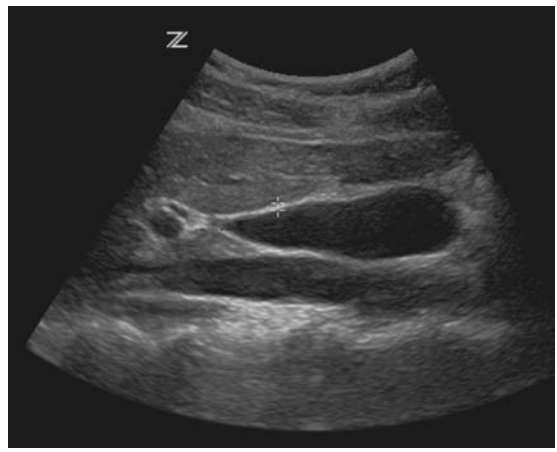

**Figure 7.6**
Exclamation point with CBD viewed well just anterior to portal vein. The fluid-filled structure seen behind the gallbladder is the IVC. Courtesy of Dr. Greg Press, University of Texas – Houston, Hermann Memorial Hospital, Houston, Texas.

With a view of this characteristic exclamation point, gentle manipulation can reveal the common bile duct (CBD) – two bright/hyperechoic lines anterior to the portal vein (Figure 7.6).

In some cases, the CBD and hepatic artery can be distinguished using color flow Doppler. This can be helpful because the hepatic artery and portal vein will light up, showing the blood flow within. The common bile duct will remain dark (i.e., no flow – see Figures 7.10–7.12 below).

Next, scan the gallbladder in multiple longitudinal and transverse planes. It is important to fan through the entire gallbladder in a longitudinal and transverse plane to make sure you are not missing any stones. Often, the shadowing artifact is your only tip-off that a stone is present – even if you cannot see the white reflective wall of the stone itself. Follow the shadow, and you can usually find the stone.

Finally, if evaluating for acute cholecystitis, find the fundus of the gallbladder and use the probe tip to compress the fundus to assess the presence or absence of a "sonographic Murphy sign." This is probably the most specific sign of inflammation, and the technical challenge is to make sure that you are below the costal margin so that the probe pressure is directly compressing the fundus and not pushing on the ribs. A true sonographic Murphy sign shows deformation of the fundus with compression.

**Table 7.1** Differential for Thickened Gallbladder Wall (3,4)

| | |
|---|---|
| Postprandial | HIV/AIDS |
| Renal failure | Adenomyomatosis |
| Ascites | Multiple myeloma |
| Hepatitis | |
| Hypoalbuminemia | |
| CHF | |
| Cholecystitis | |

## Measurements

As mentioned previously, two measurements are important when evaluating the gallbladder: the anterior gallbladder wall and the common bile duct.

A gallbladder wall that is thickened is a sign of inflammation. However, this is a nonspecific finding, and many other pathologic processes (see Table 7.1), as well as evaluating a postprandial gallbladder, can give you falsely elevated measurements. However, a complete exam does include this measurement. It is important that you measure the wall of the anterior gallbladder surface because of the acoustic enhancement artifact mentioned in Chapter 1 (shown again in Figure 7.7). Because sound waves travel through a fluid-filled structure, no attenuation occurs. Thus, when those sound waves hit the back of the gallbladder, they will be so strong that they will obscure an accurate picture of the wall thickness.

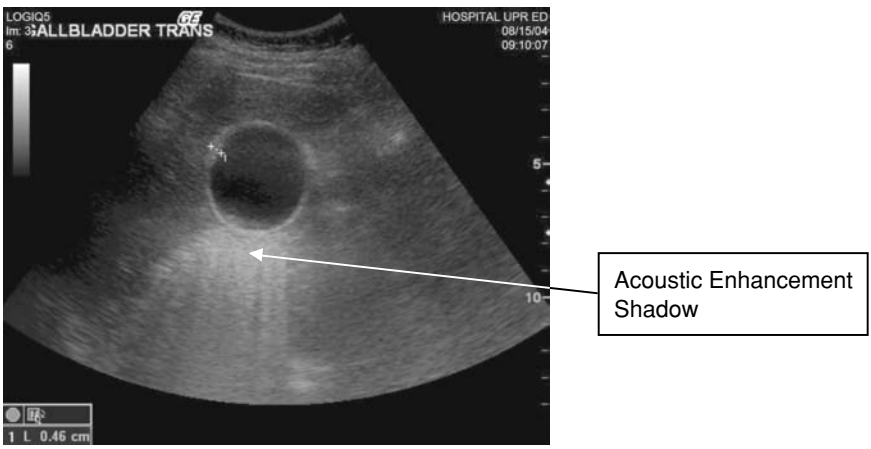


**Figure 7.7**

Posterior acoustic enhancement distal to the anechoic gallbladder. For more detailed explanation of this phenomenon, see Chapter 1).

For gallbladder wall thickness, the number to keep in mind is that a wall >3 mm is abnormal (see Table 7.1) (3,4).

A common bile duct that is dilated is evidence of obstruction. This is the second measurement required for a complete evaluation. The common bile duct is typically <6 mm in transverse diameter (5). The common bile duct diameter should be measured from inner wall to inner wall. The diameter can increase with age so another way to measure it is to say the diameter should be less than one-tenth of the patient's age. Moreover, in patients who have had a cholecystectomy, the CBD may normally range up to 1 cm (5). The ranges you must remember are as follows:

- 2–5 mm – normal range
- 6–8 mm – clinical correlation required
- 6 mm – 11% normal subject
- 7 mm – 4% normal subject
- >8 mm – abnormal (5)

Biliary obstruction, regardless of the etiology, will be demonstrated by a dilated biliary tree. Dilatation of the extrahepatic ducts implies common bile duct obstruction. This can eventually lead to intrahepatic duct dilatation. (Note that dilatation of the intrahepatic ducts *alone* suggests obstruction within the common hepatic duct or more proximal.)

## Scanning Tips

### Trouble with Gallbladder Scanning

*Rib shadow in the way?*

- Try angling the probe obliquely to sneak in-between the ribs.
- Have the patient take a deep breath to lower the diaphragm and bring the gallbladder lower in the abdomen below the ribs.

*Can't see the gallbladder at all?*

- Try having the patient roll onto his or her left side to bring the gallbladder more anterior in the peritoneal cavity or if the patient is sitting up have him or her lean forward.
- One unorthodox view is to have the patient get on his or her hands and knees and scan the abdomen this way so gravity works in your favor to pull the gallbladder toward the anterior abdominal wall.
- It is always easier to see the gallbladder if the patient has been NPO because this causes the gallbladder to dilate. If feasible, you can wait for an hour to see if the dilating gallbladder will be easier to find.

*Can't find the common bile duct?*

- Have the patient take a deep breath or change position – sometimes this makes things easier to find.
- If the patient has gallstones and has a sonographic Murphy sign, you have done your job with bedside ultrasound and do not need to spend more than a few minutes trying to confirm ductal dilatation.
- Use color Doppler to help distinguish the hepatic artery and portal vein from the common bile duct.

*Unsure if the patient has a sonographic Murphy sign?*

- Make sure that you are not pressing directly on the ribs and causing pain that way.
- Have the patient take a breath to see if you can get the fundus below the costal margin.

*Object in the gallbladder isn't shadowing?*

- Increase the probe frequency – sometimes higher-frequency sound waves make shadowing more obvious.
- Move the patient – if the object does not respond to gravity, it is likely a polyp (or a tumor) and further imaging should be arranged.

## Normal Images

The following images are examples of normal gallbladder anatomy and normal gallbladder ultrasound scans.

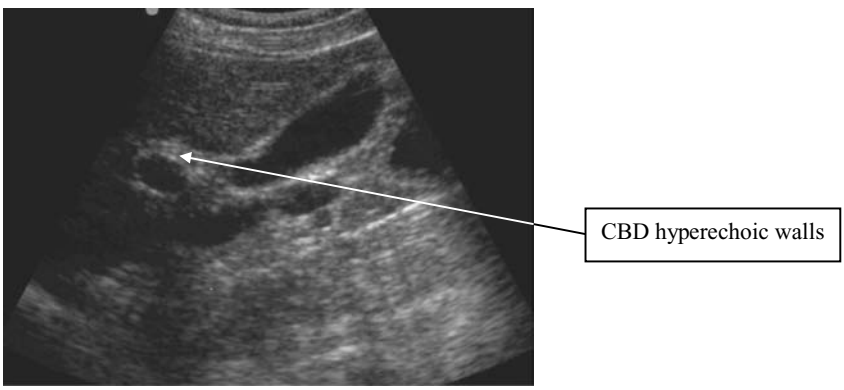


**Figure 7.8**
Normal gallbladder scan.

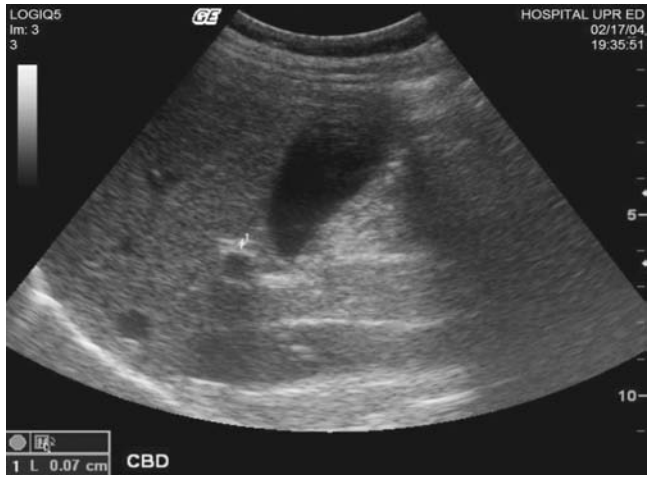


**Figure 7.9**

Normal gallbladder – CBD just anterior to portal vein. Courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

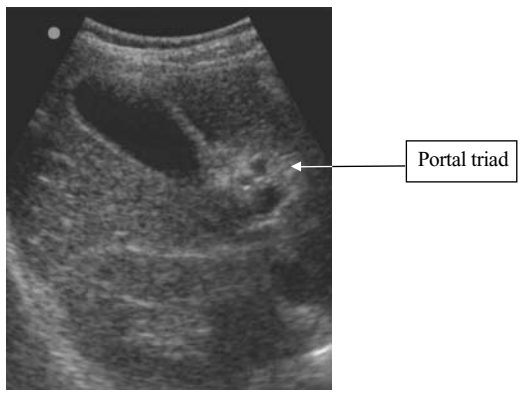


**Figure 7.10**

In this image, it is difficult to interpret which is the CBD without color Doppler.

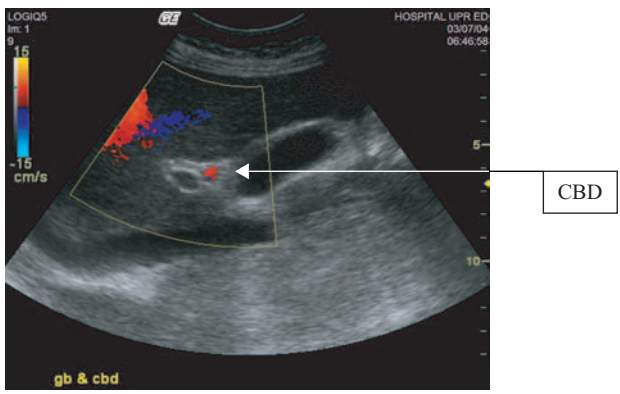


**Figure 7.11**

In this image, the CBD is much more apparent and is the bright echogenic walled structure with no flow to the left of the artery. Courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

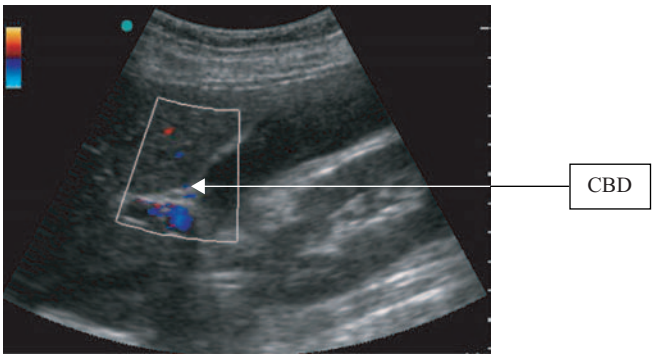


**Figure 7.12**
The CBD is easily identifiable when color Doppler is used. Note the absence of flow in the tubular structure with bright echogenic walls indicating CBD.

# Abnormal Images

## Cholelithiasis

Cholelithiasis is the presence of gallstones within the gallbladder. This is distinct from the presence of inflammation of the gallbladder due to gallstones (cholecystitis; see next section).

Gallstones appear as echogenic foci with acoustic shadowing (Figures 7.13–7.17). (*Note*: Shadowing may be absent in gallstones that are <4 mm in diameter.) Most will layer in the most dependent portion of the gallbladder and will move when the patient is repositioned – unless they are impacted or are of high cholesterol content.

One distinct finding is the wall echo shadow (WES) sign, which can be seen in gallstone-filled gallbladders (Figure 7.18) (6). It is characterized by the following:

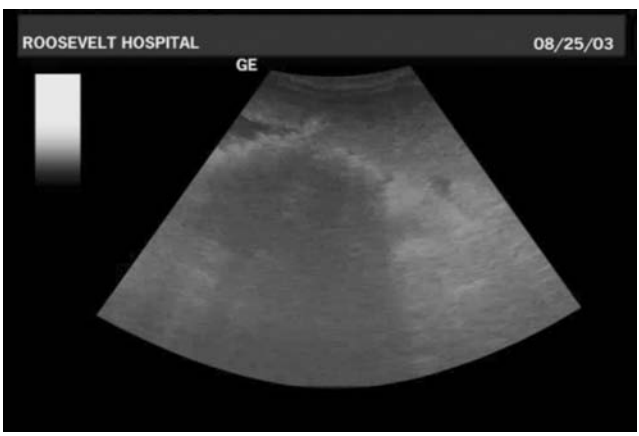


**Figure 7.13**
This image shows the contours of many small stones, even if the gallbladder itself is not well visualized. Your tip-off is the large shadow being cast. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

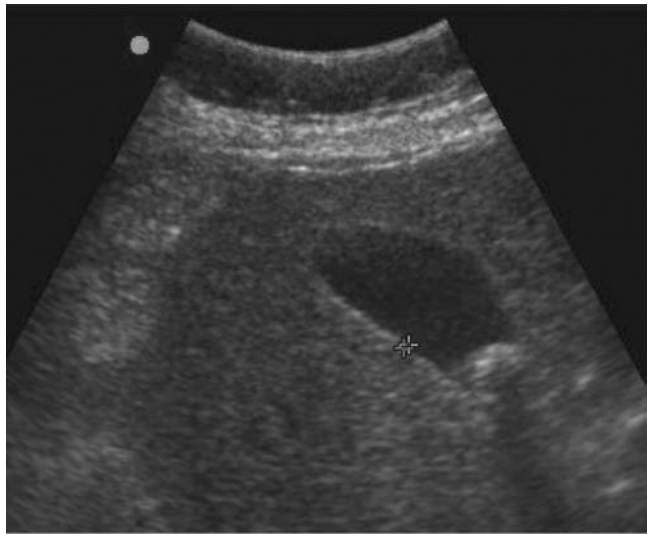

**Figure 7.14**
Large stone in the neck of the gallbladder casting a stone. The posterior wall is being measured, but given the lack of posterior acoustic enhancement, this is acceptable.

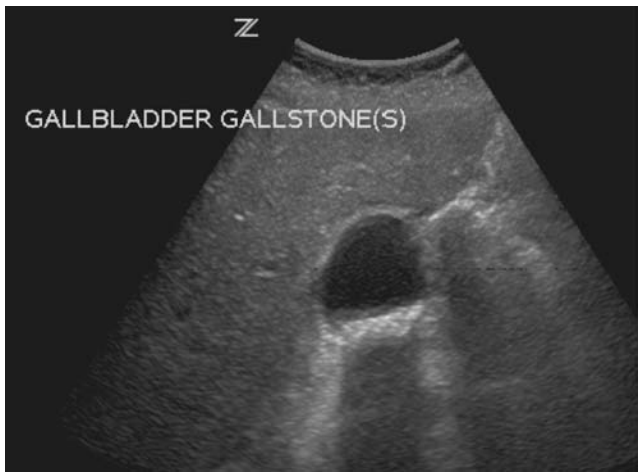


**Figure 7.15**
Large shadow cast by multiple small stones. Anterior wall appears thickened. Courtesy of Dr. Greg Press, University of Texas–Houston, Hermann Memorial Hospital, Houston, Texas.

- Anterior echogenic line within the near wall of the gallbladder
- An anechoic stripe representing bile
- A hyperechoic line representing stone
- A posterior acoustic shadow

## Cholecystitis

Cholecystitis is the inflammation of the gallbladder caused by obstruction of the draining ducts. Most commonly, this inflammation is caused by gallstones, but it can also be caused by sludge or tumors. The danger of this inflammation is that obstructed bile is highly susceptible to infection; thus, cholecystitis

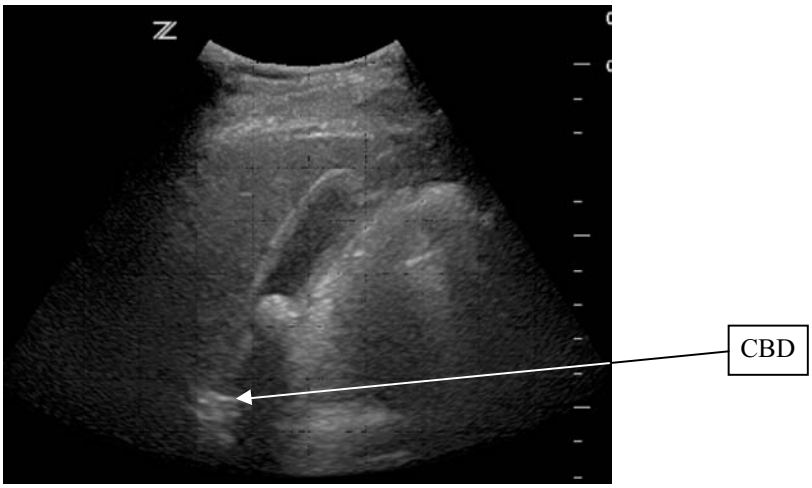


**Figure 7.16**

Large stone in the neck of the gallbladder casting a shadow. Echogenic walls of the CBD are faintly visible at the bottom of the image, and the CBD appears dilated. Courtesy of Dr. Greg Press, University of Texas–Houston, Hermann Memorial Hospital. Houston, Texas.

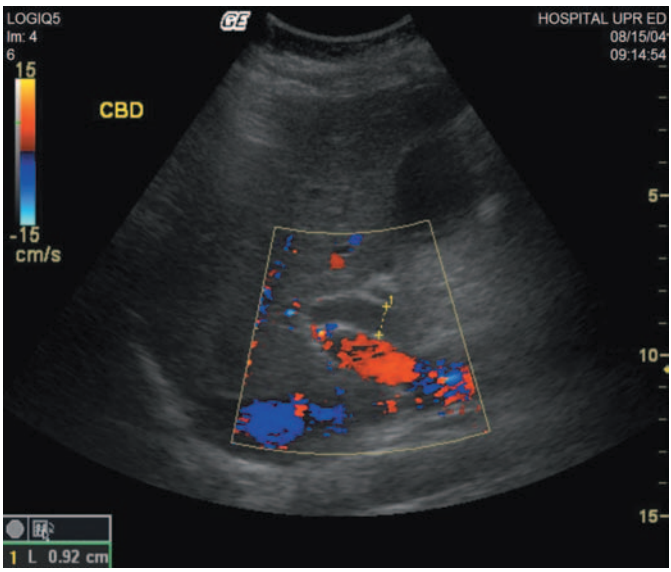


**Figure 7.17**

Color Doppler helps identify dilated common bile duct. Courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

is usually treated and cured by surgery to remove the gallbladder (cholecystectomy) (7). Common sonographic findings include gallbladder wall thickening (Figures 7.19), wall thickening with gallstones (Figure 7.20) or wall thickening, pericholecystic fluid and gallstones (Figure 7.21).

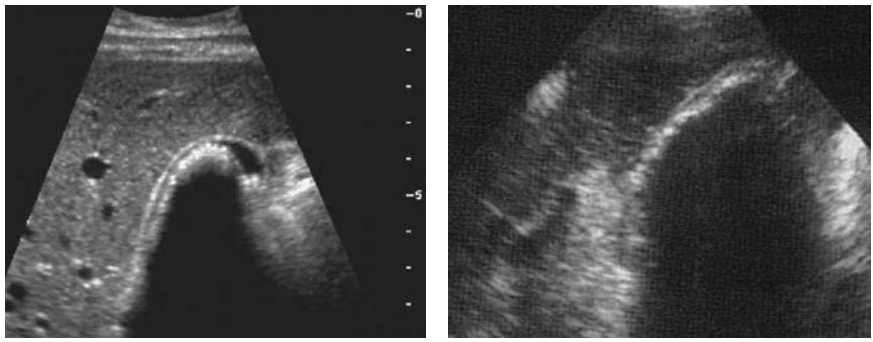

**Figure 7.18**
Two images of the WES sign.

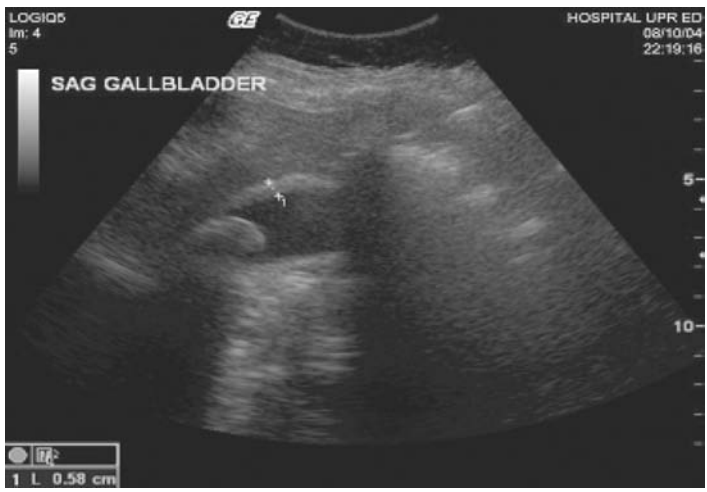


**Figure 7.19**
Thickened anterior gallbladder wall (0.58 cm). Courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

The most important study for emergency department goal-directed ultrasound is a study by Ralls et al., which showed that finding gallstones and a sonographic Murphy sign had a positive predictive value of 92.2% for diagnosing cholecystitis and a negative predictive value (no stones, no sonographic Murphy) of 95.2% (1). This is important because it gives literature support to the goal-directed study idea and removes some of the diagnostic insensitivity of the common bile duct and anterior gallbladder wall signs.

Chronic cholelithiasis is usually accompanied with chronic cholecystitis. The wall of the gallbladder may become thickened and fibrotic, which may prevent the gallbladder from contracting and expanding normally.

There are many common variants and additional abnormalities that may be visualized during an ultrasound examination of the gallbladder – most

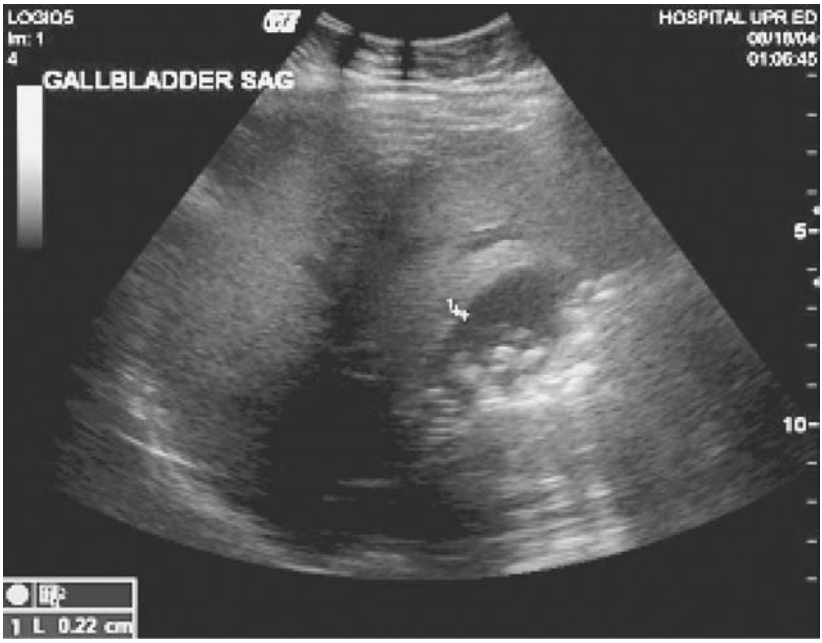


**Figure 7.20**

Thickened gallbladder wall secondary to chronic inflammation. Shadows from stones can be seen. Courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

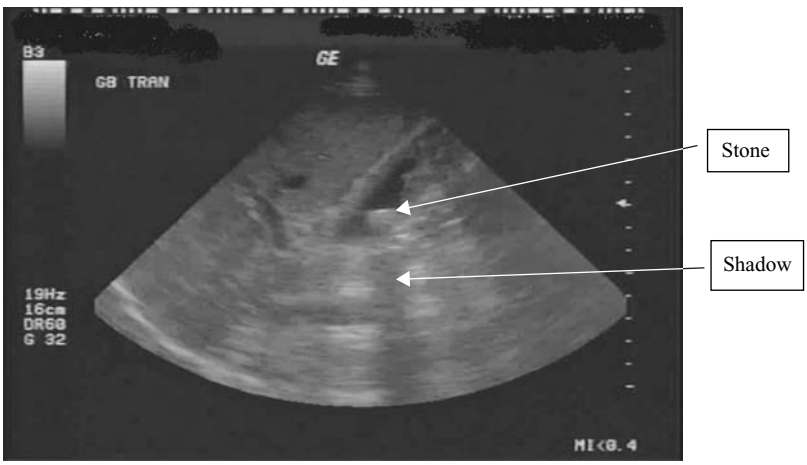


**Figure 7.21**

Thickened wall, pericholecystic fluid, and multiple stones. Courtesy of Emergency Ultrasound Division, St. Luke's–Roosevelt Hospital Center, New York, New York.

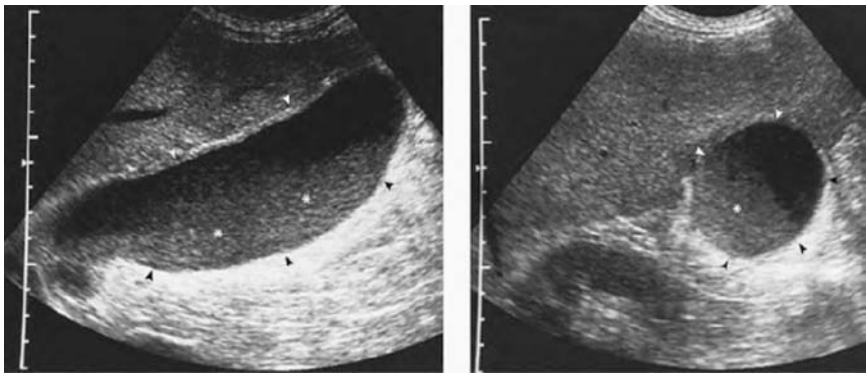

**Figure 7.22**

(*Left*) Longitudinal view of gallbladder containing sludge (*asterisk*). (*Right*) Transverse view of gallbladder containing sludge (*asterisk*).

of which are beyond the scope of this text. One additional abnormality that deserves mention is biliary sludge (Figure 7.22). Biliary sludge may be detected as a dependent layer of variable nonshadowing echogenicity in the gallbladder. It is frequently detected in states associated with biliary stasis, such as limited oral intake. It has also been known to cause biliary obstruction and cholecystitis.

## Acute Acalculous Cholecystitis

Acute acalculous cholecystitis is the presence of an inflamed gallbladder in the absence of a gallstone obstructing the cystic or common bile duct. It typically occurs in the setting of a critically ill patient (e.g., severe burns, trauma, lengthy postoperative care, prolonged intensive care) and accounts for 5% of cholecystectomies. Because abdominal pain, fever, and leukocytosis are relatively common in these patients, the physician must have a high index of suspicion to make the diagnosis. The etiology is believed to have an ischemic basis, and a gangrenous gallbladder may result. This condition has an increased rate of complications and mortality (7).

Ultrasound findings of acalculous cholecystitis would be the same for cholecystitis, except for the absence of gallstone shadowing. A sonographic Murphy's, thickened gallbladder wall, dilated common bile duct, and pericholecystic fluid are all ultrasound evidence used to help make the diagnosis in these patients.

An uncommon subtype known as acute emphysematous cholecystitis is generally caused by infection with clostridial organisms and occlusion of the cystic artery associated with atherosclerotic vascular disease and, often, diabetes. These patients will have air in the gallbladder wall, and the image will show speckled scattering of the ultrasound waves with distal reverberation artifacts. These patients are often clinically very sick, and this diagnosis carries a much higher mortality rate (8).

## Sample Clinical Protocol

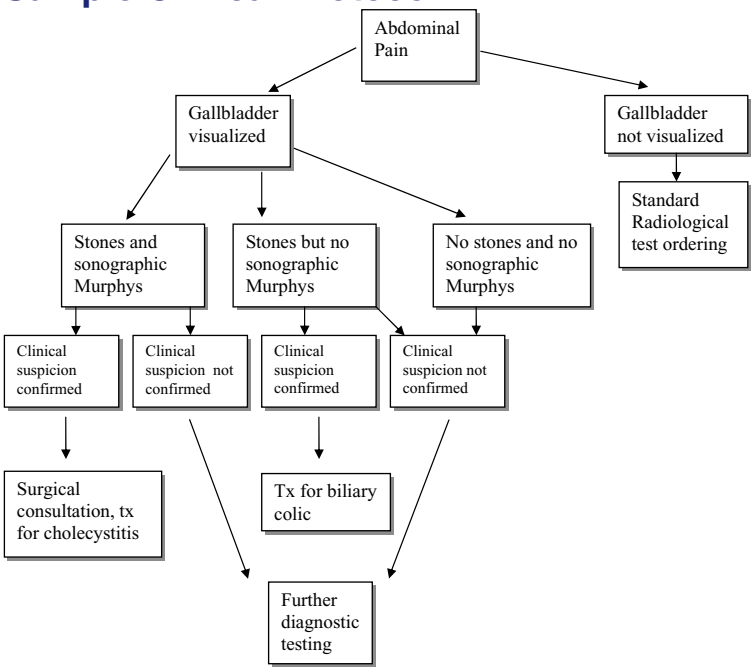


**Figure 7.23**

Figure 7.23 demonstrates how bedside sonography can be incorporated into the evaluation of patients with possible biliary disease. Application of similar protocols varies widely. In some centers, surgeons will operate based on an appropriate clinical picture and bedside ultrasound. In other centers, a normal bedside ultrasound may direct the clinician to perform a CT scan as a first line study in undifferentiated abdominal pain. It is important to adopt an algorithm which is compatible with the emergency physician and consultant practice at your own institution.

## Literature Review

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Ralls et al. (1) | Compared results for focused gallbladder US exam (look for stones and/or sonographic Murphy's sign) and full gallbladder US exam (including CBD, pericholecystic fluid, gallbladder wall thickness). | PPV of focused exam for cholecystitis 92.2%. NPV of focused exam was 95%. | Provided radiology literature support for performing focused US gallbladder exam without compromising diagnostic accuracy. |

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Johnson et al. (7) | Evaluated prevalence and incidence data in biliary disease. | 10%–15% adult population with gallstones. No symptoms after 15 years – unlikely to develop symptoms. 10%–18% risk of symptoms over 5–15 years. 900,000 cholecystectomies a year at cost of $5 billion. | Provided data for defining prevalence and incidence of disease. |
| Durston et al. (9) | Randomized patients to ED US vs. standard of care (no ED US) in undifferentiated abdominal pain. | With introduction of ED sonography, diagnostic accuracy for biliary disease improved from 28% to 70%. Decrease in return visits for pain – 1.67 vs. 1.25. Decrease in complications from stones – 6.8% vs. 1.7%. | Outcomes evaluation after introduction of ED sonography for the evaluation of undifferentiated abdominal pain. |
| Kendall and Shrimp (10) | Compared test characteristics of EP-performed and formal radiology biliary US. | Cholelithiasis diagnostic sensitivity 96%, specificity 88%.Time to EP-performed study $<$10 min. | Further define accurate test characteristics of EP-performed study. Suggest time savings as well. |
| Rosen et al. (11) | Compared sensitivity and specificity of EP-performed vs. formal radiology biliary US for diagnosis of cholecystitis. | EP sensitivity 91%, specificity 66%. Formal US sensitivity 69%, specificity 95%. | First study to note increased sensitivity of EP-performed biliary US for diagnosing cholecystitis over formal study. Suggests linkage with care physician knowledge of pretest probability. |
| Blaivas et al. (12) | Compared length of stay in patients who had EP-performed gallbladder US performed vs. those who had radiology performed gallbladder US. Retrospective study of patients who had USs done. | Median LOS 7% less in patients with EP-performed US. Median LOS “after hours” 15% less in patients with EP-performed US. | Time savings for patients with EP-performed US. |

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# 8 Deep Vein Thrombosis

## Introduction

Although not one of the original six American College of Emergency Physicians indicated exams, evaluation for deep vein thrombosis (DVT) is one of the most useful exams for critical care physicians. There are approximately 250,000 new diagnoses of DVT per year and 50,000 deaths from thromboembolic disease annually (1,2). The estimated rate of propagation from DVT to pulmonary embolism ranges from 10% to 50% (1,2). Because the incidence of DVT is so high and because this disease is so prevalent in critical and acute care settings, the ability to rule in or rule out DVT at the bedside is a particularly powerful tool. The simplified compression technique described in this chapter evaluates for DVT at two anatomic sites of the lower extremity venous system. This protocol has been evaluated in multiple randomized controlled studies and has become a well-accepted protocol used for decision making in conjunction with clinical pre-test probability assessments (3–12).

## Focused Questions for DVT Ultrasound

The questions for DVT ultrasound are as follows:

1. Does the common femoral vein fully compress?
2. Does the popliteal vein fully compress?

## Anatomy

The anatomy of the lower extremity should be reviewed so the DVT compression ultrasound exam can be done properly. The ileac vein becomes the common femoral vein (CFV) as it leaves the pelvis. The most proximal tributary of the CFV is the greater saphenous vein (GSV) (Figure 8.1). The common femoral then splits into the superficial and deep femoral in the proximal thigh – both of these vessels are part of the deep venous system despite their names. At the knee, the superficial femoral becomes the popliteal vein running in the posterior fossa of the knee joint and is joined by its tributaries, the tibial vein and peroneal vein (Figure 8.2).

It is not surprising that clots, as shown by venography studies, seem to cluster at the branch points of the venous system. One common explanation is that the increased turbulent flow at these branch points produces increased wear and tear on the vessel walls, thus making these areas predisposed to clot formation.

Data from these venography studies support the use of the simplified compression technique because identification of clot in the popliteal vein or CFV

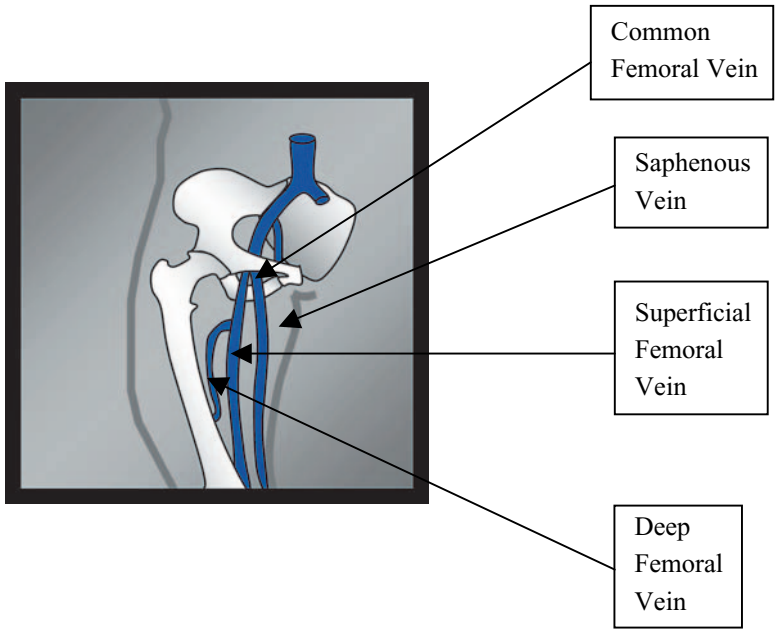



**Figure 8.1**

Proximal venous system. Courtesy of Dr. Manual Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

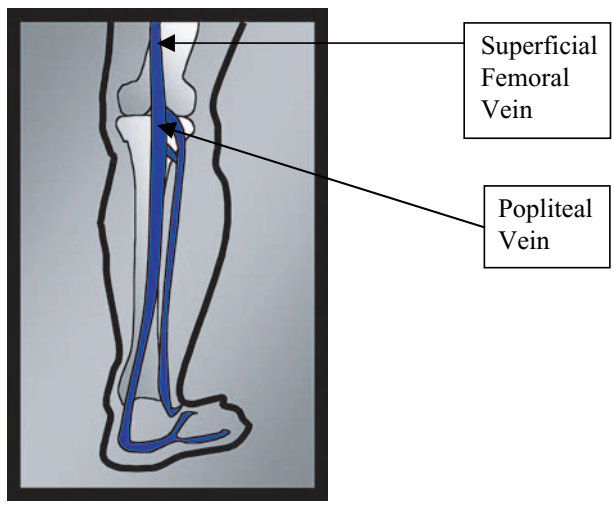



**Figure 8.2**

Distal venous system. Courtesy of Dr. Manuel Colon, Hospital of the University of Puerto Rico, Carolina, Puerto Rico.

should identify any DVTs identified by venography (Figure 8.3); there were no cases in these initial studies where a DVT did not involve the popliteal vein, CFV, or both.

Although the anatomy around the femoral triangle is described in more detail in Chapter 9, it is also reviewed here. Figure 8.4 shows a transverse view

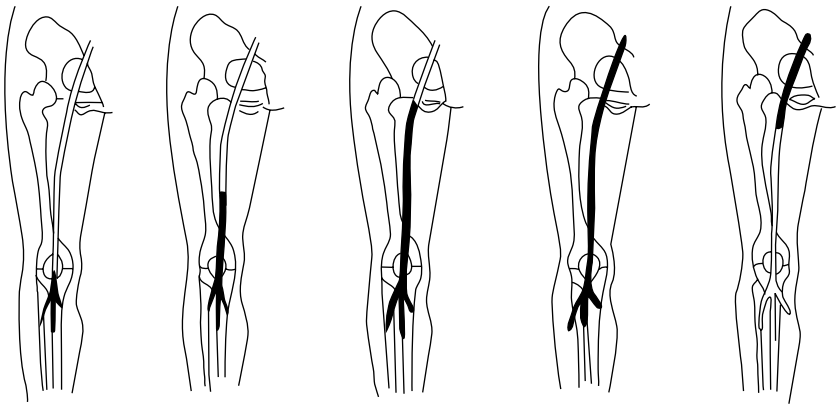



**Figure 8.3**

Proportion of DVT cases with clot at each location. Note that all clots in this series involve either the popliteal vein, femoral vein, or both. From Lansing AW, Hirsh J, Buller H, Diagnosis of Venous Thrombosis. In Colman RW, Marder VJ, Clowes AW, George JN (ed) *Hemostasis and Thrombosis: Basic Principles*. 3rd ed. Philadelphia. Lippincott, 2001, pp. 1305.

of the femoral triangle, just inferior to the inguinal canal. At this level, the CFV is distinct from the GSV, which separates to take a more superficial and medial course as it moves distally. The common femoral artery (CFA) at this level has not yet bifurcated.

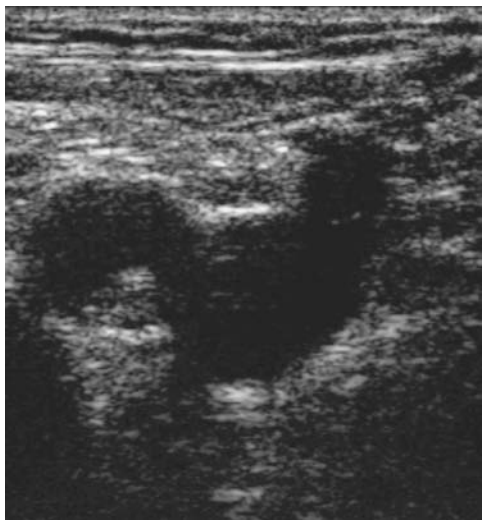
Figure 8.5 shows the probe slightly distal to the femoral triangle. Here the CFV has bifurcated into the superficial femoral vein (SFV) and deep femoral vein (not visualized at this level). The CFA has now bifurcated into the superficial femoral artery (SFA) and deep femoral artery (DFA).

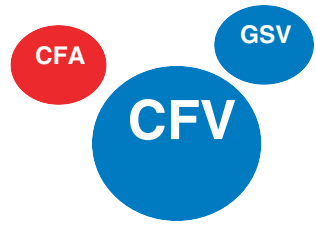
The popliteal vein (PV) and popliteal artery (PA) are found in the popliteal fossa (Figure 8.6). In general, the PV is superficial to the PA. There is occasional anatomic variability so that the artery is more anterior to the vein. This can be distinguished by using adjunctive methods such as spectral and color Doppler and compression.

## Technique

### *Probe Selection*

For the evaluation of DVT, a high-frequency linear array probe is best. In larger patients or in patients with lower extremity edema, lower-frequency probes allow for better penetration of the sound beams; however, the image can usually be obtained with the high-frequency linear probe (5–10 MHz).





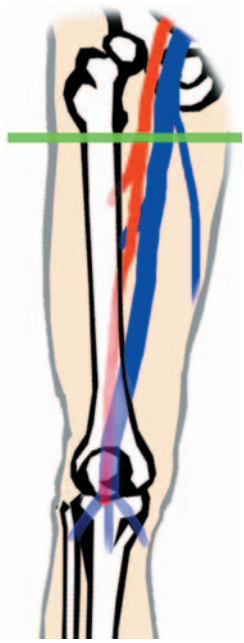
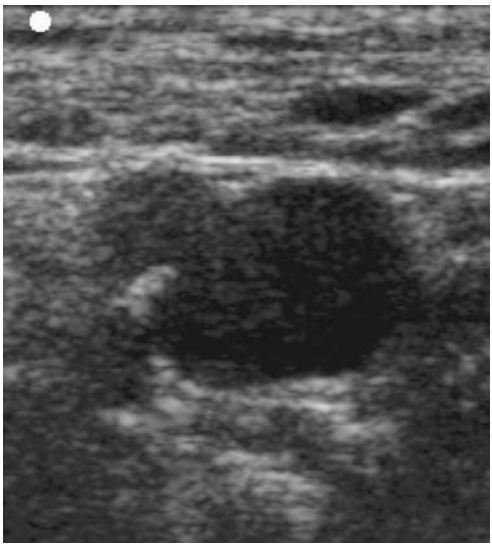
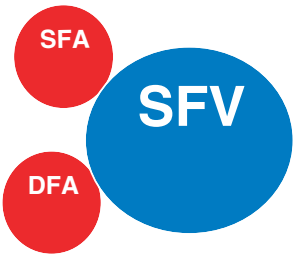



**Figure 8.4**
Common femoral vein.





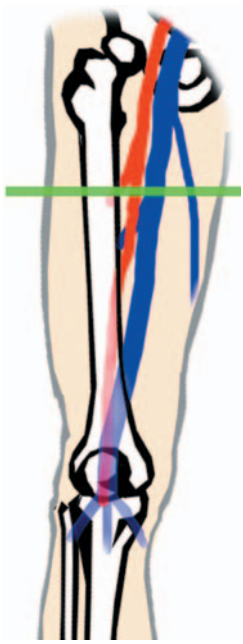



**Figure 8.5**
Superficial femoral vein.

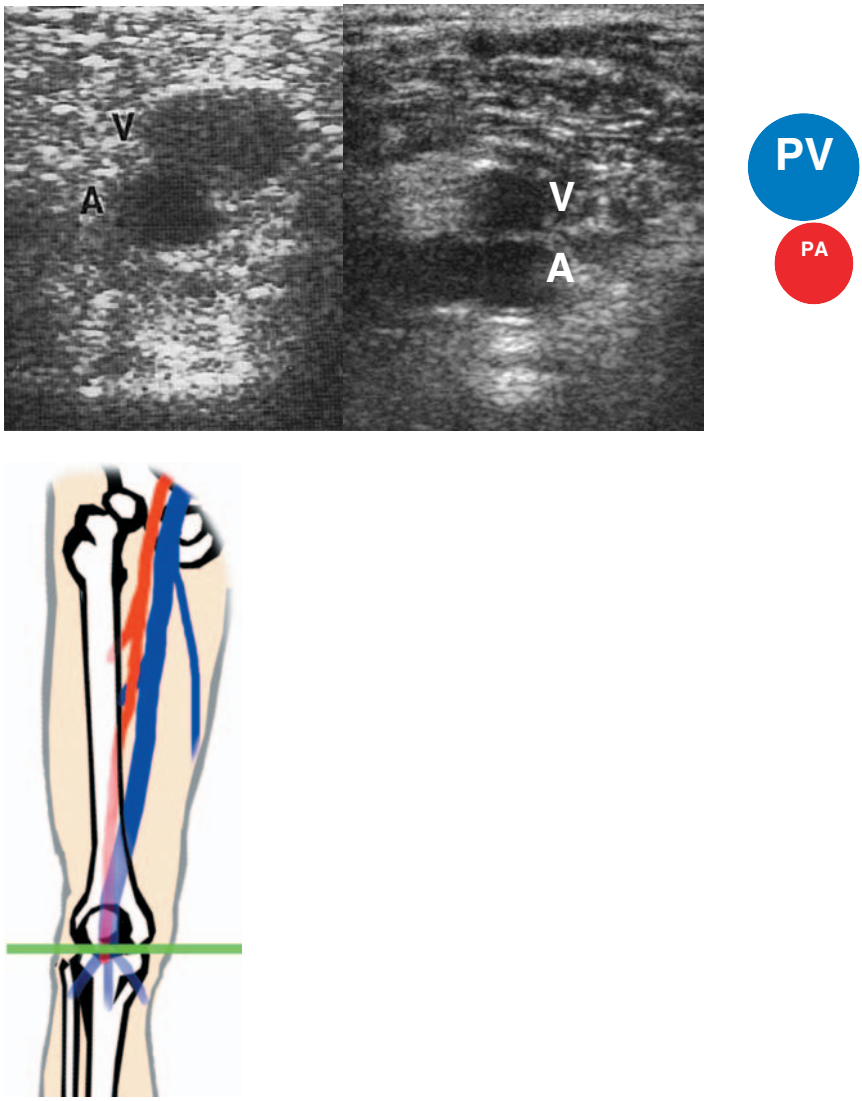



**Figure 8.6**
Popliteal vein.

***Views***

At least two views are necessary:

1. Common femoral vein demonstrating compression of vessel – this usually involves visualizing both the common femoral and greater saphenous veins as seen in Figure 8.4. Some authors have argued that it is prudent to compress both the common femoral and greater saphenous veins

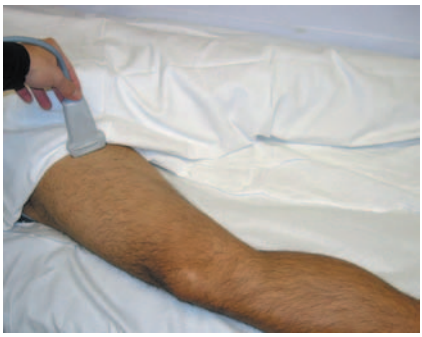


**Figure 8.7**
Probe position for common femoral vein.

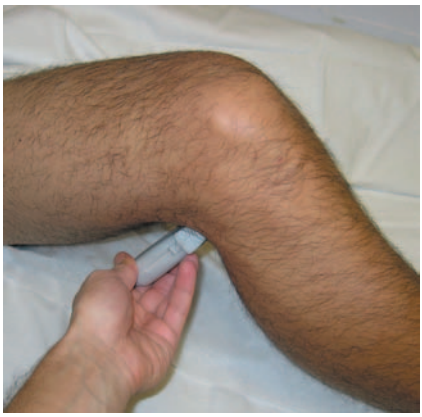


**Figure 8.8**
Probe position for popliteal vein.

and then to slide distal to the femoral triangle to compress the superficial femoral vein as well, but this is not universally accepted.

2. Popliteal vein demonstrating compression of vessel

The simplified compression technique is performed by using the high-frequency linear probe and identifying the common femoral and popliteal veins. In Figures 8.7 and 8.8, probe positioning for femoral vein and popliteal vein visualization is demonstrated. The probe marker should be directed toward the patient's right side.

If the veins are collapsible to a thin line with external pressure applied (Figure 8.9), the vein is presumed to be patent and there is no clot present. If the vein does not collapse with external pressure, there is presumed to be clot within the lumen of the vessel preventing complete collapse.

There are a few structures that can be mistaken for a noncompressible vessel and that are worth mentioning. Lymph nodes can look like clot within a hypoechoic vessel because they have a ring of hypoechoic fluid surrounding the node. However, they are easy to distinguish because if the probe is turned

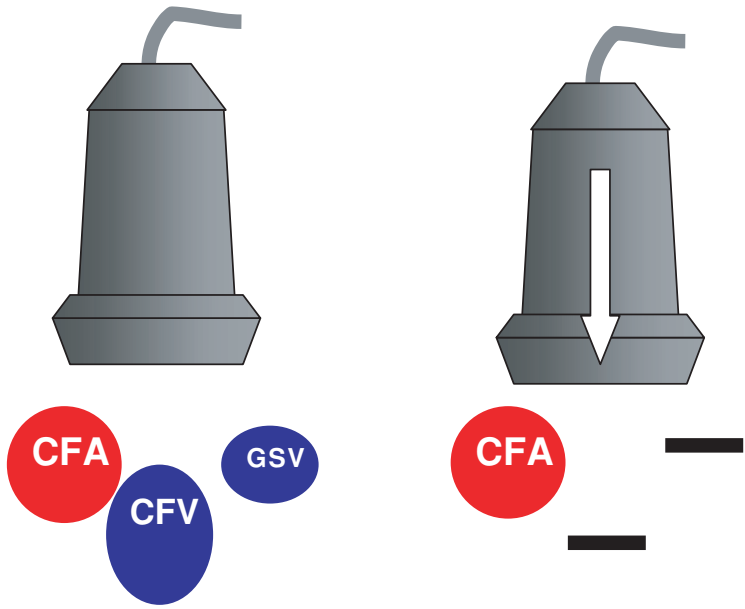



**Figure 8.9**
Compression technique.

longitudinally, it will become obvious that the object is circular and not tubular. Baker's cysts can cause the same phenomenon in the popliteal fossa but again dynamic scanning in longitudinal and transverse planes should remove any doubt. Pseudoaneurysms and groin hematomas can also be misleading, and caution should be exercised in clinical situations where these diagnoses are being considered. This is where color Doppler can often be helpful (11).

## Scanning Tips

- Proper patient positioning can greatly improve image quality.
  - Have the patient externally rotate his or her leg to better visualize the common femoral vein.
  - For the popliteal vein, have the patient hang his or her leg over the edge of the bed to distend the vessels, or perform the scan with the patient in a prone position.
- Be sure the veins fully compress. A normal vein will completely disappear when compressed enough; if the walls do not touch, consider DVT.
- Make sure you are applying pressure evenly. The probe should be perpendicular to the skin. If pressure is being applied at an angle, the vessel may appear not to collapse because of unevenly distributed pressure.

## Normal Images

The following ultrasound images are examples of normal venous anatomy.

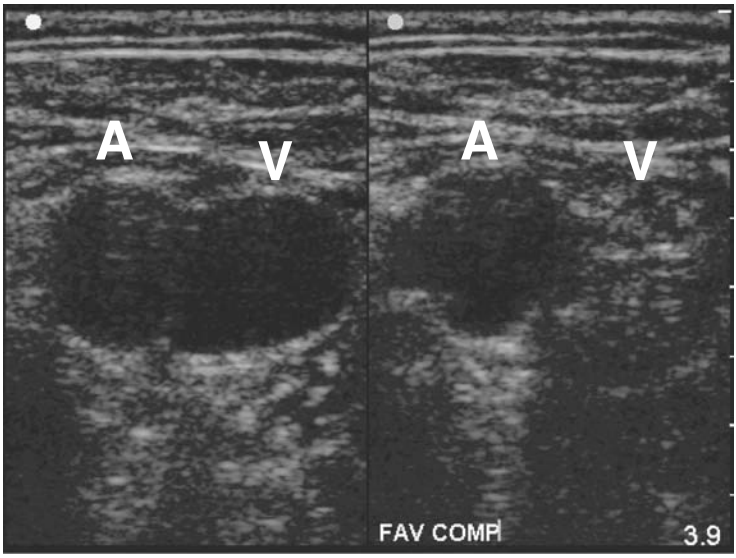



**Figure 8.10**
Common femoral artery (A) and vein (V) (with compression, right panel).

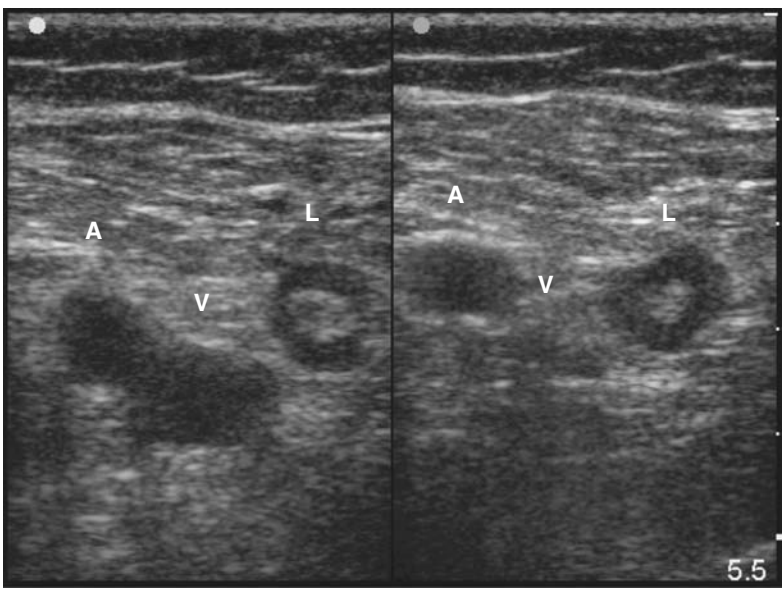



**Figure 8.11**
Common femoral artery (A), vein (V), and enlarged lymph node (L) (with compression, right panel).

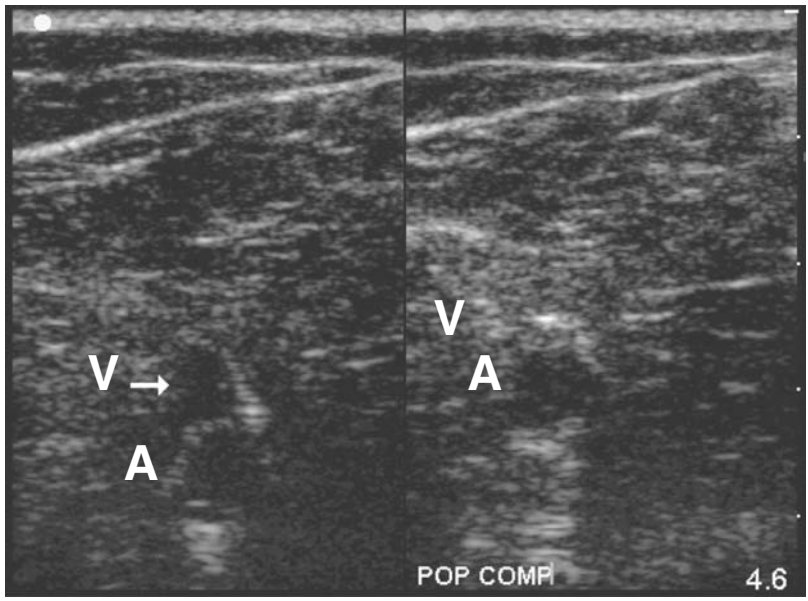



**Figure 8.12**
Popliteal artery (A) and vein (V) (with compression, right panel).

## Abnormal Images

The following ultrasound images are examples of venous anatomy with clot present.

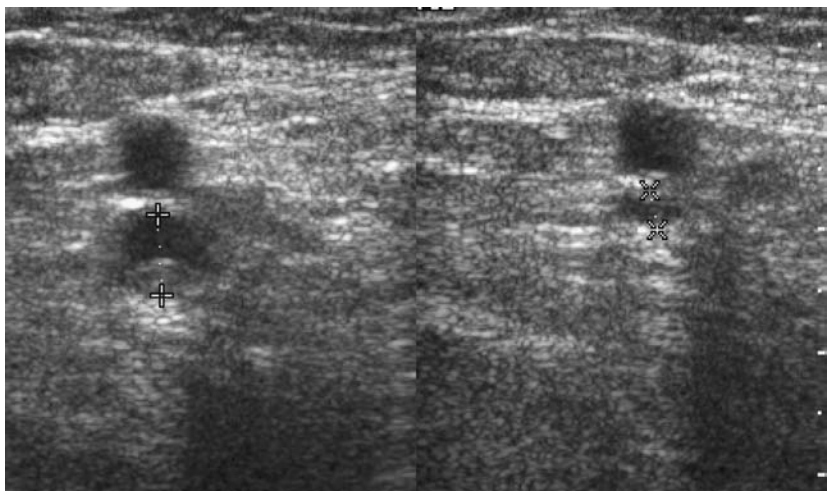


**Figure 8.13**
Common femoral artery (A) and vein (V) (with compression, right panel). The vein is marked with calipers. Note the hyperechoic material within the vein, as well as lack of compressibility of the vessel.

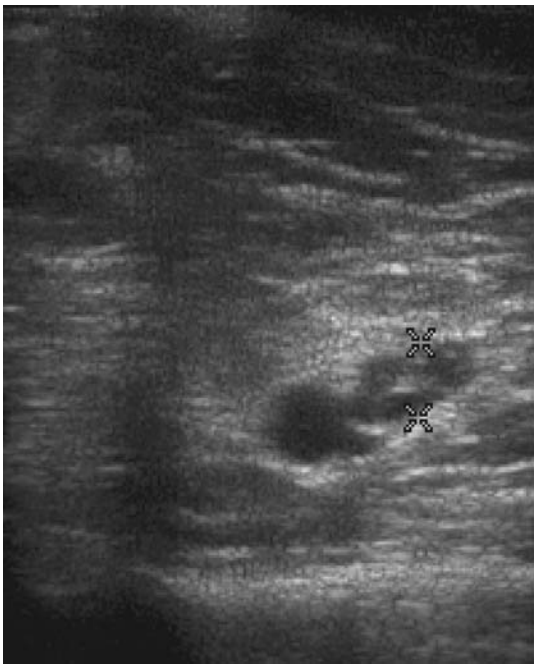


**Figure 8.14**

Popliteal artery and vein. The vein is marked with calipers. Note the lack of compressibility and echogenic material within the lumen.

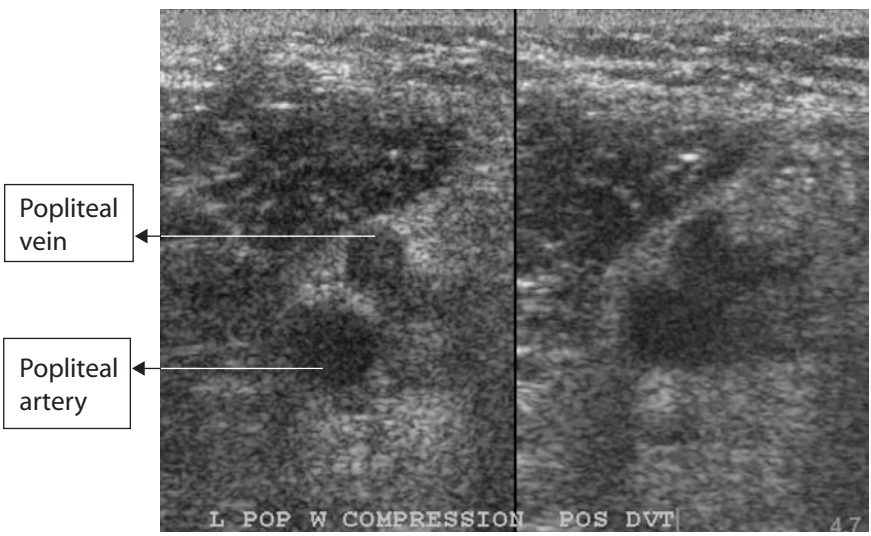



**Figure 8.15**

Popliteal vein with DVT – unable to compress vein in image on right.

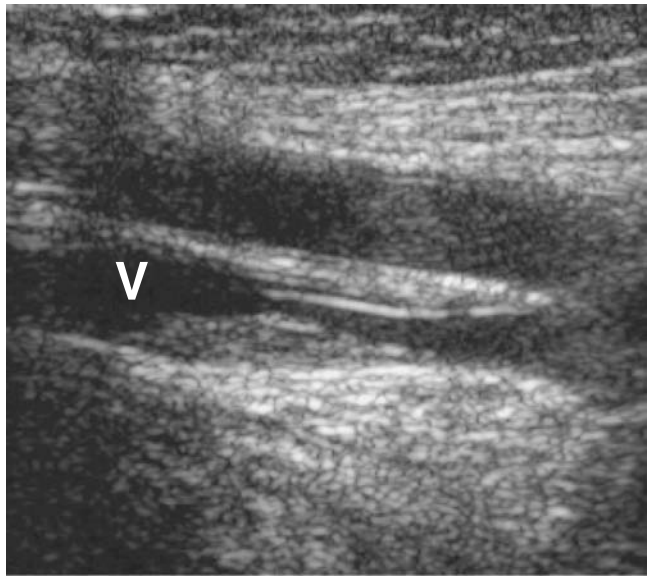



**Figure 8.16**
This longitudinal image of the common femoral vein (V) demonstrates echogenic material within the lumen. Note that the thrombus does not occlude the entire vessel diameter. This could represent a chronic DVT, where some recannulation has begun to take place.

## Sample Clinical Protocol

When used in conjunction with D-dimer testing, bedside ultrasound is sensitive enough to exclude DVT when the study is normal and specific enough to begin treatment when the test demonstrates clot (12). The protocol below (Fig. 8.17) illustrates how this concept can be applied to a patient care algorithm. The specific type of D-dimer assay as well as the experience level of the bedside sonographers must be considered when employing protocols such as this.

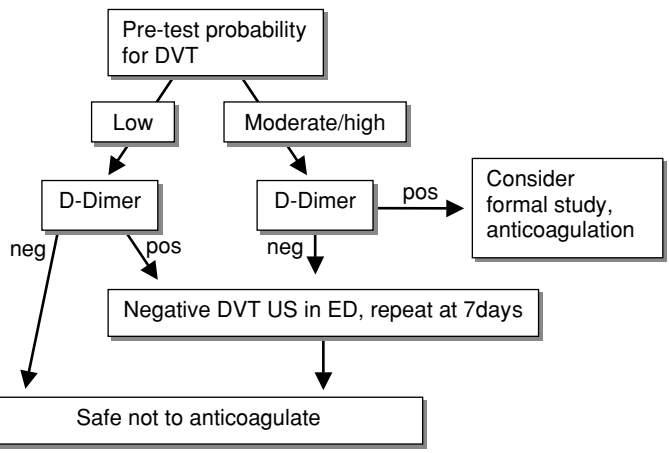



**Figure 8.17**

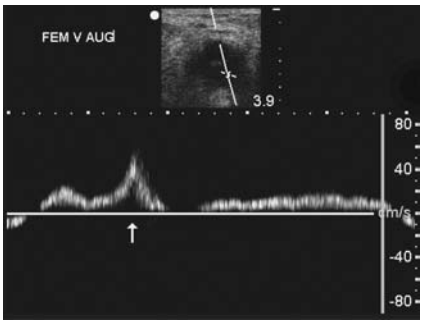



**Figure 8.18**
Augmentation.

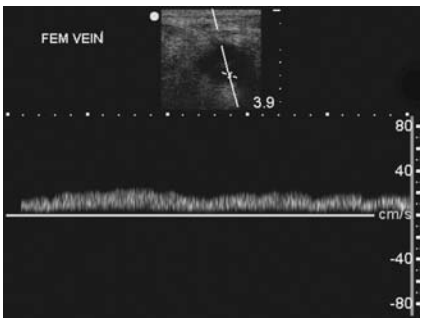



**Figure 8.19**
Respiratory variation.

## Advanced Techniques

Although not frequently employed by emergency physicians, assessing augmentation and respiratory variation using pulse wave Doppler is a common practice among radiologists. In cases where a stronger clinical suspicion for DVT may lead one to pursue a more involved bedside study, the following techniques may be employed. Both techniques involve the use of Doppler to visualize flow differences in the veins.

### Augmentation

To assess augmented venous return, compress the soft tissue of the calf at some point distal to the standard probe position on the leg. With the Doppler over the vein, note any changes in flow as the distal vein is compressed. In a normal vein, distal compression causes a rapid, temporary increase in venous return. This implies an unobstructed path for blood flow *distal* to the probe, from the point of compression. In Figure 8.18, note the rapid increase in flow velocity on the scale at the bottom of the screen. The arrow indicates the augmentation.

### Respiratory Variation

To assess respiratory variation, note any changes in flow during respiration with the Doppler over the vein. In a normal vein, changes in intraabdominal

and intrathoracic pressures during the respiratory cycle cause cyclic variations in venous return. This implies an unobstructed path for blood flow ***proximal*** to the probe, toward the iliac veins and inferior vena cava. In Figure 8.19, note the gradual variations in flow velocity on the scale at the bottom of the screen.

## Literature Review

| Article | Methods | Results | Notes |
|---|---|---|---|
| Blaivas et al. (11) | Prospective comparison of bedside compression technique with duplex sonography by radiology. | 98% correlation between bedside and formal studies; mean scan time <4 min per patient. | Bedside exam accurate, augmentation not helpful. |
| Cogo et al. (12) | Prospective evaluation of compression US, anticoagulation withheld if normal. | 0.7% complication fate during follow-up period using clinical algorithm for anticoagulation. | It is safe to defer anticoagulation when compression US is normal. |

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# 9 Chest Ultrasound

## Introduction

Chest ultrasound is reviewed for a variety of applications throughout this book. Literature to support its use in the diagnosis of pneumothorax, hemothorax, and nontraumatic pleural effusions is provided. Indeed, this literature lends support to the superiority of ultrasound as a diagnostic modality over chest x-ray for many applications. In addition, the patient safety benefits of ultrasound when performing procedures such as thoracentesis are presented.

Not surprisingly, there is more. With increased use of chest ultrasound in the intensive care unit setting has come a wider range of applications for its use. The role of chest ultrasound in the diagnosis of pulmonary edema or extravascular lung water (EVLW) is reviewed in this chapter. More important, the terminology that has been developed by pioneers in thoracic ultrasound and the concepts behind it are described because they are crucial to the diagnostic use of chest ultrasound for all chest applications.

The two most basic concepts – A lines and B lines – are described. For more detailed descriptions of these and other chest ultrasound applications, sonographers are encouraged to read Dr. Daniel A. Lichtenstein's book, *General Ultrasound in the Critically Ill* (1).

## Focused Questions for Chest Ultrasound

The questions for chest ultrasound are as follows:

1. Are A lines present?
2. Are B lines present?

## Anatomy

When using ultrasound to make diagnoses in lung pathology, it is important to recall some of the basic principles described in Chapter 1. One of the reasons that the normal lung is so difficult to image with ultrasound is that air is not a good transducer of sound waves. Air molecules tend to scatter the sound waves in infinite directions, making it difficult for the transducer to receive any organized information from the returning sound wave. This property can actually be helpful in chest ultrasound because a well-aerated and normal lung will not show much at all except for the reverberation artifact that occurs when sound is scattered, and not much information is returned to the ultrasound probe. These reverberation artifacts have been termed *A lines* (Figure 9.1) by Dr. Lichtenstein, and their presence signals the presence of normal aerated lung (1).

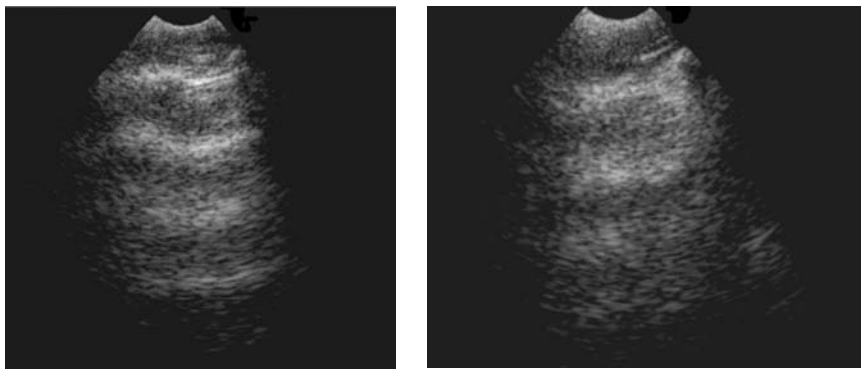

**Figure 9.1**
A lines. Note the reverberations are horizontally oriented.

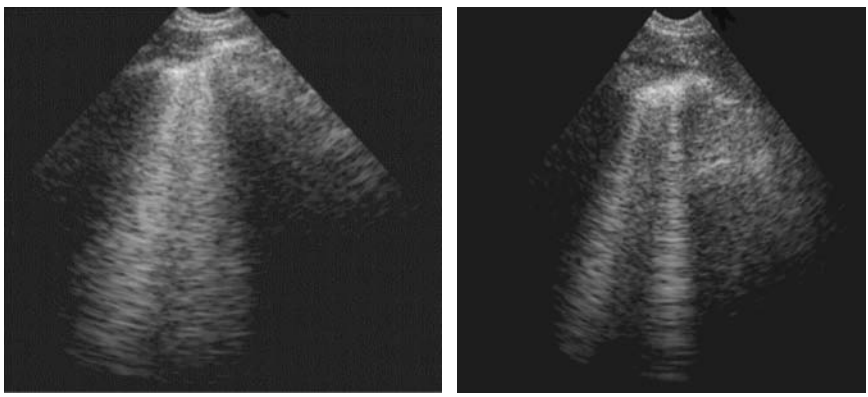

**Figure 9.2**
B lines. Note the vertical orientation of the reverberations.

This is particularly helpful because the absence of A lines indicates that something has changed the lung physiology so that healthy aerated alveoli are now transmitting sound waves in a different pattern. The most common change occurs when the interstitium of the lung begins to fill with fluid. This can occur with pulmonary edema, infection, contusion, or many other pathologic states. The importance of this to sound waves is that instead of being scattered, sound is transmitted through the abnormal interstitium. Similar to the comet tail artifact described in Chapter 2, sound wave transmission is possible because where previously there was thin alveolar wall tissue surrounded by air, now the interstitium is filled with fluid, and this space is now sound wave compatible. Therefore, similar to what happened to the sound wave that was trapped between the visceral and parietal pleura, sound waves are now trapped in the fluid-filled interstitium of pulmonary tissue and create similar artifacts called *B lines* (Figure 9.2) (1–3). For most sonographers, B lines and

comet tails are essentially the same phenomenon in slightly different tissue. The important feature to note is that this bright line or "rocket" extends all the way to the edge of the sonographic window. Lichtenstein has subdivided this phenomenon based on careful study of the pattern of these comet tails in different pulmonary pathologic states. For this introduction, however, an understanding of the basic difference between A lines and B lines and what that signifies for changes in lung physiology will suffice.

# Technique

## Probe Selection

The curvilinear lower-frequency probe is most often used to ensure that the sound waves penetrate through the chest wall tissue and into the lung parenchyma. Higher-frequency linear probes can also be used, but because their penetration can be limited, their use should be limited to those with thin chest wall musculature and tissue.

## Views

Lichtenstein describes nine zones of the chest (1,4). The anterior zone (Area 1 in Figure 9.3) is bound by the sternum, clavicle, and anterior axillary line, and can be divided into four quadrants. The lateral zone (Area 2) is bound by the anterior and posterior axillary lines and is divided into two quadrants. The posterior zone (Area 3) is bound by the posterior axillary line and the vertebral column and is divided into three quadrants. For the complete lung exam, images from each zone should be evaluated. In addition, in the supine patient, consolidative fluid will be more obvious in the posterior segments while air will be more apparent in the anterior segments. However, interstitial fluid most often distributes evenly (1,4).

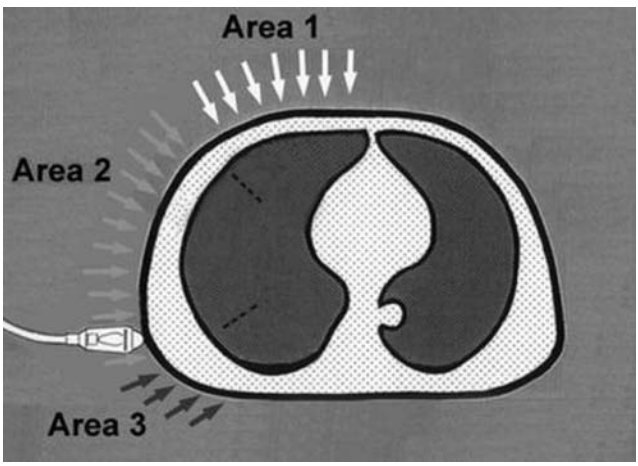


**Figure 9.3**
Chest sonography zones. From Lichtenstein DA, Lascols N, Meziere G, Gepner A. Ultrasound diagnosis of alveolar consolidation in the critically ill. *Intensive Care Med* 1004;30(2):276–81.

## Scanning Tips

- *No A lines or B lines?*
  - Try imaging in different planes or segments of the chest wall – it is important to at least look in an anterior and lateral segment.

- *Unclear image?*
  - If the patient has a pneumothorax with subcutaneous air, images can be difficult to obtain, so attempt to circumvent the subcutaneous air with different patient and probe positioning if possible.

## Images

Ultrasound can be useful to assess lung water in a dynamic fashion. Figure 9.4 demonstrates the appearance (top) and resolution (bottom) of B-lines.

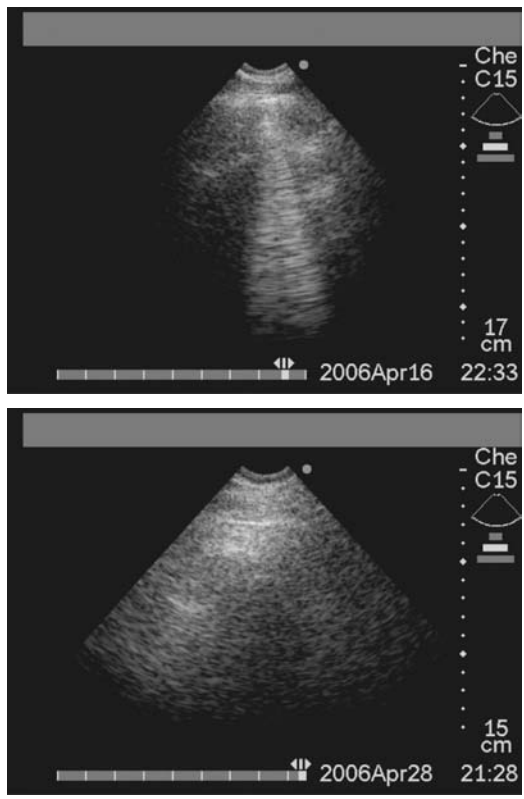


**Figure 9.4**

These images are from the same patient. The first image was taken when the patient was suffering from high altitude pulmonary edema and was symptomatic with hypoxia. The second image was taken after treatment and after symptoms had resolved. When the second image was obtained, the patient had normal oxygenation. Courtesy of Dr. Peter Fagenholz, Massachusetts General Hospital, Boston, Massachusetts.

## Literature Review

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Lichtenstein and Meziere (2) | 66 patients with dyspnea evaluated for multiple comet tail artifacts (B lines) as sign of pulmonary edema. | Sensitivity of 100% and specificity of 92% in the diagnosis of pulmonary edema when compared with COPD. | Evidence supporting the use of B lines for diagnosing pulmonary edema. |
| Volpicelli et al. (3) | 300 ED patients with dyspnea, evaluated for B lines. | Sensitivity of 85.7% and a specificity of 97.7% in recognition of radiologic alveolar-interstitial syndrome. | Evidence supporting the use of chest ultrasound for diagnosing different etiologies of shortness of breath. |

## New Directions

There are many exciting areas for expanding the use of this application. Prehospital use of chest ultrasound in assisting in the differentiation between congestive heart failure and chronic obstructive pulmonary disease could mean the early initiation of disease-specific therapy. In addition, the use of lung ultrasound in the assessment of EVLW could help with monitoring in critical care settings and could begin to replace the need for serial chest x-rays.

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# 10 Ocular Ultrasound

## Introduction

Ocular ultrasound as used by the emergency or critical care physician has several applications. The diagnosis of lens disruption and/or retinal detachment can be made with ultrasound and has been well described in the ophthalmology and radiology literature (1,2). Ultrasound can also diagnose the presence of ocular foreign bodies (1,2). However, more recently, other research focuses for ocular ultrasound have included the use of ultrasound to measure the optic nerve sheath diameter. Here, the concept is based on the idea that increased intracranial pressure (ICP) is reflected through the nerve sheath, causing edema and swelling. Since increases in ICP are transmitted by the cerebrospinal fluid (CSF) down the perineural subarachnoid space of the optic nerve, this expansion of the nerve sheath that can be measured by ultrasound (3–5). In many ways, this technique parallels the concept of papilledema as a marker for increased ICP. However, optic nerve ultrasonography is arguably easier to perform and more quantifiable than the presence or absence of papilledema. It is this interest in ultrasound's potential to measure ICP noninvasively that has sparked so much research.

Many ocular ultrasound studies have been done to try to define normal optic nerve diameter ranges and where enlargement becomes pathologic and correlates with increased ICP. Although research is ongoing, to date most researchers have found that both pediatric and adult ocular nerve sheath diameters >5 mm have correlated with evidence of increased ICP as measured by degree of hydrocephalus, intrathecal infusions where lumbar pressures were measured, or CT evidence of increased ICP (6–9). Although much research is still needed to better define the clinical utility of this technique, the literature support to date and the need for noninvasive techniques to assess ICP allow researchers to be optimistic about the future of this application.

## Focused Questions for Ocular Ultrasound

The questions for ocular ultrasound are as follows:

1. Is the optic nerve sheath diameter >5 mm?
2. Is there other obvious ocular pathology (lens dislocation, retinal detachment, foreign body)?

## Anatomy

When viewed on ultrasound, several ocular anatomic features are worth noting. The globe is seen as a dark fluid-filled structure because the vitreous is

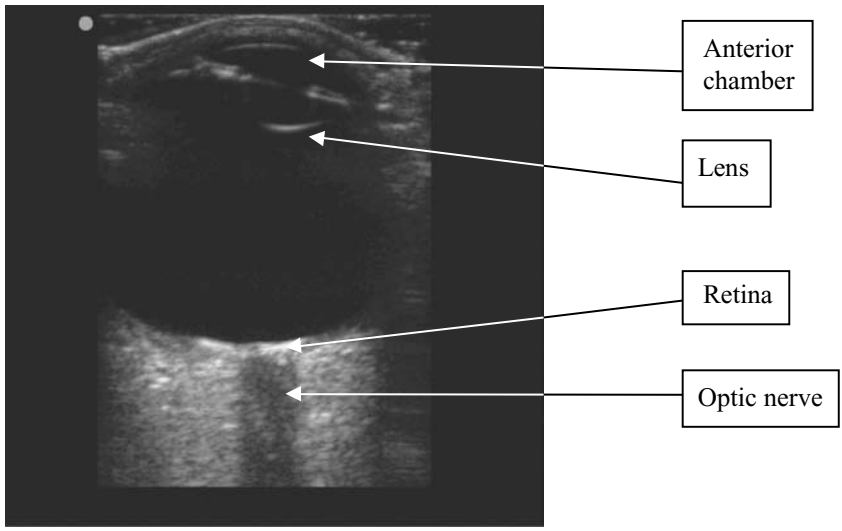


**Figure 10.1**
Normal ultrasound of the eye.

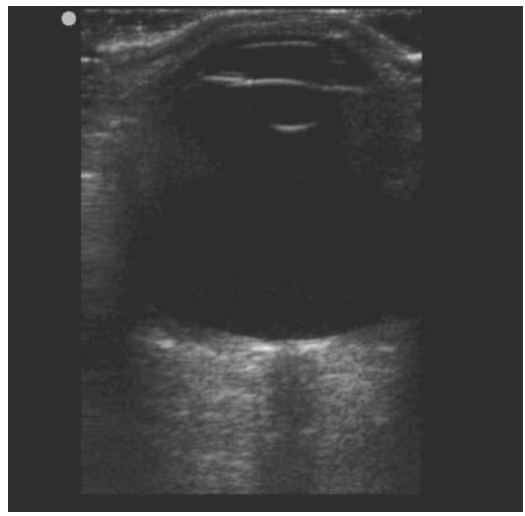

**Figure 10.2**
Normal ultrasound of the eye.

largely fluid and so will appear dark on ultrasound (Figure 10.1 and 10.2). The anterior chamber is often seen in cross section as a separate fluid-filled structure just anterior to the hyperechoic line of the lens. The retina is not seen unless it is detached from the posterior aspect of the globe. Ultrasound is used in ophthalmology for many advanced diagnostic applications, but these two structures (lens and retina) are easily assessed by the emergency physician. Ultrasound findings of abnormal lens or retinal position may help facilitate referral or consultation for formal evaluation and expedite identification of ocular pathology.

For ocular nerve sheath measurements, the dark shadow of the optic nerve should be identified posterior to the retina. The perineural sheath travels from the brain to each orbit, and communicates pressure from the CSF. Therefore, increased ICP is transmitted to the optic nerve, causing edema and swelling of the nerve sheath. Pathology studies have shown that 3 mm posterior to the retina, the nerve sheath is particularly porous and thus is postulated to be most responsive to these transmitted pressures. Therefore, when measuring the diameter of the nerve sheath to assess ICP, the convention is the nerve diameter should be measured 3 mm posterior to the retinal rim (2–9).

# Technique

## Probe Selection

Because the structures being imaged here are so superficial, the linear high-frequency probe should be used. Several ultrasound companies make probes specifically for ocular ultrasound that have a very small footprint and are even higher frequency than the standard vascular range (>10 MHz as opposed to the standard 7–10 MHz). However, this special probe is not necessary for acquiring adequate images for diagnostic applications described here (although the higher the frequency, the more detailed the image).

## Views

When imaging the eye, it is prudent to apply a clear film adhesive strip or Tegaderm over the closed lid of the eye before applying the gel to prevent contamination of the conjunctiva. In addition, it should be obvious that this exam is contraindicated in anyone with open ocular trauma, periorbital wounds, or in anyone in whom globe rupture and/or retrobulbar hemorrhage is suspected. To perform the exam, the linear probe is rested gently on the orbital rim, with the gel providing the interface with the globe itself. Caution should be used when applying pressure on the globe from the probe. Occasionally, patients can have a vagal-type response to the increased pressure being applied to the globe (oculocardiac reflex). In rare cases, this stimulus can be enough to cause bradycardia and syncope.

As with all imaging, it is standard to acquire images in two planes, transverse and longitudinal, to ensure true diameters are being measured.

# Scanning Tips

- *No nerve sheath shadow seen?*
  - For the nerve sheath shadow to be seen, the ultrasound beam or plane needs to transect the nerve, which enters the orbit at a slight angle. With gentle rocking of the probe or moving slightly to the lateral edge of the globe, the nerve sheath will usually come into view.

- *Unclear image?*
  - Often because of the variation in the curve of the orbital rim in patients, more gel is needed to increase the interface of the probe with the surface of the eye.

## Normal Images

Figures 10.3 and 10.4 demonstrate measurement of the optic nerve sheath diameter.

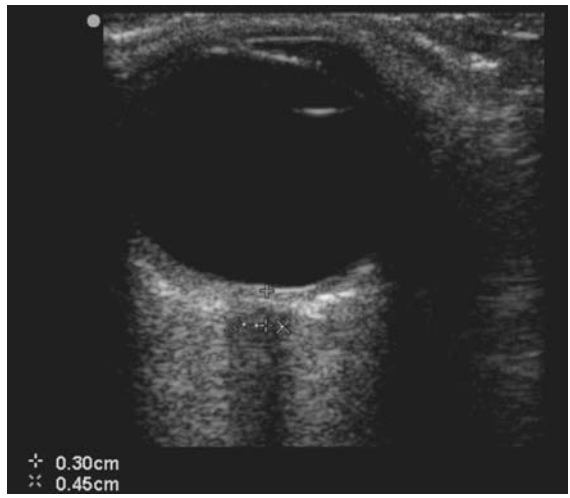


**Figure 10.3**
Normal optic nerve sheath measurements 3 mm posterior to retina.

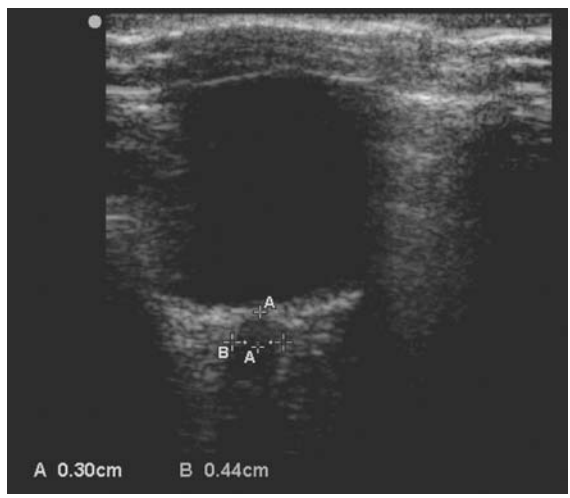


**Figure 10.4**
Normal optic nerve sheath measurement.

## Abnormal Images

A dilated optic nerve sheath (Figure 10.5) correlates with elevated ICP (3,4,6–8). The retina is not well visualized unless there is a retinal detachment. It is then seen in relief as a thin hyperechoic line (Figure 10.6) surrounded above by anechoic fluid above (vitreous) and below (often blood). Lens dislocation can also be readily seen, as in Figure 10.7.

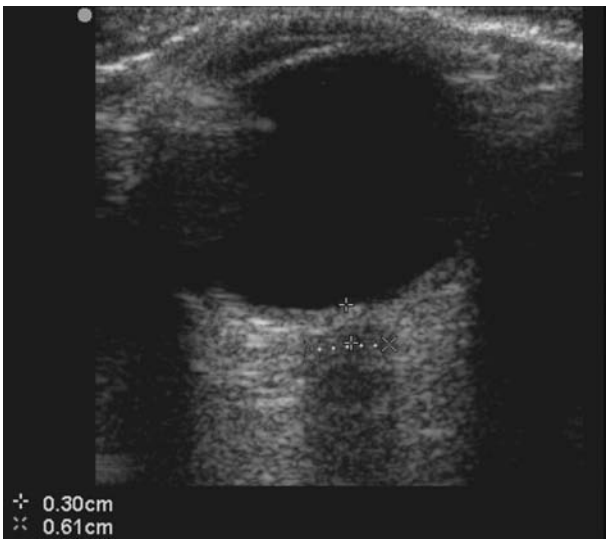


**Figure 10.5**
Dilated optic nerve sheath diameter ($D$ = 0.61 cm).

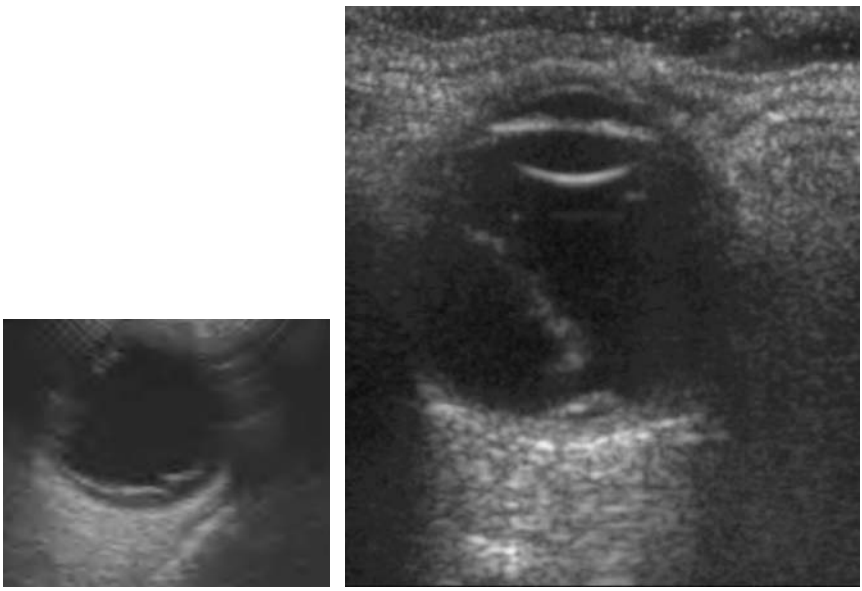

**Figure 10.6**
Retina detachment.

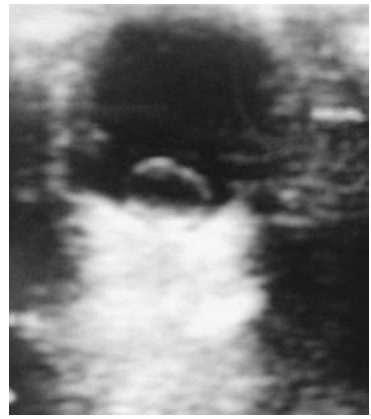

**Figure 10.7**
Lens dislocation.

## Literature Review

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Galetta et al. (3) | Pre- and postlumbar puncture sonography of optic nerve sheath in a patient with pseudotumor cerebri. | Decrease in size of optic nerve sheath with removal of CSF during lumbar puncture. | Proof of concept that optic nerve sheath size correlates with elevated ICP. |
| Newman et al. (6) | Children with VP shunts in place who were suspected of having elevated ICP had ONSD measurements taken with ultrasound. | Measurements >4.5 mm correlated with evidence of hydrocephalus and increased ICP. | By using normal controls, attempt to establish absolute ONSD value that correlates with elevated ICP. |
| Blaivas et al. (7) | Patients presenting to an ED with a clinical suspicion for elevated ICP had ocular ultrasound performed. | All patients with elevated ICP as identified by CT scan had >5 mm. | Further evidence for using 5 mm as the cutoff for abnormal optic nerve sheath diameter. |
| Blaivas et al. (2) | Patients with eye complaints presenting to the ED had ocular ultrasound performed in addition to usual standard of care evaluation. | 26/61 patients had ocular pathology identified that facilitated ophthalmology referral or further testing. | Bedside ultrasound is useful in diagnosis of multiple ocular complaints and in identifying a variety of ocular pathology. |

## New Directions

There are many exciting areas for expanding the use of this application. Prehospital or remote medical providers could use this technique to determine who should be evacuated to centers with neurosurgical capabilities. In addition, new techniques for measuring the optic nerve (measuring from the side of the orbit to identify the sheath in cross-section) show potential for having increased inter-rater reliability and increased clinical utility. As research continues, the accuracy of the test will improve defined with respect to interobserver variation (10) and the potential for this noninvasive ICP monitoring technique in critical care settings can be further evaluated.

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10. Ballantyne SA, O'Neill G, Hamilton R, Hollman AS. Observer variation in the sonographic measurement of optic nerve sheath diameter in normal adults. *Eur J Ultrasound* 2002;15(3):145–9.

# 11 Fractures

## Introduction

Although long bone fractures are often detected clinically, the sensitivity of the physical exam is insufficient to exclude pathology. In addition, the management of fractures varies considerably based on characteristics undetectable by physical exam alone (displacement, angulation, comminution). Thus, clinicians often rely on plain x-ray (as well as CT and MRI) to characterize fractures in patients with extremity trauma.

The role that ultrasound may play in the evaluation of orthopedic injuries is threefold. First, in a select group of injuries, diagnosis and treatment may be more rapid by using ultrasound over other modalities. There is some evidence that ultrasound is superior to plain x-ray in select fractures (sternal, rib) (1–3). In addition, there are some clinical scenarios where bedside diagnoses can expedite traction, anesthesia, and other maneuvers such as alignment through closed reduction (4,5). Second, imaging modalities are not always rapidly available. In some emergency departments, even plain x-rays take a significant amount of time to be performed. In austere environments (developing nations, remote areas), portable bedside ultrasound technology may be all that is available, given the setup costs and bulk of x-ray, CT, and MRI machines. Finally, radiation is relatively contraindicated in some patients, such as children or the elderly. Radiation exposure can be minimized using ultrasound as an alternative diagnostic tool.

## Focused Questions for Bone Ultrasound

The questions for bone ultrasound are as follows:

1. Is there an interruption in the bony cortex?
2. Can a degree of angulation or displacement be assessed?

## Anatomy

When assessing for fracture with ultrasound, soft tissue and bone are the primary focus. As described in Chapter 10, subcutaneous tissue and muscle are readily visualized with ultrasound because they transmit sound well. Bone will act as a bright reflector, yielding a strong echogenic signal and distal shadowing.

# Technique

## Probe Selection

Use a high-frequency linear probe to best assess the superficial soft tissue and gain the highest resolution for imaging bony structures. However, if there is substantial soft tissue present, the lower frequency probes can be used.

## Views

At least two views are useful: longitudinal and transverse.

Scan along the entire bone to be assessed (Figure 11.1) – from its proximal to distal articulation. Begin in a longitudinal plane, and note the depth of soft tissue and the intact cortex (with distal shadowing). As the site of suspected fracture is approached, soft tissue swelling or hematoma, as well as a more obvious break in the cortex, may be noted. Although the longitudinal view is often more useful, transverse views may also demonstrate these findings and give information as to the degree of angulation or displacement.

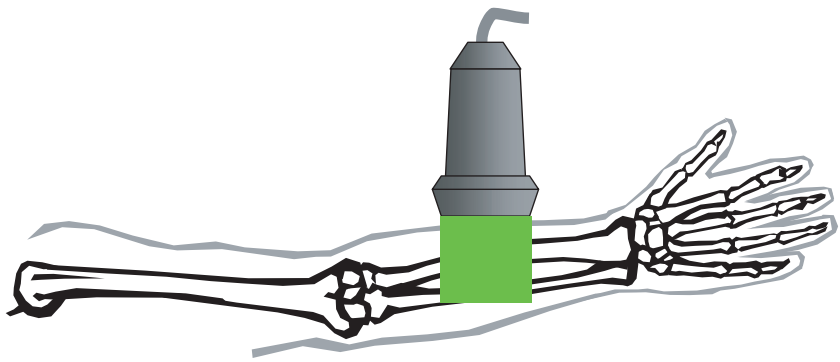

**Figure 11.1**

Probe position. In this view a longitudinal image is demonstrated; bones should be scanned in the transverse plane as well.

# Scanning Tips

- *Bone too superficial?*
  - Try using a water bath or standoff pad to bring the structures of interest further from the ultrasound beam.
- *Can't find break?*
  - It is helpful to look at the point of maximal tenderness.
- *Anatomy appears strange?*
  - Perform ultrasound on the contralateral side to compare the anatomy side by side.

## Normal Images

The following figures (Figure 11.2–Figure 11.4) demonstrate normal soft tissue and bony anatomy.

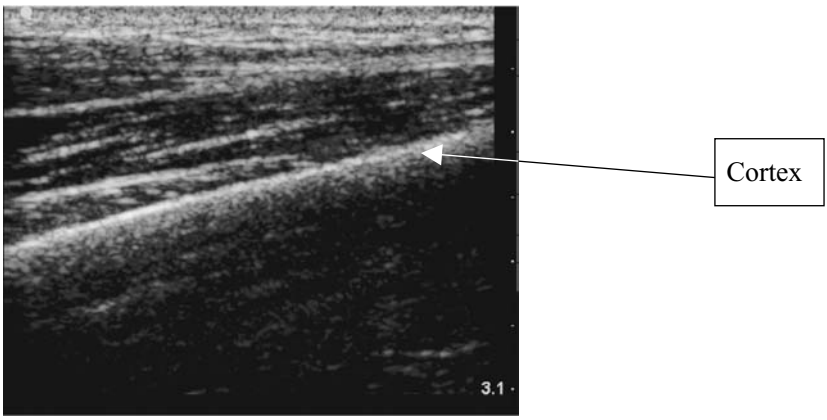


**Figure 11.2**
Normal cortex (bright white line) – smooth and uninterrupted.

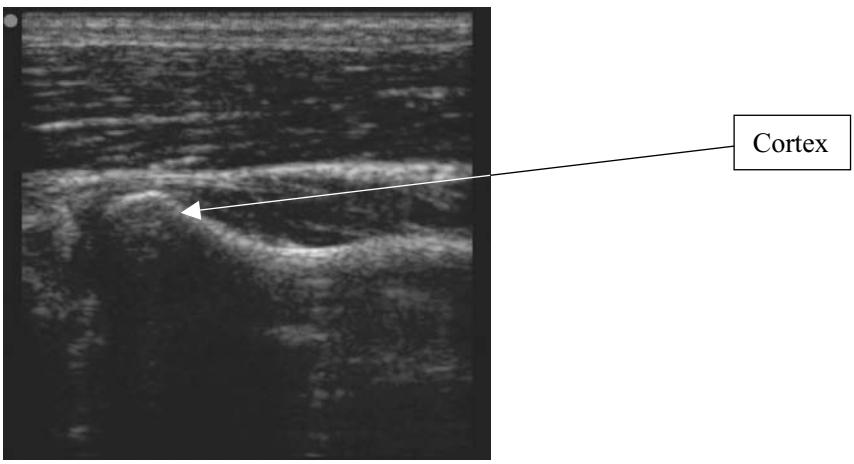


**Figure 11.3**
Normal radial head and junction with distal humerus.

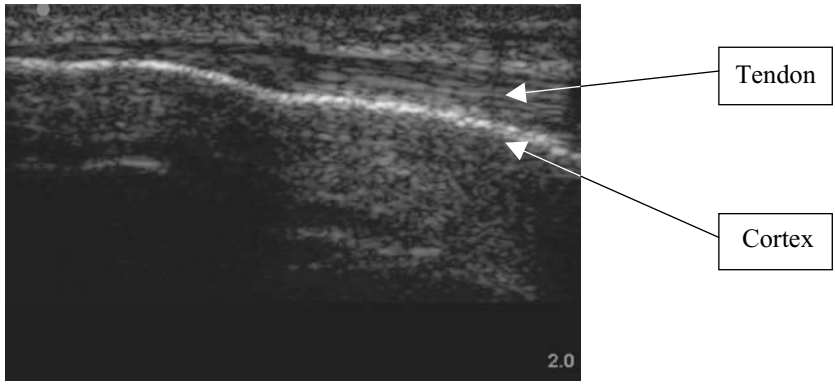


**Figure 11.4**
Normal proximal tibia with fibrillar appearing patella tendon just superior.

## Abnormal Images

Figures 11.5, 11.6 and 11.7 demonstrate the interruption in cotrtex seen with a fracture.

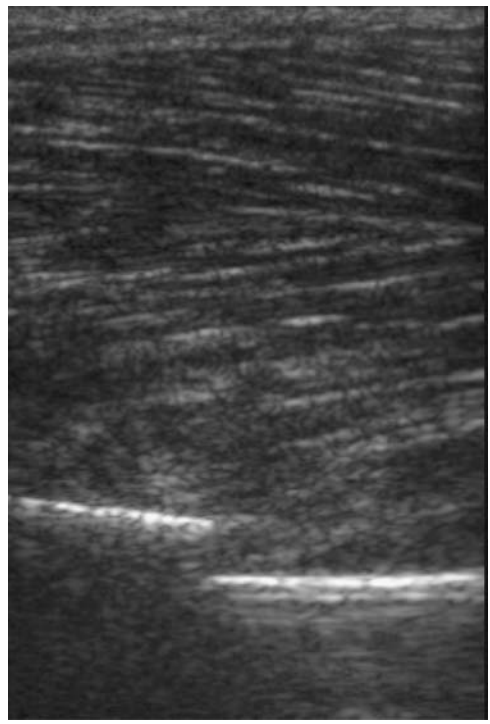

**Figure 11.5**
A fibula fracture with significant soft tissue swelling. Note the cortical disruption (broken bright white line).

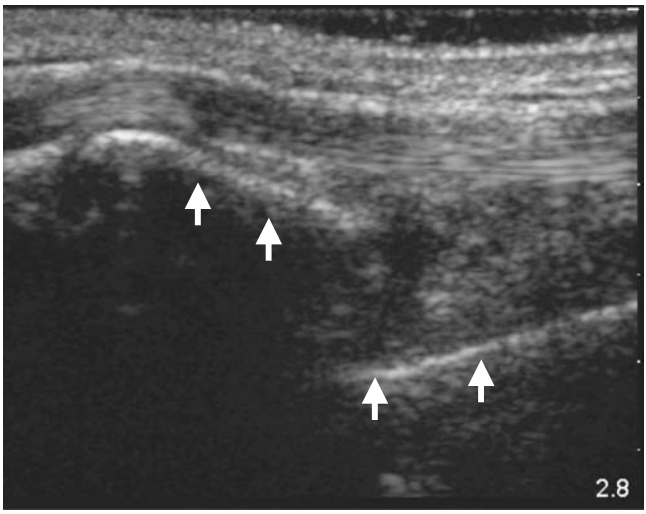


**Figure 11.6**
A distal radius fracture. Arrows represent the cortical line.

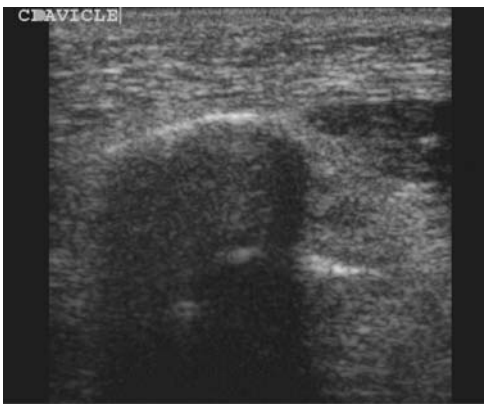


**Figure 11.7**
Clavicle fracture, with cortical interruption again visualized.

## Literature Review

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Dulchalvsky et al. (6) | 95 patients with extremity trauma evaluated with US by orthopedic cast technicians. | Specificity for all fracture types was 100%; sensitivity varied by location (83%–92% long bones, 50% hand/foot). | Nonphysicians with minimal US training can accurately diagnose long bone fracture; test not sufficiently sensitive. |
| Marshburn et al. (7) | 58 patients with suspected long bone fractures assessed with US by EPs. | Sensitivity 92%, specificity 83% for fracture detection. | US may be more sensitive than physical exam for fracture evaluation. |

| Reference | Methods | Results | Notes |
|---|---|---|---|
| Atkinson and Lennon (5) | Case series of several patients with femur fracture detected in the ED with US. | One adult and one child with femur fractures. US then used to successfully guide femoral nerve block. | US may assist diagnosis and treatment of femur fractures. |
| Chern et al. (4) | 27 patients with displaced distal radius fractures. Ultrasound guided reduction by orthopedic surgeons in ED. | Adequate reduction in all cases, radiographic and US findings post reduction matched well. | US may be useful in aiding reduction of radius fractures (potential for lower radiation dose than x-ray techniques). |
| Griffith et al. (3) | Compared ultrasound with x-ray in the diagnosis of rib fractures. | Ultrasound superior to plain x-ray in diagnosing rib fractures. | Open door for further study given gold standard outperformed by new modality. |

## New Directions

There are some diagnostic applications where ultrasound may actually be an improvement over standard of care for fractures. As mentioned, the diagnosis of rib and sternal fractures by ultrasound has been shown to be more accurate than plain films (5–7).

In addition, there are several areas of active research for bone ultrasound in pediatric medicine. First, using US only for fracture identification and reduction is an area of active research in pediatrics. While this has been successful in limited adult studies (4), there is still much research to be done before it becomes standard of care in pediatrics but the advantages (less radiation exposure, less time required, less resources needed) make this very attractive.

Another area of active research is in using ultrasound to aid in the diagnosis of pediatric skull trauma and fracture. The difficulties in obtaining a head CT scan in pediatric patients are well known and often require conscious sedation, which can be relatively contraindicated in patients with head injury because it has risks of its own. The ability of ultrasound to show skull fractures quite easily and without conscious sedation can either help push for the need for further imaging and sedation or rule it out as a diagnosis. In addition, there is research into the use of ultrasound by nonneonatologists to use the fontanelle as an acoustic window for evaluation of intracranial hemorrhage. Although both applications are currently used for research purposes only, the ease of performing ultrasound at the bedside (or in a parent's arms), the ability to image without sedation, and the lack of radiation exposure all make this an appealing diagnostic option in pediatrics.

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# Part II

# Procedural Ultrasound

Performing procedures on acutely ill patients can be one of the most rewarding and challenging aspects of emergency medicine and critical care practice. These patients present unique challenges to the clinician for a variety of reasons. Most notably, since they are acutely ill or decompensating, there is an urgency to perform procedures in suboptimal conditions. The patients themselves often pose unique challenges. Many patients have abnormal anatomy due to prior surgical procedures, scarring, trauma, or acute or chronic illness. In addition, obesity can obscure standard anatomic landmarks. Perhaps the clinician attempting to perform the procedure will not be the first operator or must navigate through a prior failed procedural attempt. Finally, due to the acuity of their illness, many patients do not have the functional capacity to remain in standard procedural positions (i.e., laying in Trendelenburg position or sitting upright), and this often makes successful procedural outcomes more challenging. These conditions are found in many critical care settings; therefore, the benefits of ultrasound guidance for procedures are not limited to the ED.

Any advantage over standard surface anatomy or landmark-based techniques should be a welcome addition to the arsenal of all critical care physicians. As with the diagnostic applications of ultrasound, ultrasound for procedure guidance is meant as an adjunct to the physical exam. When the sternocleidomastoid muscle cannot be seen or felt, ultrasound can help visualize the internal jugular vein and obviate the need for such landmarks. When clinical acumen alone cannot distinguish a subcutaneous abscess from an area of induration, ultrasound can help make the distinction.

The chapters that follow describe techniques whereby ultrasound can aid in the performance of common and often lifesaving procedures. As with all ultrasound use, the skills described here are operator dependent. But then so is the interpretation of electrocardiograms or laceration repair; this should not be an excuse but a call to practice and to build comfort with the techniques described. In addition, the same tenet of a simple, algorithmic approach toward procedural ultrasound should apply. In the case of procedure guidance, the questions may be “How deep is the effusion?”, “Is there an abscess at this site?” or “Where exactly is my needle with respect to the vein?”.

There is an ever-increasing body of literature to support the use of ultrasound for procedures, and nationally patient safety is becoming a leading priority for both federal and private health care agencies. As ultrasound use becomes more widespread and the impact on patient satisfaction, safety, and operator preference becomes more pronounced, we may see the end of the era of procedures performed without the use of radiographic guidance.

# 12 Vascular Access

## Introduction

Vascular access is one of the most basic required skills of the critical care physician. Many factors – including body habitus, volume depletion, shock, history of intravenous drug abuse, prior cannulation, scarring, thromboses, congenital deformity, and cardiac arrest – can make it difficult to obtain vascular access in patients who are critically ill or injured. Traditionally, surface anatomy and anatomic landmarks have served as the only guides for locating central veins. The incorporation of ultrasound into the procedure allows for more precise assessment of vein and artery location, vessel patency, and real-time visualization of needle placement.

The paradigm for radiology is to perform invasive procedures such as vascular access under real-time direct visualization so as to reduce complications. Although patients may have complicating medical problems, those scheduled for procedures in radiology are usually hemodynamically stable. Why then would critical care physicians perform invasive procedures on more unstable patients without the same tools and techniques to increase safety?

Real-time bedside ultrasonography facilitates rapid and successful vascular access (1–6). Indeed, there is increasing institutional and literature support for performing cannulation under direct visualization as the technology spreads throughout the hospital. This is not limited to the ED but is applicable to any critical care unit or patient care area in the hospital.

## Focused Questions for Vascular Access

The questions for vascular access are as follows:

1. Where is the target vein?
2. Is it patent?

This chapter covers techniques to make this assessment seem second nature.

## Anatomy

The most common venous cannulations assisted by ultrasound guidance are internal jugular, femoral vein, and peripheral venous cannulations. Ultrasound-guided subclavian vein cannulation has been described but is technically more challenging because the clavicle serves to obstruct ultrasound waves, and imaging can be difficult.

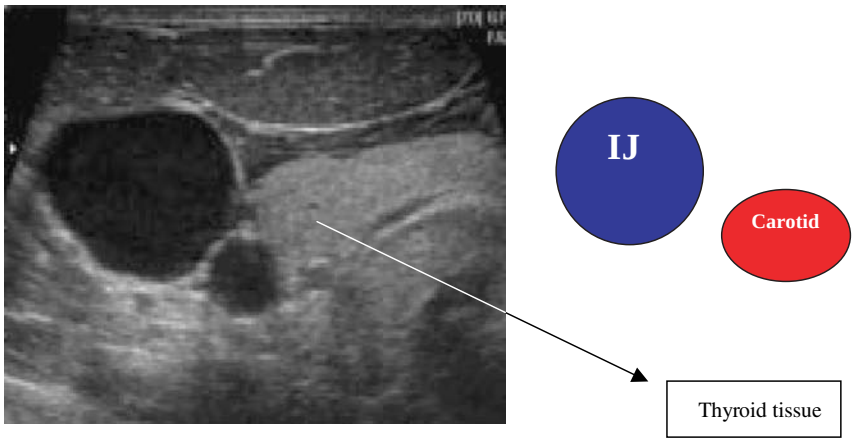


**Figure 12.1**
Internal jugular vein ultrasound image (left) and schematic (right).

Anatomic landmarks for internal jugular and femoral vein cannulation are well described. However, a brief review of relevant anatomy as it applies to sonographic evaluation is warranted.

## Internal Jugular Anatomy

Figure 12.1 shows the image obtained when the US probe is placed at the apex of the sternocleidomastoid muscle triangle (where the sternal and clavicular heads of the muscle meet near the level of the larynx). The internal jugular in most patients will be strikingly obvious, and with compression, it will be easy to identify whether the vessel is patent and thus amenable to cannulation. To the right of the internal jugular vein in this image, a gray homogenous tissue is noted. This is the thyroid tissue.

## Femoral Triangle Anatomy

Just distal to the inguinal ligament is the femoral triangle. From lateral to medial, this space contains the femoral nerve, artery, and vein, then empty space and lymphatics. This arrangement is sometimes recalled using the mnemonic "NAVEL." Typically, one would palpate for a pulse in this area and then direct a needle medially to find venous blood. Figure 12.2 shows the image obtained when the US probe is placed just distal to the inguinal ligament over the common femoral vein.

If the same ultrtasound probe were then guided more distal along the vein, Figure 12.3 would be obtained. Here, the superficial femoral vein is demonstrated. At this level, the common femoral artery has bifurcated to superficial and deep femoral arteries. The common femoral vein has also bifurcated into superficial and deep, and usually the superficial is the only vessel seen at this

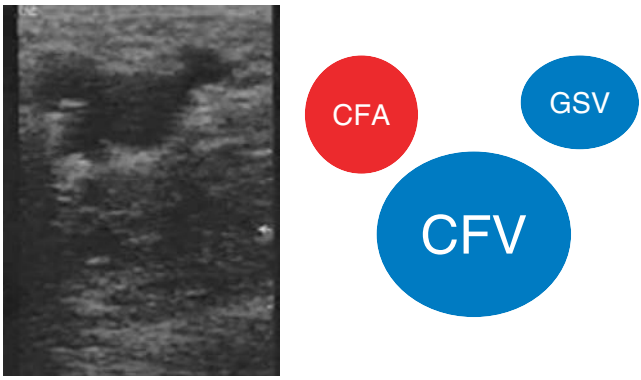


**Figure 12.2**
Common femoral vein ultrasound image (left) and schematic (right).

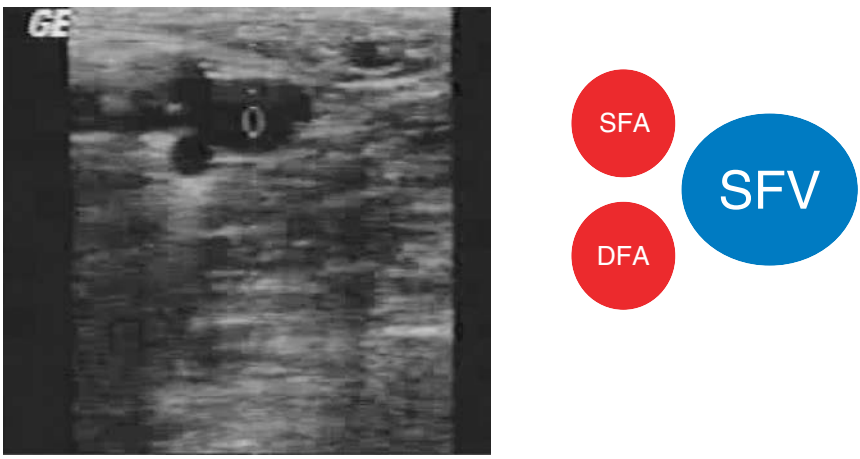


**Figure 12.3**
Superficial femoral vein ultrasound image (left) and schematic (right).

level. As described in Chapter 8, patent veins will completely compress to a thin line. If they do not, a clot is present, and cannulation should be attempted on another vessel.

Although it is helpful to have color flow to show patency and spectral Doppler to distinguish flow patterns, it is not necessary. In fact, it can sometimes be misleading because partial vein occlusion will still show flow, and transmitted pulsations can affect spectral wave forms. The most important distinguishing characteristic is that veins have thinner walls and as such are easily and completely compressible. If the vein is not completely compressible, a clot or thrombosis should be suspected and another vessel selected (see Chapter 8). Moreover, it is instructive to observe a vessel throughout the respiratory cycle before attempting cannulation because the level of respiratory variation and change in caliber or diameter that is observed is quite surprising. This is even more marked in dehydrated or septic patients and thus, if observed, may require more reverse Trendelenburg positioning.

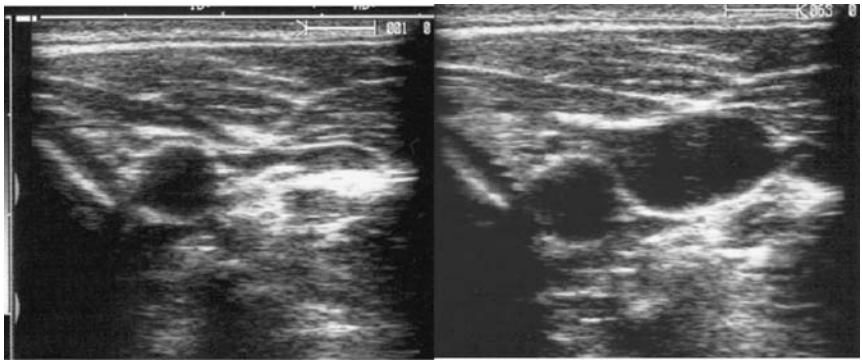

**Figure 12.4**

Internal jugular vein and carotid artery. When the patient is not laying flat (left image), the carotid is seen as a round anechoic structure but the jugular vein is collapsed. When the Valsalva maneuver and Trendelenburg position are applied (right), the highly distensible internal jugular vein fills with blood and is easily seen to the right of the carotid.

Figure 12.4 shows the same patient with and without Valsalva and increased Trendelenburg positioning. In the image with Valsalva and Trendelenburg (image on the right), the internal jugular is much easier to visualize, and the increased caliber will improve cannulation success.

# Technique

## Probe Selection

Generally, a high-frequency (5–10 MHz) linear probe (Figure 12.5) is used for vascular access. The higher frequency generates higher-resolution pictures, and the linear image display makes needle guidance and identification somewhat more intuitive.

## Special Equipment

A sterile probe cover (Figure 12.6), typically packaged with sterile conducting gel, should be used when performing the venous access with maximal sterile barrier technique. Sterile gloves can be used as a substitute probe cover if these packages are not available.

## Approaches

Two general approaches are used during vascular access: *static* and *dynamic*. Ultrasound is used to verify the vessel location prior to using external standard landmark-based approach (static technique), or it is used for real-time imaging of the venipuncture (dynamic technique). The dynamic technique may use a short axis (where cross-sectional anatomy of the vessel is visualized) or a long axis (using the longitudinal view of the vessel and needle) approach. Each

**Figure 12.5**
A high frequency linear probe

**Figure 12.6**
A typical sterile probe cover kit, consisting of a clear plastic probe cover and sterile ultrasound gel (in the silver packet). The round rubber bands can be applied to help keep the probe cover from sliding out of place on the transducer.

technique has benefits and drawbacks, some of which are highlighted in Table 12.1. However, when beginning, it is preferable to use the dynamic short axis view. This is because the relative location of artery and vein is easier to appreciate, and the risk of sliding off one vessel onto the other is eliminated.

The procedure can be performed by a single operator or by two people, with one person holding the ultrasound probe and one performing the procedure. When a two-operator approach is used, the more experienced US

**Table 12.1** Static versus dynamic techniques

| Approach | Benefits | Drawbacks |
|---|---|---|
| Static | Transducer is not needed during the sterile portion of the procedure | No real-time guidance for trajectory, dynamic changes in anatomy |
| Dynamic-long axis | Clear view of needle depth, trajectory throughout procedure | Technically difficult, no guidance laterally for left–right trajectory changes |
| Dynamic-short axis | Provides view of structures surrounding vessel, allows for lateral trajectory correction | More difficult to visualize the needle tip |

operator should be the one holding the ultrasound probe, whereas the more novice operator should perform the cannulation. For either technique, the preparation and probe orientation are the same.

## Setup

This book assumes familiarity with the standard techniques for the procedures described. Thus, Chapters 12 and 13 highlight only the techniques related to ultrasound use.

### *Patient Positioning*

Position the patient as you would normally (Figure 12.7). The ultrasound machine should be placed immediately next to the patient so you can visualize the relevant patient anatomy and the ultrasound image at the same time. The operator will therefore be facing both the patient and the ultrasound machine.

If a static approach is employed, the vessel should be visualized at this point, and patency should be checked (using compressibility as described in Chapter 8). Center the target vessel on the screen – this places the transducer over the center of the vessel. A mark should be placed on the skin at the midpoint of the transducer to mark vessel location. To assess vessel trajectory,

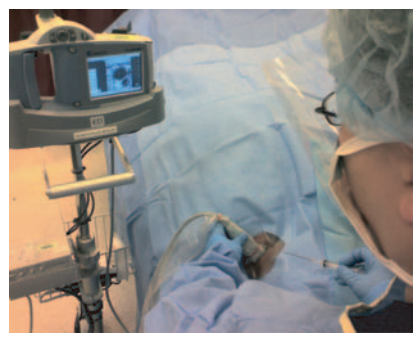

**Figure 12.7**
Patient positioning for central venous access.

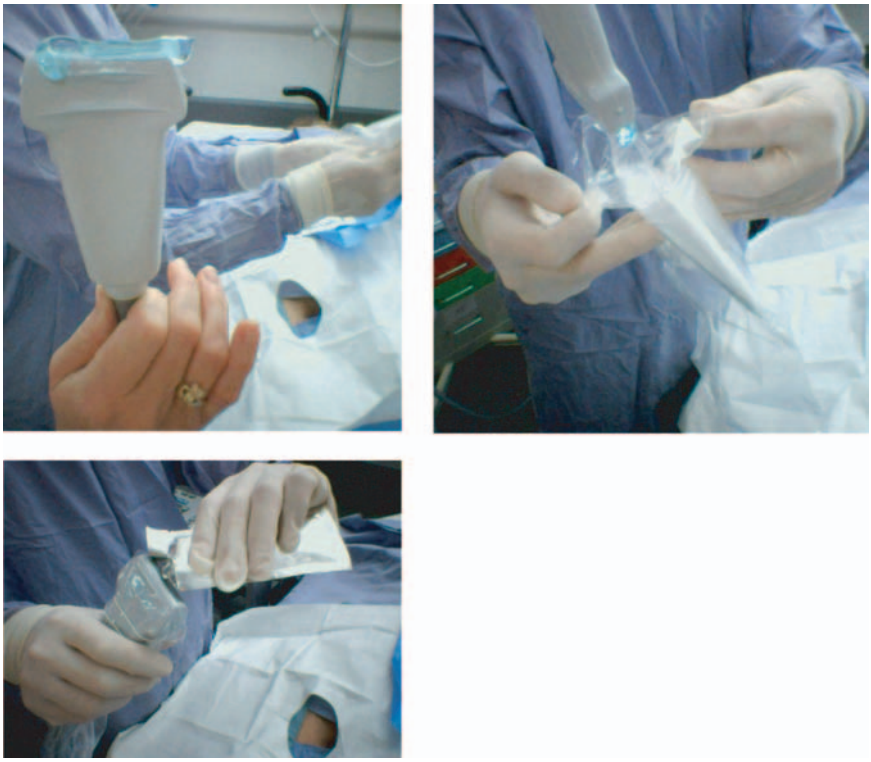

**Figure 12.8**
Probe preparation.

repeat this process once more at a point on the vessel 1 to 2 cm away. Thus, the two points marked on the skin will define a line and act as a better guide for needle direction than a single point.

For dynamic approaches, the patient should be draped and prepped in the usual sterile fashion. Next, the transducer should be prepped in a sterile fashion.

### *Transducer Preparation*

The sterile probe cover kit (or a sterile glove if kits are unavailable) should be placed on the sterile field. A nonsterile assistant should hold the probe upright and apply standard (nonsterile) conducting gel to the transducer. The probe is then inserted into the sterile sheath and placed on the sterile field. Sterile gel (from silver lubricant packages) can then be placed on the sterile glove on top of the probe (Figure 12.8).

### *Probe Orientation*

Note the location of the probe marker. The probe marker and the screen marker (see Chapter 1) should be pointing in the same direction. That is, the

probe marker should correspond to the left side of the operator (not necessarily the left side of the patient) and the left side of the ultrasound image on the screen. This way, if the needle moves to the left of the probe, it will also move to the left on the screen.

### *Vessel Identification*

Place the transducer at the site of anticipated needle placement. Search for the vessel using local ultrasound landmarks as a guide (sternocleidomastoid muscle, carotid artery for the internal jugular approach; femoral artery for the femoral vein approach). Check compressibility of the vein. This serves to distinguish artery from vein and to reduce the risk of attempting catheter placement at the site of a deep vein thrombus. At this point, the center of the vessel should be held in the center of the screen. This means that the vessel is beneath the center of the probe.

### *For a Short Axis Approach*

Center the cross section of the vein on the screen.

One simple way to assess the proper distance from the transducer is to use the geometry of an isosceles triangle or the Pythagorean theorem. As shown in Figure 12.9, measure the depth from the surface to the vessel ($D_2$). This is equal to the distance from the transducer to where the skin puncture should be made ($D_1$), as long as the needle enters the skin at a 45-degree angle. When a more

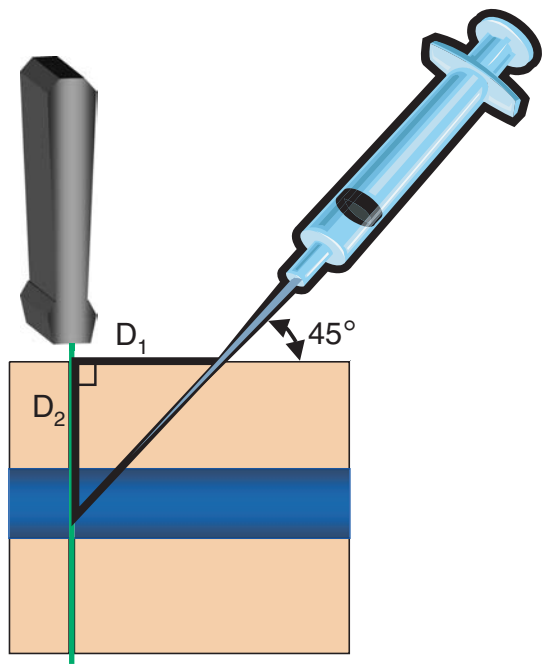


**Figure 12.9**
Pythagorean theorem – needle orientation.

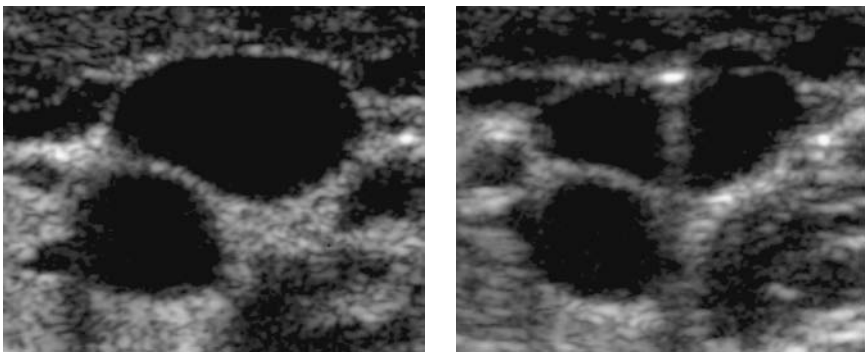

**Figure 12.10**

(*Right*) The needle tenting the internal jugular vein as it is about to puncture the vessel. Note the vessel is pushed inward as compared to the image on the left, prior to cannulation.

shallow angle is desired, the distance from the transducer (for a given vessel depth) must be increased. Thus, if the vessel is centered 1 cm beneath the skin, puncture the skin 1 cm toward the operator from the transducer and the vein will be punctured by 1.4 cm. If the vein is 2 cm deep, puncture 2 cm from the transducer and hit the vessel when the needle has traveled 2.8 cm. It is useful to make this calculation before attempting cannulation to avoid complications. If the needle is at distance (H) and the vessel has not been cannulated, then the trajectory is not correct and the needle should be repositioned before injuring deeper structures such as the carotid or femoral artery. Puncturing the skin at a point too close to the transducer position will yield a steep trajectory and will make cannulation more difficult.

In the short axis approach, the needle is only viewed when it crosses the ultrasound plane perpendicular to it. The needle will be seen as a dot, often with either a faint shadow (black) or reverberation artifact (white) deep to the needle. However, often the needle itself will not be visualized. This is because the needle width is quite small, and during the initial portion of the path, the needle has not yet crossed the plane of the ultrasound beam. It is possible to angle the probe toward the needle to ensure that it is traveling along the correct trajectory. Signs of the needle pushing through tissue will be seen (muscle displacement, bowing in of the vein when the needle is attempting to pierce the wall), and thus, it is not essential that the needle be visualized.

As the needle approaches the vessel, the walls of the vessel will tent downward and then pop back when the wall is punctured. In Figure 12.10, the needle cross section is visualized as a bright point with some reverberation artifact. Tenting of the internal jugular vein is also seen. After the vein is punctured, a flash should be seen in the syringe, and the usefulness of the ultrasound is complete. Proceed with normal cannulation techniques (guidewire, introducer) from this point onward.

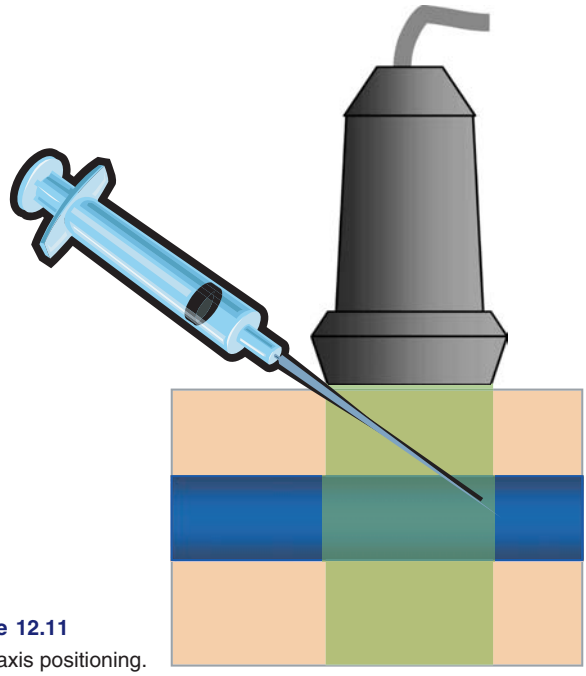

**Figure 12.11**
Long axis positioning.

### *For a Long Axis Approach*

Again, it is recommended that the short axis approach be mastered before attempting the dynamic long axis approach because the technique is similar. Center the long axis of the vein on the screen. To ensure that you are in the center, focus on the largest diameter of the vessel. Hold the needle in line with the trajectory of the vessel, which should be in the same plane as the ultrasound beam (Figure 12.11).

With this technique, it is important to keep the transducer steady over the center of the vessel. If the needle is misdirected out of the plane (seen as losing the image of the needle), it should be withdrawn toward the skin and redirected. *Do not* redirect the ultrasound beam to find the needle, *instead* redirect the *needle* toward the *beam*.

When visualizing the long axis of the needle and vessel, the entire length of the needle (including the all-important tip) can be visualized (Figure 12.12). The arrows point out the highly conductive metal needle with reverberation artifact emanating parallel to it.

For the novice user, it can be challenging to correlate movements of the needle with changes in appearance of the image on the screen. However, it is important to stress that the ultimate goal of ultrasound use is vessel cannulation. Thus, one cannot lose sight of the syringe and needle during the procedure. It is easy to focus on the screen and miss a flash of blood, or to focus on the syringe and miss the needle veering dangerously off course on the screen. With practice, it becomes easier to simultaneously focus on the screen and the

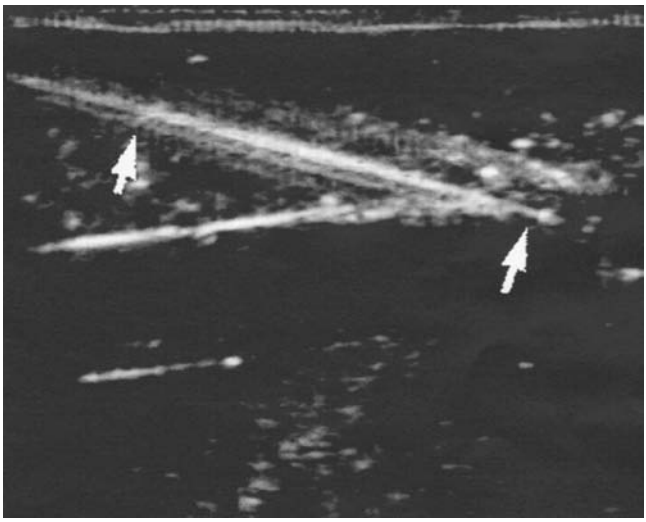

**Figure 12.12**
Long axis visualization of the needle puncturing the vessel.

syringe, just as one focuses on both the road ahead and the rearview mirror when driving a car.

## Cannulation of the Subclavian Vein

The use of ultrasound with the infraclavicular approach to subclavian vein cannulation is limited by the large acoustic shadow created by the clavicle. However, the take-off of the subclavian vein from the internal jugular vein can often be visualized by placing the probe in a supraclavicular position. Using the same basic principles outlined previously, identify the proximal subclavian vein and the internal jugular vein.

## Cannulation of the External Jugular Vein

Because the external jugular vein is superficial, it is often readily identified by visualization and palpation. However, some cases are limited by a patient's range of motion or adiposity. In such instances, ultrasound guidance may prove useful. Figure 12.13 demonstrates the sonographic appearance of the external jugular vein along with the internal jugular vein. The technique of vessel cannulation is identical to that of the internal jugular vein as described previously. Of note, the superficial external jugular vein is easily collapsed with even slight pressure of the transducer on the skin.

## Peripheral Venous Cannulation

Peripheral veins are sometimes difficult to cannulate because of their inconsistent anatomic relationships and because they are sometimes too deep to palpate. Again, ultrasound can be useful in these situations (Figure 12.14). Either

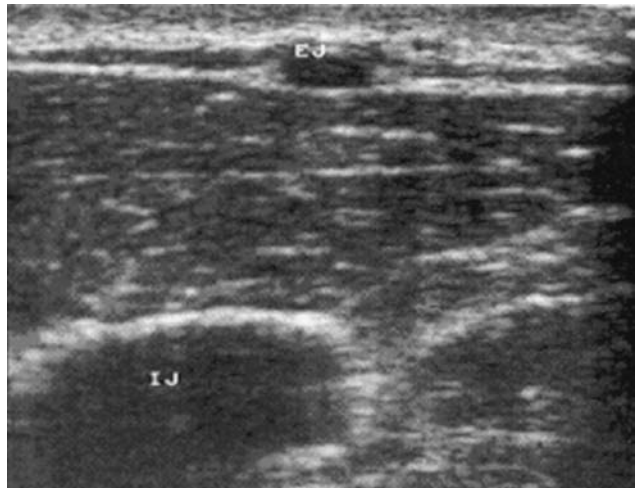


**Figure 12.13**
Transverse view of external jugular (EJ) and internal jugular (IJ) veins.

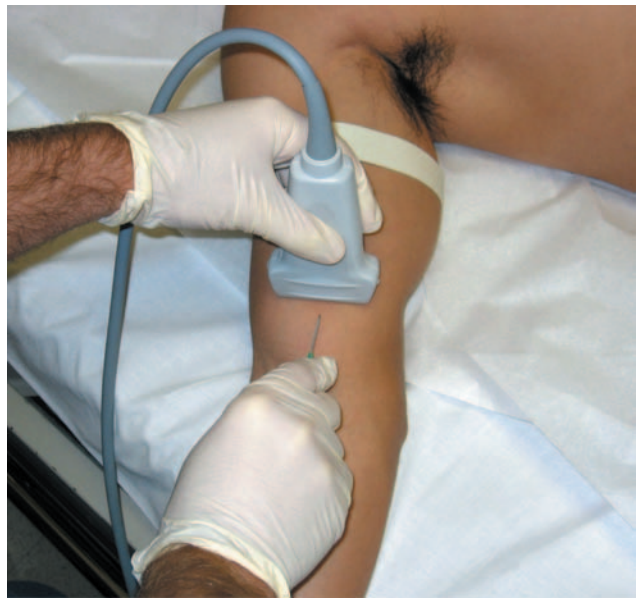

**Figure 12.14**
Ultrasound guidance for peripheral vein cannulation.

the static or dynamic technique can be employed. Remember, however, that inadvertent transducer pressure can collapse the veins and preclude their identification. Once a suitable vein is identified, the process of intravenous catheter placement is largely unchanged from standard practice.

## Scanning Tips

- Tilt probe toward needle tip when using a short axis approach.
- Remember to image the tip of the needle; visualizing the needle shaft is not useful.

- Be sure to check for depth, compressibility, Doppler flow, and location of nearby arteries.
- Note how subtle changes in patient positioning, Trendelenburg, and so on impact vessel location and distention. Take some time prior to the procedure to maximize the positioning using ultrasound as a guide.
- When using a two-person technique, the more experienced sonographer should hold the probe, and the less experienced one should direct the needle.

## Pitfalls

- Keep the vein centered on screen in the short axis view. Remember that the needle will be inserted at the center point of the transducer. If the transducer is not centered over the vein, the needle will be directed to the wrong location.
- After the flash of blood, the procedure is no longer facilitated by ultrasound. At this point, put the probe down, and continue the procedure as you normally would.
- Be sure to angle or slide the transducer (in the short axis technique) to visualize the tip of the needle. If the transducer remains in a static position, it cannot be relied on to demonstrate the needle trajectory accurately. In the short axis approach, the plane follows the needle.
- In the long axis approach, the opposite is true. Keep the probe (and plane of the ultrasound beam) steady in the optimal position. If the needle deviates from the plane, it (and not the probe) should be redirected. In the long axis approach, the needle follows the plane.

## Literature Review

Ultrasound use in central venous access was first described in the early 1990s. Since then, dozens of studies have sought to assess the efficacy of the technique. Recently, Milling et al. (1) randomized patients to landmark-based, static, or dynamic ultrasound guidance for central venous cannulation. The study found that ultrasound guidance was associated with a higher success rate. In 1997, Hilty et al. (2) found a reduction in the number of attempts and complication rates when using US. Notably, the authors determined that the femoral pulsation felt during cardiopulmonary resuscitation (CPR) was frequently venous and not arterial. This finding should call into question common assumptions about venous anatomy during chest compressions, and the technique of directing the needle medial to the pulse felt during CPR.

Several meta-analyses have examined pooled data from studies of patients in a variety of settings (intensive care unit, transplant unit). Hind et al. (3) found that use of US reduced the risk of failed catheter placement (relative risk reduction of 0.14). A similar analysis by Randolph et al. (4) found that ultrasound guidance in seven patients would prevent one complication. A review

**Table 12.2** Summary of complication rates for central venous access approaches

| | Frequency (%) | | |
|---|---|---|---|
| **Complication** | **IJ** | **Subclavian** | **Femoral** |
| Arterial puncture | 6.3–9.4 | 3.1–4.9 | 9–15 |
| Hematoma | <0.1–2.2 | 1.2–2.1 | 3.8–4.4 |
| Hemothorax | NA | 0.4–0.6 | NA |
| Pneumothorax | <0.1–0.2 | 1.5–3.1 | NA |
| **Total** | **6.3–11.8** | **6.2–10.7** | **12.8–19.4** |

From McGee DC, Gould MK. Preventing complications of central venous catheterization. *N Engl J Med* 2003;348(12):1123–33.

article by McGee and Gould (5). noted the high complication rates of central venous access (Table 12.2) and recommended US be used for line placement when available.

The U.S. Department of Health and Human Services published recommendations in 2001 regarding techniques to reduce medical errors (6). Among the recommendations (which included handwashing and electronic medical records) was the recommendation that US should be used to guide the placement of central venous catheters.

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2. Hilty WM, Hudson PA, Levitt MA, Hall JB. Real-time ultrasound-guided femoral vein catheterization during cardiopulmonary resuscitation. *Ann Emerg Med* 1997;29(3):331–6.
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4. Randolph AG, Cook DJ, Gonzales CA, Pribble CG. Ultrasound guidance for placement of central venous catheters: a meta-analysis of the literature. *Crit Care Med* 1996;24(12):2053–8.
5. McGee DC, Gould MK. Preventing complications of central venous catheterization. *N Engl J Med* 2003;348(12):1123–33.
6. Rothschild JM. *Evidence Report/Technology Assessment Number 43: Making Health Care Safer: A Critical Analysis of Patient Safety Practices*. U.S. Department of Health and Human Services Publication 01-E058. 2001. (found at http://www.ncbi.nlm.nih.gov/books/bv.fcgi?rid=hstat1.chapter.59276)

# Cannulation of the Brachial and Cephalic Veins of the Upper Extremity

Peripheral venous cannulation can sometimes be unsuccessful after multiple attempts – even with attempts at the relatively larger antecubital veins. In this case, one might consider attempting cannulation of the brachial or cephalic veins. These veins lie deeper in the structures of the upper arm and are not readily palpable. Consequently, these veins are not generally used for intravenous catheter placement in the absence of ultrasound guidance. In most patients, the depth of these vessels requires that a longer intravenous catheter (1.75–2.0 in) be used. Caution should be exercised with the more proximal brachial vein because it lies immediately adjacent to the ulnar and median nerves.

## Focused Question

1. Where is the target vein?

## Anatomy

The axillary vein divides into the cephalic vein, which runs superficially toward the lateral (dorsal) aspect of the upper arm; the basilic vein, which courses superficially along the inferior and medial (ventral) aspect of the arm; and the brachial vein, which runs deeply inferior to the biceps muscle (Figure 13.1). The basilic and cephalic veins rejoin in the antecubital fossa, and the brachial vein runs deep in this location. Frequently, the brachial vein will be found as paired superficial and deep brachial veins.

## Technique

### Probe Selection

Generally, a high-frequency linear transducer is used.

### Special Equipment

For deep vein cannulation, a longer catheter is required (at least 2 in). Sterile probe covers (described in Chapter 12) can be used for sterile peripheral access.

### Setup

As usual, the ultrasound machine should be placed in a position where the target anatomy on the patient and the ultrasound screen are both readily visible.

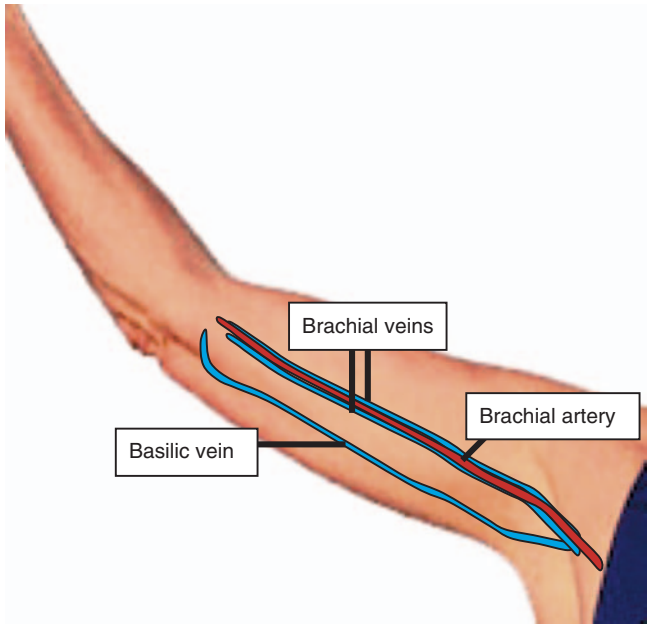


**Figure 13.1**
Upper arm vasculature. Note the close proximity of the brachial artery to the superficial and deep brachial veins, and also the basilica vein with no paired artery.

Thus, the operator will generally be facing both. The patient should be placed in the standard position for the procedure.

## Procedure

As described in Chapter 12, survey the vessels of interest using the transducer in the transverse plane. Either the static or dynamic technique can be employed. In Figure 13.2, the brachial artery is seen adjacent to the superficial brachial vein (SBV) and deep brachial vein (DBV). The humerus lies at the bottom right-hand corner of the screen.

It is important to check compressibility and vessel patency. Smaller veins and arteries often do not have sufficient flow to generate a brisk Doppler signal; differences in compressibility often highlight the veins from the arteries that the brachial veins (V) readily compress, (Figure 13.3), but the brachial artery (A) remains patent. In real time, even small arteries can be seen to pulsate when pressure is placed on them. Once the target vein is identified, the process of intravenous catheter placement is largely unchanged (except for the use of a longer catheter).

# Tips

Peripheral veins are more superficial, inconstant, and fragile than central veins. All the care and finesse one usually employs in cannulating a difficult peripheral vein should still be used with ultrasound.

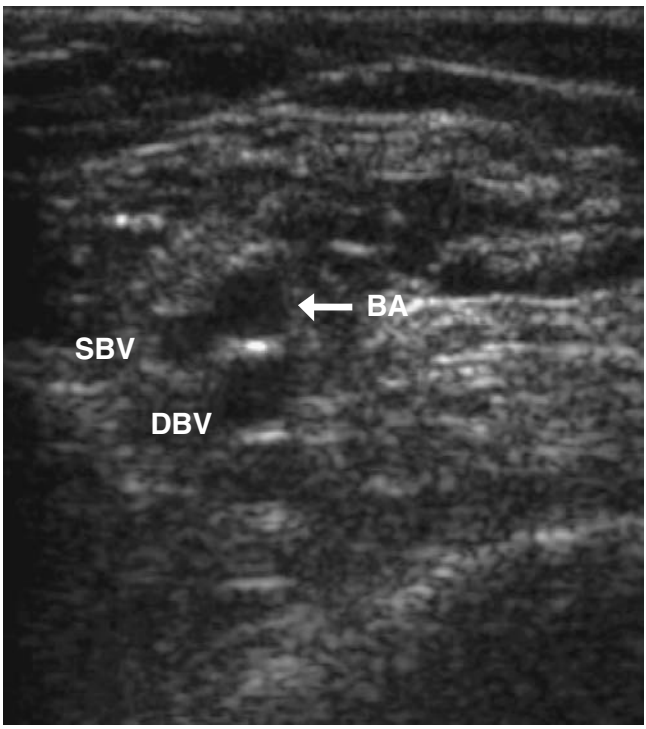


**Figure 13.2**
The superficial and deep brachial veins (SBV and DBV) are visualized adjacent to the brachial artery (BA).

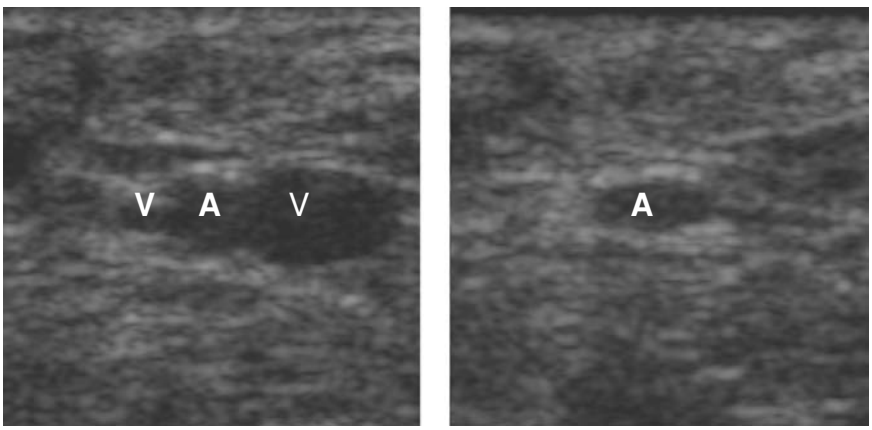


**Figure 13.3**
The brachial veins (V) and artery (A) without compression (*left*) and with compression (*right*).

Use the least amount of pressure possible with the transducer when imaging the veins. Often, no veins are visible because they have all been collapsed by too much pressure.

## Pitfalls

Difficult veins are difficult veins. Ultrasound can help find veins that would otherwise be invisible, but it cannot prevent veins from rolling or collapsing.

Do not approach peripheral veins with a catheter at an acute angle. Remember that getting *to* the vessel is only one step – do not forget that you must thread the catheter *into* the vessel. If you would normally place an IV at a 15- to 30-degree angle to the skin, ultrasound cannot make a 60-degree angle of approach feasible.

## Literature Review

Several studies have examined the use of ultrasound in gaining peripheral intravenous access. Studies in the emergency (1,2) and anesthesia (3) literature have demonstrated higher success rates using ultrasound in patients deemed to be difficult venous access cases or in whom prior (non–US-guided) approaches had failed.

## References

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# Pleural Effusion and Thoracentesis

Pleural effusions typically appear as an echofree space on sonography. Internal echoes may be present in the fluid. The echogenicity may be homogenous as occurs with proteinaceous or highly cellular effusions, or heterogenous as in septate effusions or more exudative effusions. The positive identification of pleural fluid requires the demonstration of dynamic signs such as a change in shape of the echofree space during the respiratory cycle, atelectatic or compressed lung, and swirling motion in the echofree space.

## Focused Questions

1. Is there pleural fluid?
2. Where is the optimal site for needle placement?

## Anatomy

Fluid accumulates between the visceral and parietal layers of the pleura. It collects in the most dependent portions of the pleura (the costophrenic angles) and rises from that level as more volume accumulates. One of the first signs of pleural fluid is the loss of the normal mirror image artifact caudal to the diaphragm and liver or spleen. In Figure 13.4, the liver, kidney, diaphragm, pleural fluid, and lung are all visible.

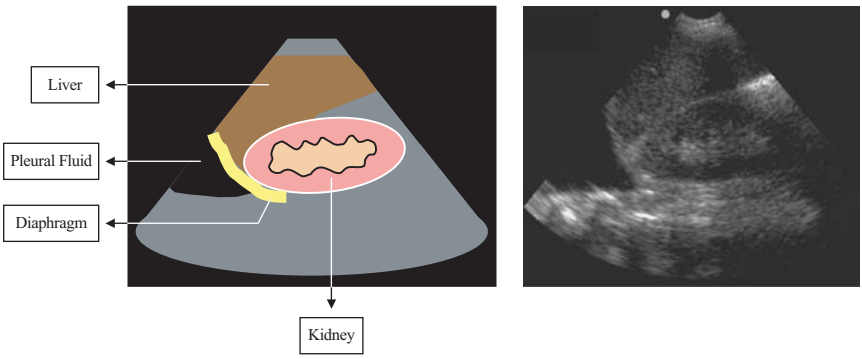


**Figure 13.4**

Black pleural fluid is demonstrated superior to the diaphragm and liver. The kidney is also well visualized in this view.

## Technique

### Probe Selection

Ultrasound of the pleural space may be performed with a 2.5- to 5.0-MHz transducer.

### Special Equipment

A marking pen is used (Figure 13.5).

### Setup

The patient is positioned in a seated-upright position when possible. Scanning is performed from the anterior axillary line to the paravertebral space and from the superior and inferior aspects of the fluid collection. The feasibility of thoracentesis requires the demonstration of a sonographic window to

**Figure 13.5**
Marking pen

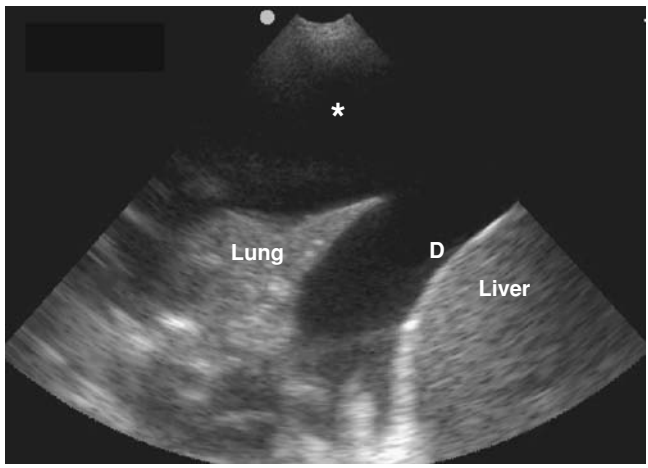


**Figure 13.6**
Pleural fluid (*) is noted above the diaphragm and liver. Lung tissue is normally not well visualized because of the large amount of air. In this case the pleural fluid provides a good acoustic window and the normally aerated lung tissue has been compressed somewhat and made more dense by the additional fluid pressure in the thorax.

the fluid *persisting* throughout the respiratory cycle. There is no formal lower limit of effusion size beneath which thoracentesis is contraindicated. However, many operators recommend that a visceral to parietal pleural distance of at least 10 mm is preferable to minimize the risk of an adverse outcome. Moreover, incursions of lung or diaphragm (D) during the respiratory cycle into the sonographic window are considered absolute contraindications to thoracentesis at that site. Positive identification of the diaphragm plus liver or spleen is required to avoid puncture of these organs. If no safe sonographic window is identified, seriously consider aborting the procedure.

After identifying a suitable sonographic window, the angle of the transducer/probe is noted. In addition, measure the depth required to achieve penetration into the pleural space (*) containing fluid (Figure 13.6). Last, mark the skin at the site of planned needle entry.

## Procedure

Immediately following ultrasound examination, prepare the site in a sterile fashion and perform thoracentesis in the usual fashion (Figure 13.7), with care not to alter the patient's position.

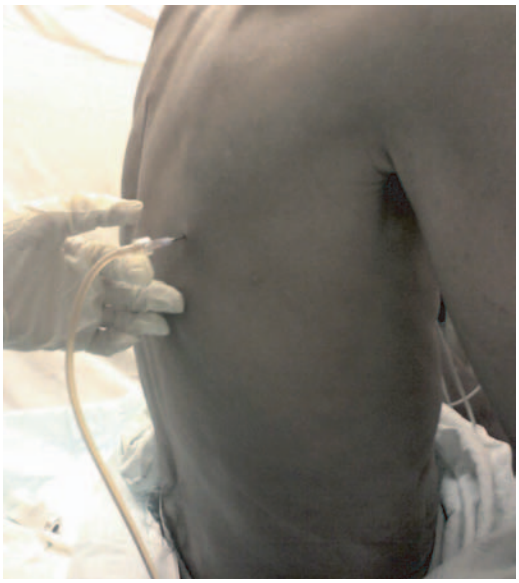

**Figure 13.7**
Thoracentesis setup. Note the needle placement and patient position are the same as for a standard landmark-based technique.

Duplicate the angle of the transducer/probe with the thoracentesis needle/catheter during the procedure. Direct visualization of needle entry is not necessary if the prior steps are followed.

## Tips

Measuring the depth from the skin to the parietal pleura allows for needle entry to a depth that should yield fluid but lower the risk of puncturing the visceral pleura.

## Pitfalls

Observe the proposed puncture site during the entire respiratory cycle. Significant changes in diaphragm position occur during respirations.

## Literature Review

Ultrasound was first used as a rescue method for failed or difficult thoracentesis. One early study demonstrated US-guided thoracentesis was successful in 88% of previously failed landmark-based attempts. The authors noted that scanning over the initial attempt sites found it to be above or below the effusion in 69% of the cases, and that the initial attempt was directly over the spleen, liver, or kidney in 58% of the cases (1). Ultrasound guidance has a high success rate, even in cases where no fluid is visible on chest x-rays (2). More recently, a study by interventional radiologists demonstrated a low complication rate (2.5% pneumothorax) when using US guidance, compared to historic

pneumothorax ranges of 4% to 30%. Interestingly, this study also noted that complications were not correlated to the amount of fluid removed during the procedure (3). A retrospective study of US guidance versus landmark-based techniques demonstrated a significantly lower pneumothorax rate in the US guidance group (4.9% vs. 10.3%) (4).

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4. Barnes TW, Morgenthaler TI, Olson EJ, Hesley GK, Decker PA, Ryu JH. Sonographically guided thoracentesis and rate of pneumothorax. *J Clin Ultrasound* 2005;33(9):442–6.


# Ascites and Paracentesis

Detection of ascites by ultrasound is useful in the patient presenting with abdominal distension. Many patients without a known history of ascites present with abnormal transaminase levels and distension, and the presence of ascites is often incorrectly assumed. Beyond the diagnostic utility in confirming the diagnosis, ultrasound is helpful in choosing the optimal site for paracentesis.

## Focused Questions

The questions for ascites and paracentesis are as follows:

1. Is there free fluid (ascites) in the abdomen?
2. Where is the optimal location for paracentesis?

## Anatomy

Ascites accumulates in a gravity-dependent fashion within the peritoneum, similar to blood in trauma, as discussed in Chapter 2. Unless prior surgery, infections, or scarring alter the anatomy, the fluid tends to be free flowing. If loculations are present, the location of fluid pockets will be highly variable, and bowel may not "float" in the ascites as it normally would.

# Technique

## Probe Selection

Ultrasound of the abdomen may be performed with a 2.5- to 5.0-MHz transducer.

## Special Equipment

A marking pen is used.

## Setup

Place the patient in the normal preferred position for paracentesis. Some authors prefer a decubitus position, while others have the patient sitting upright. The ultrasound technique employed is similar to that used in the FAST examination. In addition to the left and right upper quadrant exam, check the lower quadrants for fluid collections, and note the position of bowel, mesentery, and bladder. Note the echogenicity of any detected intraperitoneal fluid. Recall that this fluid may be transudate, exudate, malignant, or blood. The depth from the surface of the skin to the ascites should be measured using the caliper function on the ultrasound machine or the depth gauge on the side of the screen.

On ultrasound, ascitic fluid appears anechoic with occasional echogenic strands (Figures 13.8 and 13.9).

## Procedure

After a puncture site is identified and marked, the patient should remain in the same position for the paracentesis. Alternatively, real-time scanning can be used to guide the trajectory of the needle, similar to the dynamic approach in

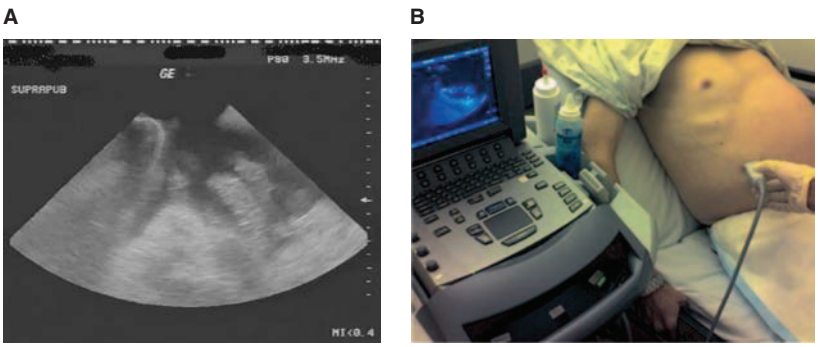


**Figure 13.8**
Suprapubic view showing ascites (black fluid) and patient positioning.

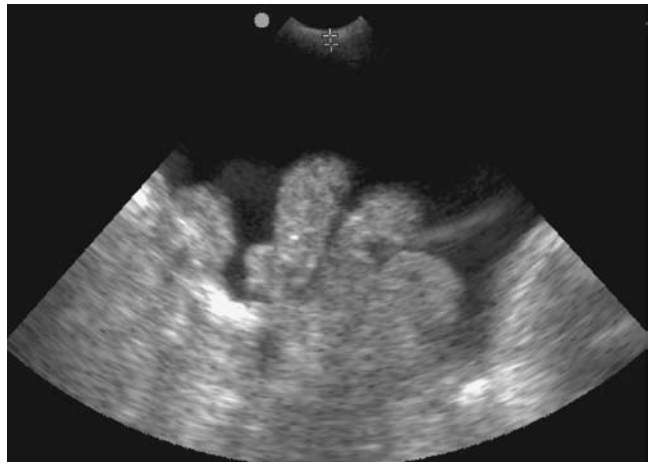

**Figure 13.9**
Left lower quadrant showing ascites and bowel loops.

central venous cannulation. Ultrasound can also be used after a large-volume paracentesis to assess the adequacy of drainage.

## Tips

Although the left lower quadrant approach is most commonly cited as best when using a landmark-guided technique, ultrasound allows for more latitude in site selection. Any site where ascites is present without nearby bowel, bladder, or vascular structures would be appropriate, including a midline approach. This approach, through the linea alba, would be inappropriate if the exact location of the bladder or potential adhesions were not known.

## Pitfalls

Be sure that the patient's position does not change from the time of scanning to the time of the procedure.

Bowel can sometimes move quite dynamically. Be sure the site of proposed paracentesis remains free of bowel for a minute or so before attempting needle puncture.

## Literature Review

When performed in a conventional blind manner, paracentesis is safe (1). In a prospective study of 229 paracenteses performed on 125 patients, only two major complications (transfusion-requiring abdominal wall hematomas) and two minor complications (non–transfusion-requiring hematomas) occurred, yielding complication rates of 0.9% each. None of the procedures resulted in spontaneous bacterial peritonitis or death.

Some studies, however, suggest that the safety and efficacy of paracentesis may be improved through the use of ultrasound guidance. Bard et al. (2)

studied twenty-seven consecutive patients with ascites detected by ultrasound. In six of the eight patients with fluid in the flank region, air-filled loops of bowel were interposed between the abdominal wall and the fluid collection. It was suggested that a blind approach may have injured the bowel. Overall, the investigators concluded that ultrasound is helpful for selecting the puncture site so as to avoid intraperitoneal structures during the paracentesis.

A more recent study randomized patients to US-guided versus standard paracentesis. In patients where fluid was visualized, there was a 95% success rate in paracentesis, compared to 65% success in patients without the use of ultrasound. Of the failed paracenteses in the landmark-based group, US guidance found no fluid in two cases and was able to guide successful aspiration in all others (3).

## References

1. Runyon BA. Paracentesis of ascitic fluid. A safe procedure. *Arch Intern Med* 1986;146(11):2259–61.
2. Bard C, Lafortune M, Breton G. Ascites: ultrasound guidance or blind paracentesis? *CMAJ* 1986;135(3):209–10.
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# Joint Effusions and Arthrocentesis

Ultrasound is more accurate and reproducible than clinical evaluation for effusions (1,2). There are multiple clinical situations where it is not obvious that there is an effusion. Ultrasound can not only assist in making this diagnosis but can also guide aspiration to ensure successful aspiration.

## Focused Questions

1. Is there a joint effusion?
2. Where is the optimal location for arthrocentesis?

## Anatomy

In visualizing joints on ultrasound, recall that fluid appears anechoic, and bone will be a bright reflector with distal shadowing. Thus, in normal joint sonography, the intersection of two bones will appear as a V-shaped gap, sometimes referred to as the "seagull sign." (Figure 13.10).

The linear dark striated structures are the muscles and tendons traveling above the joint. The bright echogenic structures with shadowing are the two bones coming together in a joint (Figure 13.11).

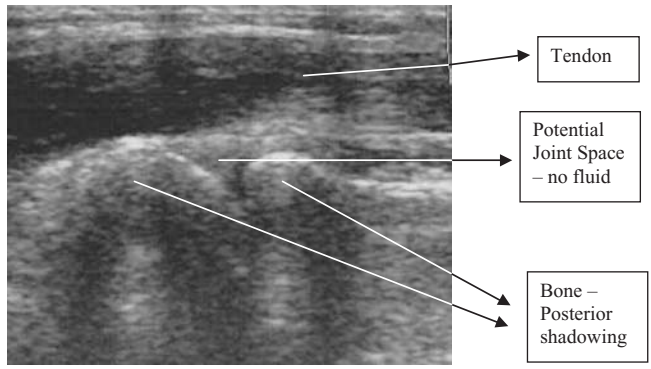


**Figure 13.10**
Joint anatomy. Note the bright, crisp white lines delineating bone, and the V-shaped space between adjacent bones creating the joint space.

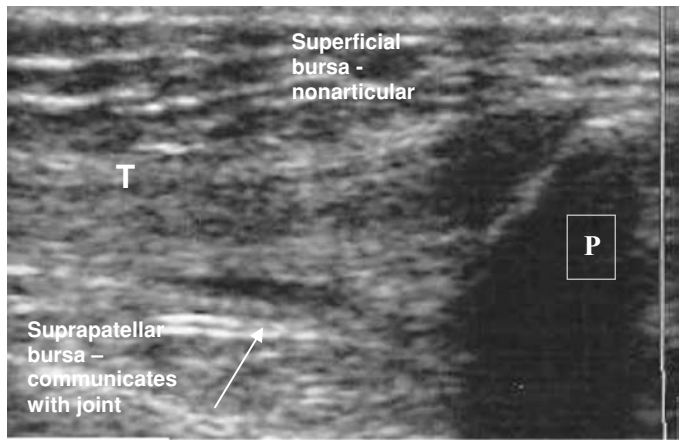


**Figure 13.11**
Knee anatomy. T, tendon; P, patella. Note the patella (as all bone) is seen as a crisp white line with distal shadowing.

# Technique

## Probe Selection

Ultrasound of the joints should be performed with a high-frequency (5- to 10-MHz) linear probe.

## Special Equipment

A marking pen is used.

## Setup

Place the patient in a comfortable position (based on which joint is involved) for the procedure. Scan over the area in question to search for signs of effusion in the joint space. Using the bony landmarks discussed previously (the "seagull sign") can be helpful if the superficial anatomy is obscured by edema

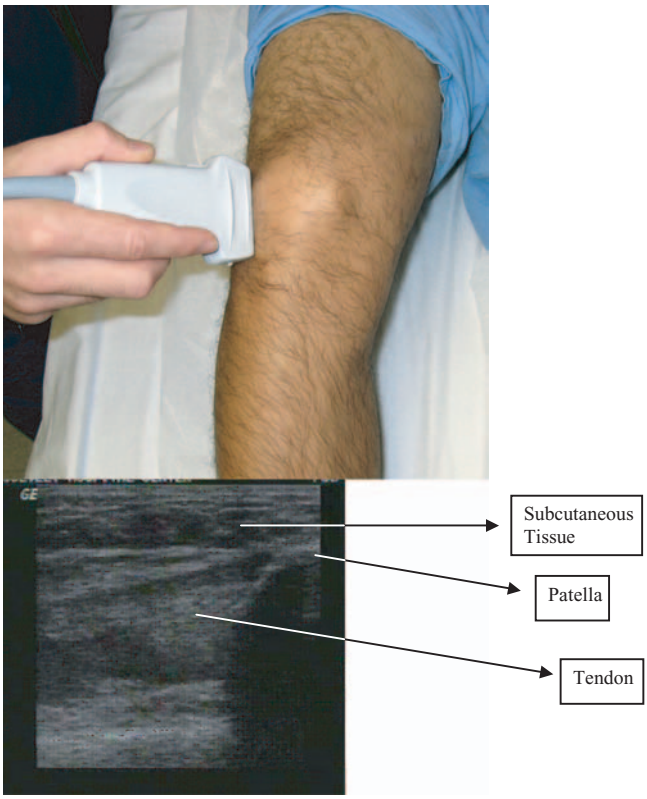


**Figure 13.12**
Lateral placement of probe for knee arthrocentesis, and image seen on screen.

or effusion. When an area demonstrating adequate fluid is located, mark the spot with a pen, and prep and drape the area in the usual sterile fashion.

### Procedure

The rest of the procedure should be carried out using standard technique, being careful to maintain the same position used when mapping the fluid collection.

## Knee

The knee joint may be well visualized from a medial or lateral approach. In Figure 13.12, a standard probe position and normal joint appearance is demonstrated. In Figure 13.13, abnormal fluid is visualized in the bursa.

## Ankle

Figure 13.14 demonstrates placement of the probe longitudinally across the joint. Again, note the "seagull sign," which directs the search for black fluid

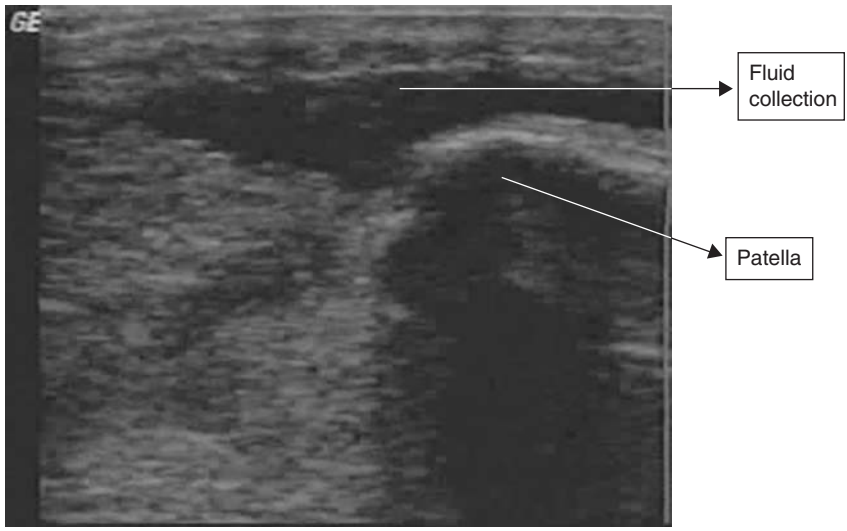


**Figure 13.13**
Black fluid collection in both the superficial and suprapatellar bursa.

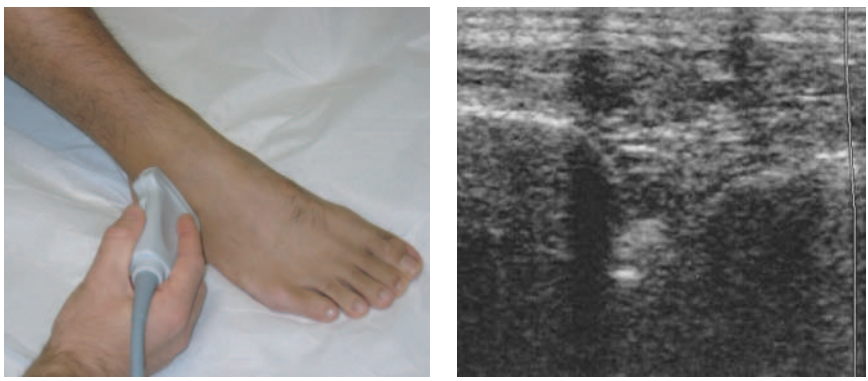

**Figure 13.14**
Ankle probe position (left) and the ultrasound image obtained at this site.

in the "V." Fluid in this location, often accompanied by displacement of the bright echogenic joint capsule, represents an effusion.

## Shoulder

Look for biceps tendon in bicipital groove (Figure 13.15). Here fluid is observed in the subdeltoid bursa. It is extraarticular, because it does not displace the biceps tendon.

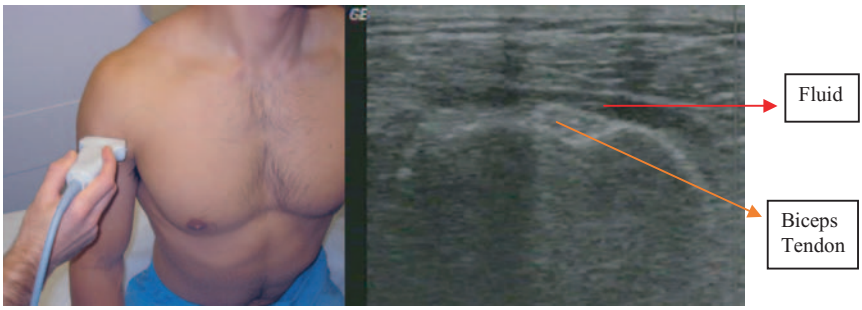


**Figure 13.15**
Shoulder probe position and the ultrasound image obtained at this site.

## Tips

When only a small amount of fluid is seen on ultrasound, it is sometimes useful to place some pressure on the joint at a different location to bring more fluid to the puncture site. For example, suprapatellar pressure can increase the size of the synovial space inferior, medial, and lateral to the patella, and make aspiration of the joint at these sites simpler.

## Pitfalls

Even slight movements of the joints will have a major impact on the location and depth of fluid collections. Be sure the patient is in his or her final position for the procedure when beginning ultrasound. Alternatively, ultrasound can be used to assess the optimal joint position in real time, and the patient can hold that position for the procedure.

## Literature Review

Although no randomized controlled trials of US-guided arthrocentesis exist in the emergency literature, some authors have reported success when using the modality in ankle arthrocentesis (1) and hip arthrocentesis (2). Both real-time needle guidance and static techniques have been described.

## References

1. Roy S, Dewitz A, Paul I. Ultrasound-assisted ankle arthrocentesis. *Am J Emerg Med* 1999;17(3):300–1.
2. Smith SW. Emergency physician-performed ultrasonography-guided hip arthrocentesis. *Acad Emerg Med* 1999;6(1):84–6.

# Foreign Body Identification/Localization

Ultrasound can also be used to identify foreign bodies – either by direct visualization (metal) or by shadowing (wood, stones) or edema (inflammation and secondary tissue effects from wood or organic material). Physical exam can be extremely challenging in these situations, and a patient's own foreign body sensation can often be misleading. Many common foreign bodies (e.g., wood) are not well visualized by x-ray, and triangulating the exact location of a small foreign body can be difficult and time consuming using standard radiographic techniques.

## Focused Questions

1. Is there a foreign body?
2. Are there vascular structures near the foreign body?

## Anatomy

The appearance of normal superficial tissues is shown in Figure 13.16. Note that the subcutaneous fat has a speckled appearance, which is slightly hypoechoic when compared to the appearance of organs such as the liver or spleen. Muscle appears "marbled" because hypoechoic muscle tissue is divided by hyperechoic fascial planes. Vascular structures will appear anechoic and will be compressible. Bone will act as a strong reflector, creating a bright boundary beyond which only shadowing will be visible.

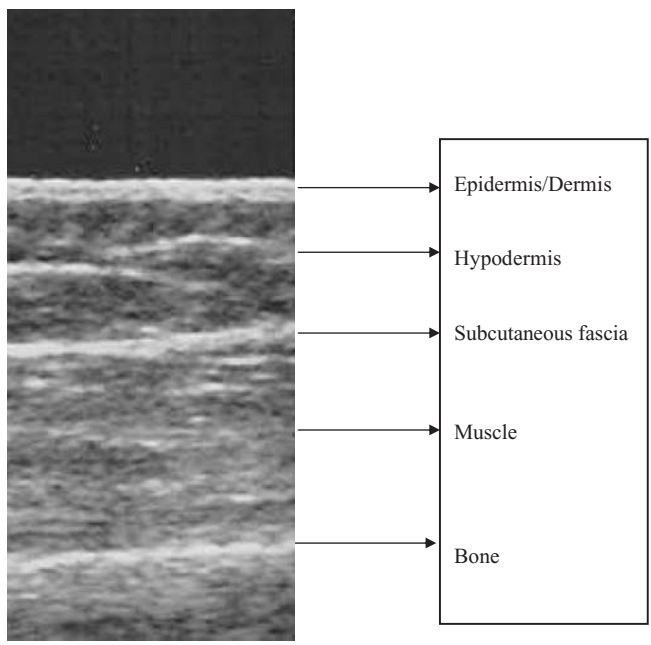


**Figure 13.16**
Normal dermal tissue, with component layers.

# Technique

## Probe Selection

Ultrasound of the superficial soft tissue should be performed with a high-frequency (5- to 10-MHz) linear probe.

## Special Equipment

The following special equipment is required:

- Lidocaine or other local anesthetic
- Water bath or standoff pad for superficial structures
  *Note:* Be sure to check the manufacturer's instructions regarding the safety of water bath use with your particular transducer. Any transducer with a cracked housing should *not* be used because the gel may conduct electrical signals to the operator or the patient. Thus, a cracked housing would be *extremely dangerous* when used with a water bath.
- Alligator forceps (Figure 13.17) or other small grasping implement
- Sterile wire (e.g., Kopans wire) or needle if this will be used to guide a dissection

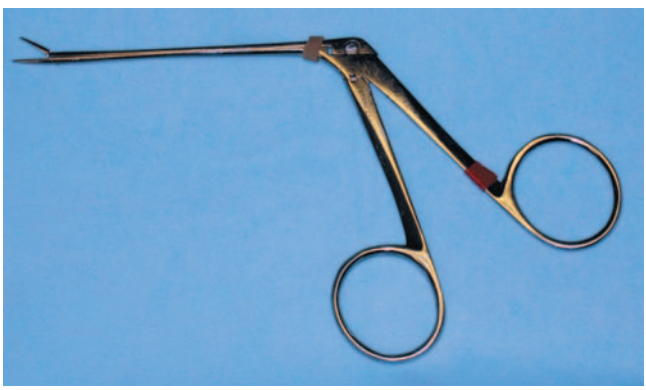

**Figure 13.17**
Alligator forceps.

## Setup

The patient should be placed in a comfortable position. As with other US-guided procedures, the ultrasound will be performed in the same position as the procedure itself.

Scan over the area of suspected foreign body and note the appearance of bright reflectors and/or shadowing in the area. Familiarize yourself with the appearance of normal bony anatomy (bright reflector with shadowing, described previously) as well as soft tissue, tendons, and vascular structures. Common foreign bodies such as wood or metal have a characteristic

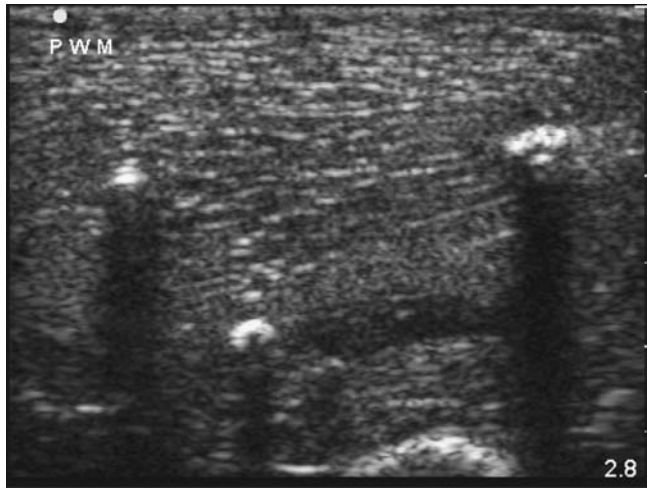


**Figure 13.18**
Transverse images of plastic, wood, and metal foreign bodies (from left to right) are demonstrated. Note the shadows deep to each structure.

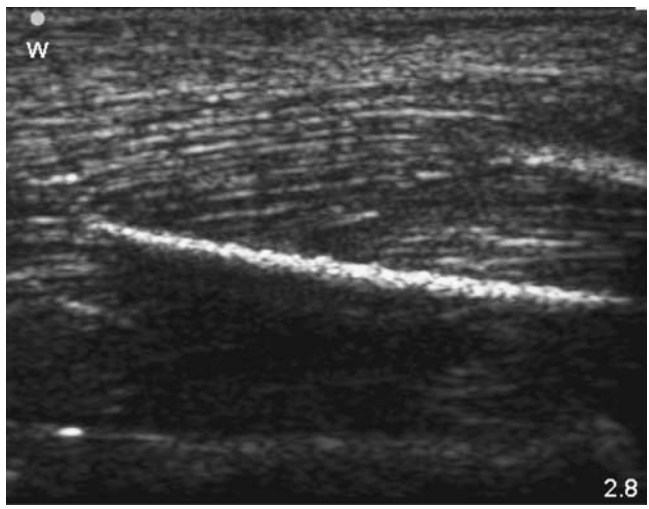


**Figure 13.19**
A wooden foreign body is demonstrated in the long axis.

appearance on ultrasound (Figures 13.18 and 13.19). Glass is sometimes visualized on ultrasound, but small pieces may frequently be missed using this technique.

## Procedure

Once the foreign body is localized, several techniques can be employed to remove it. One simple method is to guide a needle or wire to the foreign body using ultrasound, and then dissect to the foreign body using the metal guide. Kopans wires, often used for radiographic localization of breast masses prior to dissection, have been used by some operators. This technique can be useful when guiding the dissection for a consultant who will then use standard techniques.

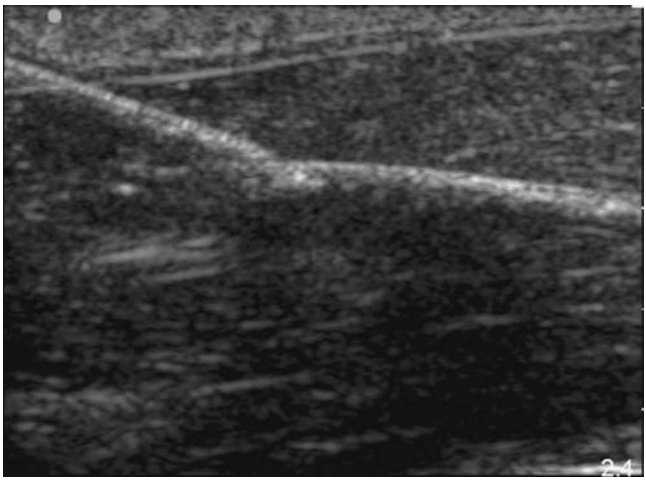

**Figure 13.20**
The needle (left side of screen) approaches the wooden foreign body.

Alternatively, many foreign bodies can be directly removed using ultrasound to guide the entire procedure. First, localize the long axis of the foreign body (splinters, toothpicks, and many metal foreign bodies are quite linear). Keeping the long axis of the foreign body centered on the screen, guide a needle with anesthetic solution to the foreign body using the same "long axis" approach described in Chapter 12. It is often easiest to enter the needle into the skin at the puncture point for the foreign body. Once contact with the foreign body is felt at the end of the needle (sometimes a tap can be heard as well), inject a generous amount of anesthetic at the site of contact (Figure 13.20).

In most cases, the solution will track around the entire foreign body with three consequences. First, the foreign body will be better visualized as it is now surrounded by a rim of anechoic fluid. Second, the area will be well anesthetized without the need for multiple injections. Third, the foreign body will often be "loosened" a bit by the extra fluid.

Now that a track of anesthetic has been deployed from the surface of the skin down to the foreign body, the object can be removed under direct visualization. Make a small nick in the skin (or use the entry point for the foreign body) at the site of desired entry. Using the same long axis technique, use an alligator forceps to follow the same path the anesthetic needle just took. Be sure to keep the forceps in the plane of the ultrasound beam. If the forceps veer off course, then back up toward the skin surface and redirect into the plane. Once contact with the foreign body is felt at the end of the forceps (sometimes a tap can be heard as well), open the jaws slightly to grasp the end of the object. The object can then be withdrawn along the previously anesthetized track.

Proper hand positioning is demonstrated in Figure 13.21. The nondominant hand holds the probe along the long axis of the foreign body. The dominant hand then guides the forceps in the same plane.

Figure 13.22 depicts the closed and open positions of the forceps and their appearance on ultrasound. The superficial aspect of the forceps will be visualized, but beam scatter will obscure the deeper portion.

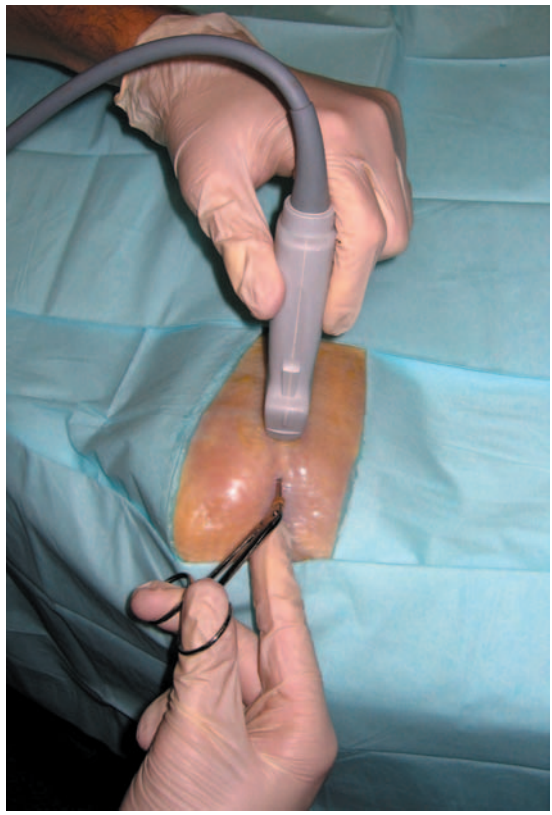

**Figure 13.21**
Probe positioning during procedure.

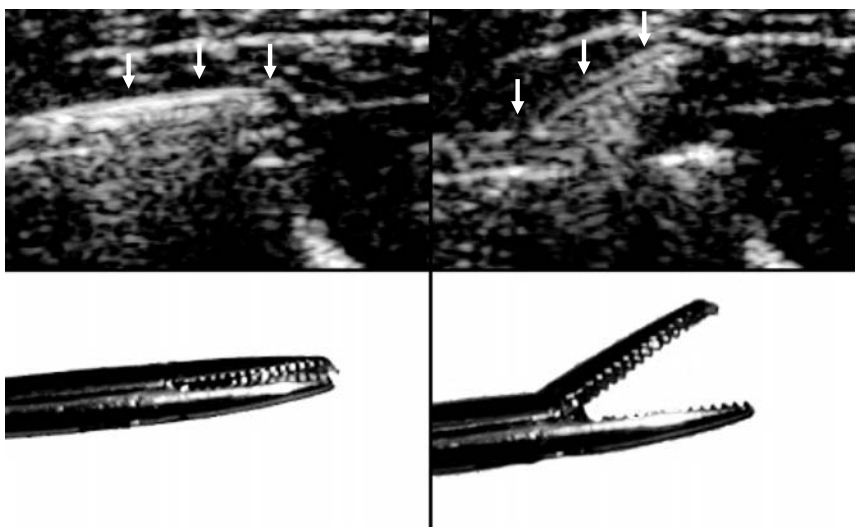

**Figure 13.22**
Sonographic appearance of the forceps while closed (left) and open (right).

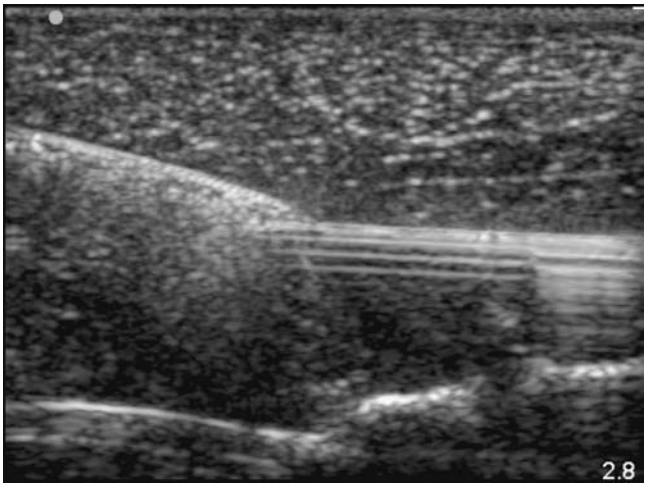


**Figure 13.23**
Grasping foreign body. The forceps are visualized coming in from the left of the screen, and a metallic foreign body (with reverberation artifact) is seen on the right.

Figure 13.23 shows the forceps approaching from the left, nearing a metallic foreign body. Note the reverberation artifact commonly seen with metallic objects on ultrasound.

## Tips

The long axis approach is better than a short axis method for this technique due to the small size of most foreign bodies, and it is the method preferred by most interventional radiologists.

Generous use of local anesthetic increases patient comfort and also mechanically facilitates the procedure.

## Pitfalls

The long axis approach is technically more challenging and requires more practice. Familiarize yourself with the mechanics of the procedure using a model such as a chicken breast with embedded toothpicks.

Be sure to pull out long foreign bodies in line with their long axis. When grasped from an oblique or perpendicular angle, the object will act as a barb and remain fixed.

## Literature Review

Many studies of US detection of foreign bodies have determined accuracy of the technique in cadaveric or simulated models. One study demonstrated a sensitivity of 93% for detection of wooden objects and 73% for plastic in human cadaver legs (1). Another study demonstrated similar accuracy in the detection of wooden foreign bodies by a radiologist (83%), US technicians (85%), and emergency physicians (80%) in a chicken thigh model (2). Other authors have

described the use of US in localizing radiolucent foreign bodies in live human subjects, especially in the extremities (3).

## References

1. Hill R, Conron R, Greissinger P, Heller M. Ultrasound for the detection of foreign bodies in human tissue. *Ann Emerg Med* 1997;29:353–6.
2. Orlinsky M, Knitel P, Feit T, Chan L, Mandavia D. The comparative accuracy of radiolucent foreign body detection using ultrasonography. *Am J Emerg Med* 2000;18:401–3.
3. Blankstein A, Cohen I, Heiman Z, Salai M, Heim M, Chechick A. Localization, detection, and guided removal of soft tissue in the hands using sonography. *Arch Orthop Trauma Surg* 2000;120:514–17.

# Abscess Identification

In the setting of a patient with local swelling, induration, tenderness, and redness, it is often difficult to differentiate between cellulitis and underlying abscess. Traditionally, needle aspiration was employed to differentiate between the two cases. However, this is painful and may increase the risk of infection.

## Focused Questions

1. Is there an abscess?
2. Are there vascular structures near the abscess?

## Anatomy

It is important to recognize the normal appearance of subcutaneous and skin tissue (discussed in the previous section). Often, there are obvious changes from cellulitic tissue to normal tissue, and the relative thickness of different tissues can indicate the location of inflammation or infection. Abscess will be swellings that are hypoechoic or dark (Figures 13.24 and 13.25), often with gray heterogeneous swirling material inside. These swellings will distort local tissue architecture (Figures 13.26 and 13.27). They are compressible because they are fluid filled. They can also have posterior enhancement because the sound waves that have traveled through the fluid-filled structures are less attenuated than surrounding waves.

## Technique

### Probe Selection

Ultrasound of the superficial soft tissues should be performed with a high-frequency (5- to 10-MHz) linear probe.

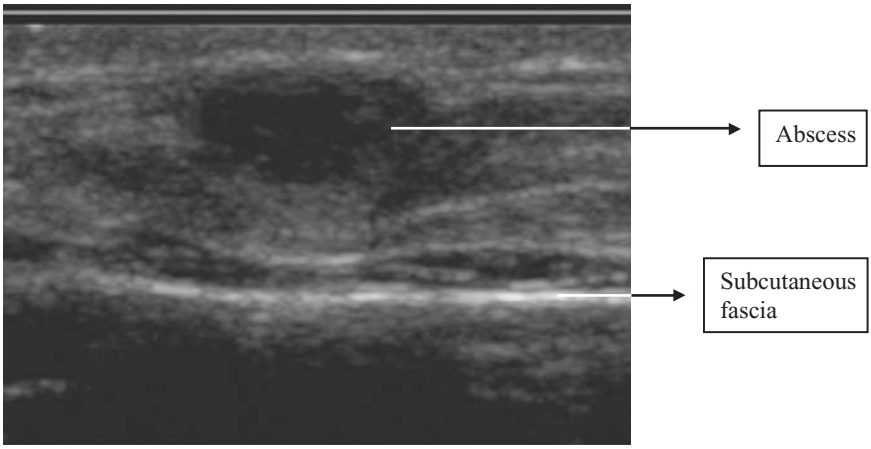


**Figure 13.24**
Ultrasound visualized soft tissue abscess.

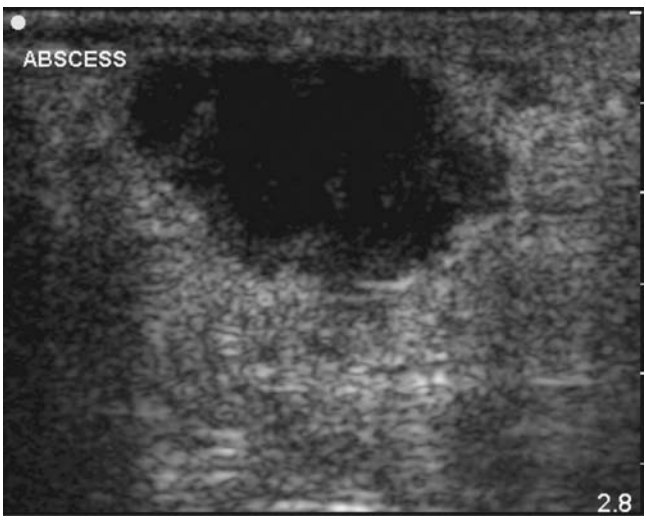


**Figure 13.25**
Another abscess.

## Special Equipment

A marking pen is used.

## Setup

Position the patient as you normally would for the procedure. Scan over the area of greatest fluctuance or over any suspicious area. Note the presence or absence of any abscess cavity, as well as any nearby vascular structures that would preclude safe incision and drainage. Also note any deeper or lateral extension of the fluid collection. Ultrasound can sometimes highlight that the

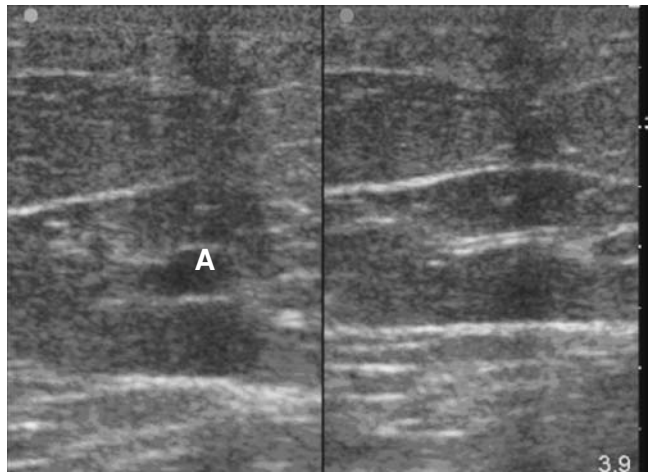


**Figure 13.26**
Left and right forearms – the image on the left is more edematous and a small deep space abscess (A) is seen.

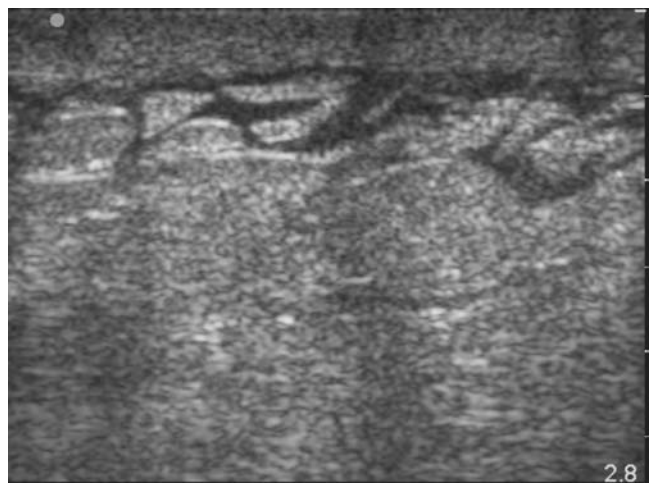


**Figure 13.27**
"Cobblestoning" seen with cellulites but no abscess pocket is identified.

superficial inflammation was only the "tip of the iceberg" and drive the operator to obtain further imaging or consultation before embarking on a deep dissection. Using the caliper function, measure the depth from the surface of the skin to the cavity. A marking pen may be used to note the location of the cavity.

## Procedure

The remainder of the procedure can commence without further use of ultrasound. Alternatively, ultrasound can be used to guide needle placement for aspiration in real time using the same long axis technique described in Chapter 12.

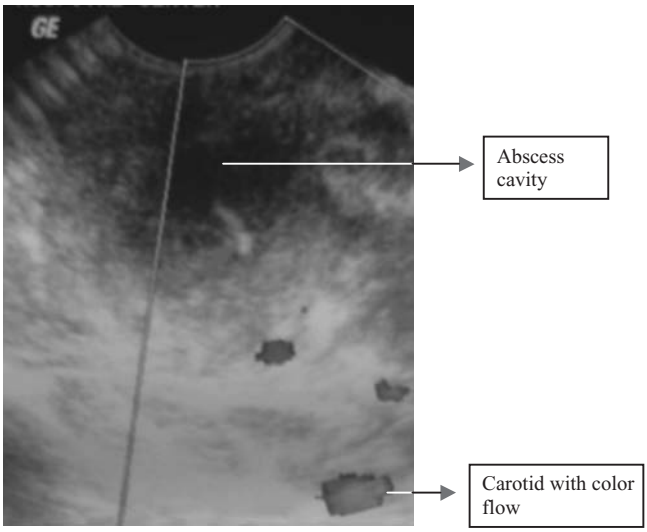


**Figure 13.28**
A peritonsillar abscess is seen in the near field (top of screen), and the carotid artery is visualized in the far field (bottom of screen).

## Peritonsillar Abscesses

The technique for peritonsillar abscess is the same as with other abscess ultrasounds. The only difference is that the high-frequency intracavitary probe is the most conducive to identifying these abscesses because their thin structure makes it possible to place them in the posterior pharyngeal space, and their high-frequency makes the image generated easy to interpret. Gel is applied to the end of the probe, and a sterile cover shields the patient from the probe. Again, an abscess is identified as a hypoechoic space over the area of maximal swelling. The use of ultrasound in this setting has several potential benefits. First, it may be possible to avoid the discomfort of a "dry tap" where there is induration but no abscess. Second, color Doppler may be used to identify the depth and location of the carotid artery so it can be avoided during the incision and drainage procedure (Figure 13.28).

In Figure 13.29, the needle is visualized as the abscess cavity is drained. Like vessel cannulation, static localization or dynamic cavity aspiration is possible and may depend on the patient's ability to tolerate continuous ultrasound imaging.

## Literature Review

Ultrasound is more accurate than physical exam alone in detecting abscess (positive predictive value: 93% vs. 81%; negative predictive value: 97% vs. 77%) (1). Thus, the number of nontherapeutic incision and drainage procedures could be reduced using ultrasound guidance. Another study of soft tissue infections in the emergency department demonstrated that US changed the management of nearly 50% of patients. Management changes included

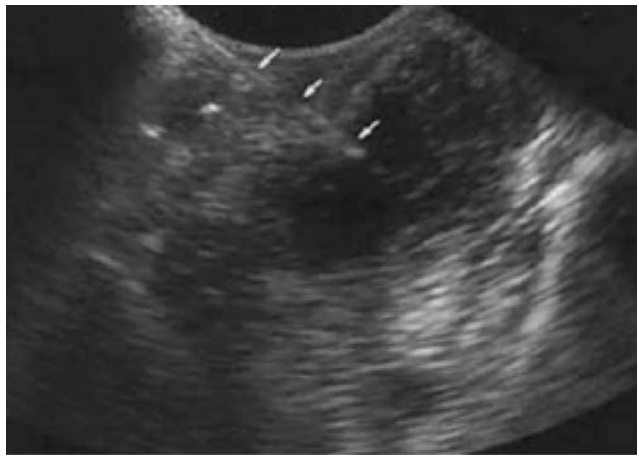

**Figure 13.29**
Peritonsillar abscess drainage. Image courtesy of Dr. Michael Blaivas, Professor of Emergency Medicine, Northside Hospital Forsyth, Atlanta, Georgia.

recognition of occult abscess where only cellulitis was expected, deferring incision and drainage where no abscess was found, and obtaining further diagnostic studies or consultation (2).

In the setting of possible peritonsillar abscess, ultrasound has demonstrated promise in preliminary studies. One study demonstrated negative aspirates in three patients without abscess identified on ultrasound, and positive aspirates in three patients with sonographic findings of abscess (3).

## References


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2. Tayal VS, Hasan N, Norton HJ, Tomaszewski CA. The effect of soft-tissue ultrasound on the management of cellulitis in the emergency department. *Acad Emerg Med* 2006;13(4):384–8.
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# Lumbar Puncture

One of the classic landmark-guided procedures, lumbar puncture, can be quite challenging in patients without classic landmarks. In many ED patients, spinous processes are not readily palpable, and it is not uncommon for the iliac crests to be obscured by certain body proportions as well. Ultrasound can be used to locate the orientation and depth of the spinous processes, which can be a huge advantage for a critical diagnostic procedure.

## Focused Questions

1. Where is the interspinous space?
2. How deep is the interspinous ligament?

## Anatomy

The goal of lumbar puncture (using a midline approach) is to place the needle through the skin and subcutaneous tissues, into the interspinous ligament, through the ligamentum flavum, and into the subarachnoid space. Ultrasound can demonstrate much of the target anatomy. In some patients, the ligamentum flavum can be visualized, but more commonly, at least the spinous processes are well visualized on ultrasound.

## Technique

### Probe Selection

Ultrasound should be performed with a high-frequency (5- to 10-MHz) linear probe.

### Special Equipment

A marking pen is used.

### Setup

Place the patient in the desired position for lumbar puncture (lateral decubitus or sitting upright). Using the linear transducer, locate the midline at the desired lumbar spine level in a transverse and longitudinal orientation. Note the appearance of the spinous processes on ultrasound. They will appear as bright echogenic crescents with shadowing posteriorly. When using a transverse approach, note the location of the spinous processes above and below the desired puncture site (Figure 13.30).

It is often easier to use a longitudinal approach, where two spinous processes are visualized simultaneously. When the ultrasound image is obtained, the probe is oriented in the midline of the spinous processes (sagittal hash marks on patient, Figure 13.31), and the interspinous space is centered in the middle of the probe (transverse hash marks on the patient). The initial needle puncture can then be made at the center of the "cross-hairs," which should line up with the interspinous space (Figure 13.32).

### Procedure

Once the optimal entry point is found and the distance from the skin to the interspinous space is measured, the patient can be prepped and draped in the

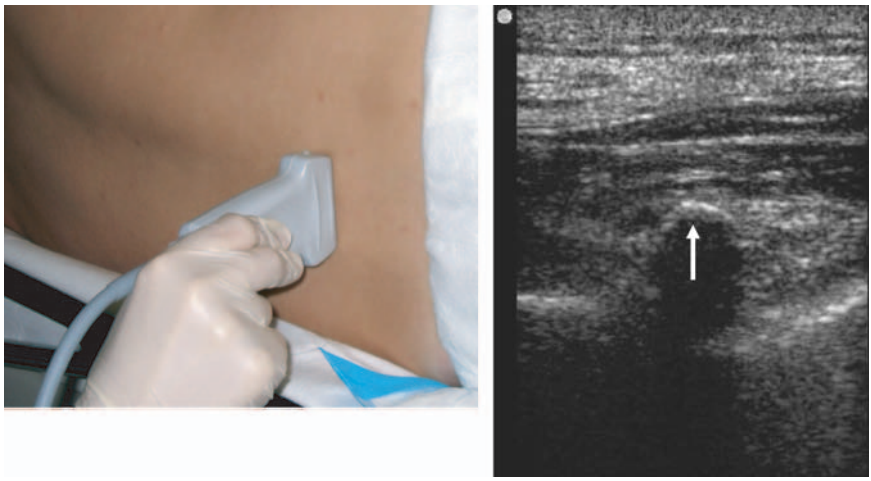

**Figure 13.30**
Transverse probe positioning (left) and the image obtained at this level (right). Note the crisp white line and posterior shadowing which delineates the spnous process.

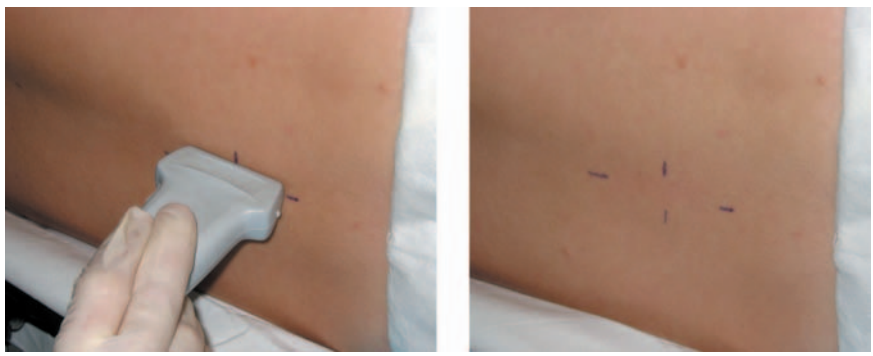

**Figure 13.31**
Marking interspinous space.

standard fashion for the procedure. No real-time guidance is used for this technique.

## Tips

Take the time to note the optimal location for needle entry. The remainder of the procedure is not guided by ultrasound, so thorough setup is key.

Measuring the depth to the interspinous space is crucial. In larger patients, longer needles must often be used, and it is better to know this in advance.

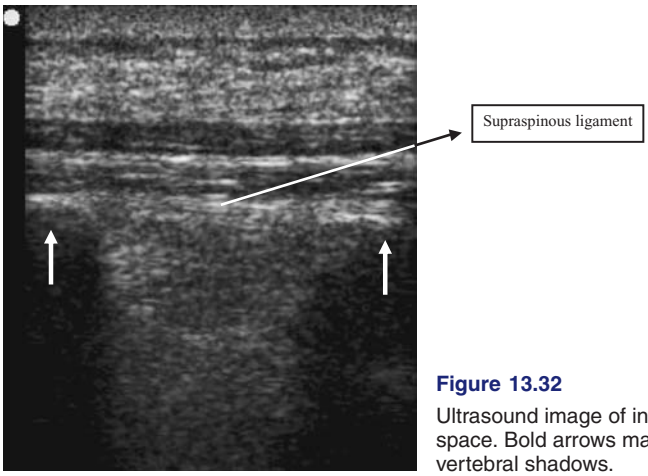


**Figure 13.32**
Ultrasound image of interspinous space. Bold arrows mark vertebral shadows.

## Pitfalls

Be sure to direct the needle along the same trajectory as the ultrasound beam. Knowing the right vertical and horizontal coordinates for puncture is not useful if an incorrect trajectory is taken from the skin to the deeper tissues.

As with other procedures, the patient should not be moved after ultrasound localization. The relationship between the skin surface and deeper landmarks can change considerably with motion, and this is more pronounced in larger patients.

## Literature Review

Ultrasound has been used to guide the placement of epidural catheters in laboring women without palpable landmarks (1). Although there was no difference in success rates (100%) using ultrasound or standard techniques, pain scales and number of attempts were reduced in the group where ultrasound guidance was used. A case series of successful use of ultrasound in challenging cases has been described in the emergency medicine literature as well (2).

## References

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# Index