INTRODUCTION
The advent of high-quality, portable equipment has enabled the dissemination of ultrasound technology to the bedside physician. Led by a few pioneers, the development and application of diagnostic ultrasound are occurring in a variety of settings, including bedside medical-surgical care, ambulatory clinics, and medical education. In addition to its role in clinical medicine, ultrasound is quickly becoming recognized as an excellent tool to teach anatomy and physiology to students of medicine, and in several institutions ultrasound is seamlessly integrated into the medical curriculum (see Chapter 20).1,2

The safe performance of procedures is an important part of both medical education and medical practice. In recent years, ultrasound has improved the safety of key procedures including central venous catheter placement and thoracentesis.3–5 This chapter will serve as a guide to the proper use of ultrasound for the performance of five common procedures, a how-to manual that can be taken to the bedside, opened to the relevant section, and placed in a convenient location to allow for frequent consultation during the procedure. Each procedure includes an anatomic review, a review of the pertinent physical examination findings, correlation with ultrasound findings, and the most common problems encountered. Reminiscent of anatomy texts taken into the gross anatomy laboratory, this book is meant to get dirty.

VENOUS CANNULATION
Introduction
Central venous catheterization is commonly performed, with an estimated 5 million central venous catheters (CVCs) placed annually in the United States.5 In addition, peripherally inserted central catheters (PICCs) and peripherally inserted catheters sited in a midline position (midlines) have gained increased popularity as an alternative to CVCs in the care of selected patients because of their ease of insertion, longevity, and low rate of early complications.

Although venous cannulation is associated with a relatively low rate of serious complications,6 complications do occur. However, an improved understanding of the cause of complications may help the provider reduce their occurrence. Interestingly, ultrasound has been used to guide vascular access and as a research tool to study the cause of certain complications of venous cannulation, such as the incidence of significant anatomic variation and the likelihood of puncturing the posterior venous wall.

Complications associated with vascular access procedures are well described6 and can be categorized as patient or operator dependent (Table 18.1). Patient-dependent factors include body habitus, coagulopathy, and anatomic variation. Operator-dependent factors include the operator’s level of experience, time allotted to perform the procedure, and human factors such as fatigue and lack of ultrasound guidance.7–9 The most common complications of CVC placement include accidental arterial puncture, failed placement, malposition of the catheter tip, hematoma, pneumothorax, and hemothorax, the frequency of which varies depending on the site of catheter insertion. PICC and midline placement are also associated with hematomas, and these catheters are sometimes inserted into an artery.

The most common complication of PICC line placement is malposition of the catheter tip into the ipsilateral internal jugular vein or coiling in the subclavian vein or a thoracic branch such as the thoracodorsal vein.

Complications of venous cannulation are not merely inconvenient; there are tangible repercussions, including increased costs derived from prolonged hospital and intensive care unit lengths of stay and additional procedures, such as chest tube insertion or hematoma evacuation, to treat the complications. For example, a single episode of iatrogenic pneumothorax has an attributable length of stay of 3 to 4 days.10 Indirect costs such as additional provider time and patient suffering are also important issues to consider.
The rationale for ultrasound use to guide vascular access is robust. Legler and Nugent published a brief report describing the use of Doppler ultrasonography to locate the internal jugular vein for cannulation back in 1984. Since then, two meta-analyses investigating the use of ultrasound for CVC placement, several review articles, standardized procedure guidelines, and results from the Sonography Outcomes Assessment Program (SOAP-3) trial have been published. These and other studies clearly demonstrate that the use of two-dimensional (2D) ultrasound during central venous access is associated with fewer complications, fewer attempts before successful cannulation, shorter procedure times, and fewer failed procedures when compared to a landmark-based approach. As a result, the Agency for Healthcare Research and Quality and the British National Institute of Clinical Excellence (NICE) have issued statements advocating the use of ultrasound guidance in central venous access procedures. A 2007 study by Wigmore et al confirms that implementation of the NICE guidelines has resulted in fewer complications.

Some providers continue to resist the adoption of the ultrasound-guided technique and use ultrasound only in potentially "difficult to cannulate" patients such as the morbidly obese or when landmark-based cannulation has failed. Unfortunately, it is difficult to predict which patients will be hard to cannulate, and the recognition of a failed attempt, as may arise from an occluded vessel, can be viewed only retrospectively after the failure has occurred and the patient has been adversely affected. Therefore, the consideration of ultrasound up front to improve safety in all central venous access procedures is recommended. And, as evidenced by Lee et al, the technique is easily taught.


<table>
<thead>
<tr>
<th>Patient Dependent</th>
<th>Operator Dependent</th>
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<tr>
<td>Body habitus</td>
<td>Experience</td>
</tr>
<tr>
<td>Coagulopathy</td>
<td>Time allotted for procedure</td>
</tr>
<tr>
<td>Vascular anatomic variation</td>
<td>Fatigue</td>
</tr>
<tr>
<td>Prior surgery with distortion of anatomy</td>
<td>Lack of ultrasound use</td>
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### Review of Ultrasound

#### Transducer Selection

Ultrasound transducers come in a variety of frequencies, each with different properties and clinical applications. Recall that the relationship between ultrasound frequency and the depth of tissue penetration is an inverse relationship. Thus, low-frequency ultrasound (1–3 MHz) penetrates more deeply than high-frequency ultrasound (7–10 MHz). The relationship between frequency and image detail, or resolution, is proportional. This means that low-frequency ultrasound has poorer resolution than high-frequency ultrasound. Therefore, high-frequency ultrasound provides a very detailed image of superficial structures, to a depth of approximately 5 cm, but cannot penetrate into deeper tissues. Alternatively, lower-frequency ultrasound is capable of reaching into deeper structures but provides a less-detailed image. These relationships form the basis for transducer selection. For percutaneous vascular access, which is a procedure that is superficial, higher-frequency transducers are ideal.

#### Modes

A-mode ultrasound has very few clinical applications and is not discussed further here. B-mode ultrasound uses an ultrasound probe with many active elements aligned in a specific orientation, or “array,” to create a recognizable 2D image (Fig. 18.1, top). B mode is the most common mode currently employed in diagnostic medical ultrasound. M-mode ultrasound uses information obtained with B mode to create an image that demonstrates the movement of structures over time.

![Figure 18.1. Typical B-mode (two-dimensional) image (top) and M-mode image (bottom) of the internal jugular vein.](image-url)
The most common application of M mode is to assess valve leaflet movement and wall motion in cardiac ultrasound. Doppler mode also has several forms. The simplest produces no image; there is only an audible signal that varies in intensity with the velocity of the structure being studied (e.g., blood). Color Doppler takes velocity information obtained by the Doppler shift and assigns color to it. Most modern ultrasound equipment uses Doppler or color Doppler in combination with B mode to both create an image and simultaneously superimpose information about blood flow velocity (Fig. 18.2 [see also color insert]). Color Doppler is very commonly used in vascular applications, such as vascular access. An important concept to understand is that the strength of the Doppler signal is related to the velocity of the target tissue (e.g., blood) and the angle of incidence, with the best estimate of velocity occurring at an angle approaching zero. If the same vessel is imaged in a plane 90° from the direction of blood flow, there is no perceived motion of blood either toward or away from the transducer, and the Doppler signal fades. Also, when the angle of incidence changes from one “side” of the 90° mark to the other side, the color of the blood within the target vessel changes (e.g., from red to blue) (Fig. 18.3). This is very important and a potential source of error when a beginner is becoming familiar with orientation and selecting a vessel for cannulation.

**Techniques of Ultrasound Guidance**

Ultrasound is not a substitute for a thorough knowledge of the landmark-based technique for central venous cannulation. Frequently, the beginner may focus on the image on the screen and be inattentive to anatomic landmarks and the position of the needle. In fact, ultrasound should be used as an educational tool to teach and confirm the landmark-based technique whenever possible. Just as computed tomography of the chest is an excellent tool to teach interpretation of the chest x-ray in a retrospective fashion, ultrasound is an excellent tool to teach landmark-based cannulation (including its limitations).

Ultrasound guidance can be categorized as static or dynamic. Dynamic guidance refers to performing the procedure in real time with ultrasound imaging viewing the needle puncturing the vessel wall. Static guidance refers to identifying the target vessel, assessing patency, and marking an appropriate insertion site with ultrasound, then cannulating blindly. For vascular access, static guidance appears to be inferior to dynamic but still better than the landmark-based technique alone. Table 18.2 provides a comparison between static and dynamic guidance techniques. Dynamic guidance is more technically demanding since it requires significant eye-hand coordination.

**Anatomic Review and Physical Examination Correlation with Ultrasound Anatomy and Physiology**

**Planes**

For our purposes, there are two planes to be considered: transverse and longitudinal, which refer to the orientation of the ultrasound transducer and the image to the vessel axis. A transverse view is a cross sectional view and provides the operator with information...
about structures that lay adjacent to the vessel of interest. For example, a cross-sectional view of the internal jugular vein will enable visualization of the adjacent common carotid artery and, perhaps, the vagus nerve, thyroid gland, and trachea.

A longitudinal view will depict structures anterior and posterior to the vessel of interest and may allow for visualization of the entire needle during cannulation but does not allow simultaneous visualization of structures lateral to the vessel. All commonly utilized central veins can be visualized in either orientation. As a general rule, transverse views tend to be easier for the novice to learn ultrasound-guided cannulation, but complications such as puncturing the posterior vessel wall may be reduced by using the longitudinal view as reported by Blaivas et al.23 and commented on by Levitov et al.24

Recently, a study was published touting the use of a hybrid method of obliquely imaging the target vessel, the implication being that this approach may confer the benefits of both a transverse and longitudinal view.25

Methods of Orientation

Orientation is probably the most important step to a successful procedure. Problems with orientation can largely be prevented by ensuring proper patient, transducer, and ultrasound machine position. Most transducers have an identifiable mark, known as a notch, on one side. This corresponds to a mark displayed on one side of the image and allows right/left, or lateral, orientation (Fig. 18.4). Where orientation is uncertain during a procedure, a finger can be rubbed on one side of the transducer surface to produce an image and confirm the orientation. In general, the screen should be in the operator’s line of sight during vessel cannulation; in practical terms, the needle should point directly at the screen during cannulation. For a subclavian line, the machine is placed on the opposite side of the patient; the machine is placed on the ipsilateral side for an internal jugular line (Fig. 18.5). For femoral insertion, the screen can be placed on either the ipsilateral side or the contralateral side at the level of the patient’s chest.

Differentiating an Artery from a Vein

Upon reviewing the vascular anatomy of the neck, recall that the common carotid and internal jugular veins travel together in the carotid sheath (along with the vagus nerve). Despite what many readers learned in anatomy, there is significant variation in the position of the vein relative to the artery. In fact, the vein is either posterior to, directly anterior to, or medial to the vein in a significant minority of patients.15 It becomes important, therefore, to be able to differentiate artery from vein by some other means. Arteries, in general, are smaller and thicker walled than accompanying veins on ultrasound. In addition, veins are usually

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**TABLE 18.2. Comparison of Static Versus Dynamic Guidance***

<table>
<thead>
<tr>
<th>Dynamic Guidance</th>
<th>Static Guidance</th>
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</thead>
<tbody>
<tr>
<td>Ultrasonic localization and image-guided cannulation</td>
<td>Ultrasonic localization and marking of landmarks only</td>
</tr>
<tr>
<td>More precise and “real time”</td>
<td>Cannulation is not image guided</td>
</tr>
<tr>
<td>More difficult to maintain sterility</td>
<td>Time delay between marking and cannulation</td>
</tr>
<tr>
<td>Requires significant hand-eye coordination</td>
<td>Less difficult to maintain sterility</td>
</tr>
<tr>
<td></td>
<td>Less technically demanding</td>
</tr>
</tbody>
</table>

*In general, the advantages and disadvantages apply to all ultrasound-guided procedures.

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Figure 18.4. Orienting the transducer to the image. The notch on the transducer corresponds to the indicator on the screen.
very easily collapsed with the application of pressure via the transducer. The character of vessel pulsation is another clue; arteries will pulsate with the cardiac cycle, and veins may pulsate with the respiratory cycle (respiratory variation in venous diameter), unless significant right-sided heart failure is present. A fourth method is to apply color Doppler to the vessel and observe the character of the color pulsation. The correct use of color flow Doppler requires that the operator know how the machine is set up and at what angle the vessel was “Dopplered.” The machine can be set so that blood moving toward the transducer is either red or blue. However, if the angle of insonation of the vessel crosses a line perpendicular to the vessel, the color will change (see Fig. 18.3). It is useful to compare color Doppler signals of all vessels in the area of interest, paying close attention to the angle of the incident ultrasound beam; with a little practice arterial flow is easily differentiated from venous flow. Remember that large, rapid fluctuations in intrathoracic pressure can create very high venous blood flow velocities that can mimic arterial flow; this situation may require the use of other methods such as respiratory variation or compressibility to help differentiate the vessel type.

Occasionally, the vein cannot be visualized. The most common reason for this is hypovolemia with associated venous collapse, which can be remedied by placing the patient in the Trendelenburg position or applying a vagal maneuver or fluid administration. Other less common causes are agenesis, chronic occlusion or scarring of the vessel, and clot that is completely occluding the lumen. Clot may be difficult to distinguish from the surrounding tissue (Fig. 18.6). In this case, a thorough examination of the proximal and distal parts of the vessel should be performed, and a formal venous Doppler procedure should be performed to evaluate for deep venous thrombosis prior to any attempted central venous cannulation. If access is critical, and vessel presence or patency cannot be assured, a different vessel should be cannulated.

**Technique**

**Internal Jugular Vein**

1. The patient is positioned appropriately. The head should be rotated slightly contralaterally, with the neck extended. Severe rotation of the neck and head should be avoided, since this may lead to significant distortion of the anatomy and may increase the amount of overlap of the carotid artery and jugular vein. The bed should be placed in Trendelenburg position, and the ultrasound machine should be placed by the ipsilateral side of the bed, at about the level of the patient’s waist.

2. An initial examination of the landmarks without ultrasound should be performed, including selection of an insertion site. The site should then be
confirmed with ultrasound. This technique provides the operator with immediate feedback regarding landmark-based site selection and therefore facilitates teaching both the landmark-based approach and the ultrasound-guided approach. During this process, the vein should be identified and assessed for patency.

3. The patient’s skin can now be prepped in sterile fashion and full barrier precautions used to maintain sterility and reduce the incidence of catheter-related infections. Ultrasound use introduces another piece of equipment onto the sterile field, making the maintenance of sterility more difficult. While learning, one needs to pay special attention to this issue in order to develop good habits. A sterile ultrasound sheath should be placed on the sterile field for when an assistant hands the operator the ultrasound transducer.

4. After the patient is prepped and draped, the catheter is set up per normal routine. All ports should be flushed with bacteriostatic saline to remove air and to test for occlusion caused by manufacturing defects. The components needed for catheter insertion, including needles, wire, dilator, scalpel, catheter, and sterile transducer cover, should be arranged in an orderly fashion and within easy reach.

5. The operator acquires the transducer, places it in the sterile cover, and secures it on the sterile field. The transducer can either be “picked up” by the operator whose gloved and sterile hand is inside the transducer cover like a puppet or, alternatively, an assistant can insert the transducer in the open end of the cover. The end sheath is then extended to cover the transducer cord, and sterile rubber bands are applied to secure the sheath in place.

6. A second ultrasound examination should be performed to ensure that the original insertion site is still viable. Remember that proper orientation every time the probe is applied to the patient is essential for ensuring an appropriate procedure.

7. When cannulating the vessel, the operator uses the same insertion site and needle trajectory as he or she would when using the landmark-based approach (lateral, medial, etc.). If using the transverse plane for ultrasound guidance, which is especially good for novices, the operator must be sure to center the vessel lumen on the screen; remember that if the vessel is centered on the screen, it is directly underneath the middle of the transducer head.

8. Sometimes it is useful to perform a “mock poke” to confirm the proposed insertion site relative to the underlying vessel. This is done by laying the needle on the skin surface, then applying the transducer to it. The acoustic shadow produced by the needle should be directly over, or superimposed on, the target vessel (Fig. 18.7). The skin puncture should be approximately 1 cm proximal to the transducer, which in most cases will result in visualization of the needle tip entering the vessel without having to move the probe much. If the needle tip cannot be visualized indenting either the subcutaneous tissue overlying the vessel or the vessel itself, the operator moves the probe along the axis of the vessel while slightly “agitating” the needle; this will accentuate the image of the needle and tip. The point of the “V” caused by indenting the subcutaneous tissue above the vein with the needle tip should be directly over the vessel. The operator should be sure to visualize the tip of the needle at all times (it is very easy to misinterpret the shaft of the needle as the tip) and to move the probe axially along the vessel frequently to

Figure 18.7. Mock poke technique. This shows a transverse view through the internal jugular vein. Note the acoustic shadow of the overlying needle.
maintain imaging of the tip. If done properly, the needle tip should be seen entering the lumen at about the same time as the flash of blood is obtained in the syringe.

9. Once the vessel has been successfully cannulated, the operator sets aside the transducer and proceeds with wire placement. Intravascular position of the wire can be confirmed with ultrasound, which can then be saved for documentation in the medical record.

10. Once the line is in place, flushed, secured, and dressed, a quick ultrasound examination of the anterior chest wall can be performed to evaluate for a pneumothorax (see Chapter 7). Pleural ultrasound specifically looking for an absence of normal "sliding pleura" is highly sensitive for identifying pneumothorax.27

11. The use of ultrasound should be documented in the medical record. Typically, a statement regarding the use of ultrasound to assess the location and patency of the vessel and an image of the wire or catheter in the vessel lumen is sufficient for documentation and often provides sufficient documentation for reimbursement. Additionally, a statement about the presence or absence of sliding pleura should be included.

**Subclavian Vein**

Typically, the subclavian vein is slightly more difficult to visualize ultrasonographically than either the internal jugular, axillary, or femoral veins. This is because of its position under the clavicle, which requires significant angulation and manipulation of the transducer to acquire a useful image. Two additional challenges are the difficulty visualizing the vein in obese patients using an infraclavicular view and the inability to adequately compress the vein to exclude the presence of clot.

In our experience, it is usually easier to visualize the subclavian with a longitudinal supraclavicular view in obese patients since an adequate transverse view or infraclavicular longitudinal view is often technically challenging. Considering the ease with which the internal jugular and axillary veins are visualized, we have largely abandoned the subclavian vein in our practice, except for specific clinical situations, such as for long-term total parenteral nutrition administration or for emergency central venous access.

**Axillary Vein**

Using the axillary vein for central venous access has many unique advantages over using other sites.28–31 Although not well-studied, since the insertion site is on the anterior chest, axillary catheterization likely shares a low incidence of catheter-related infections with the subclavian approach. Unlike the subclavian vein, using the axillary vein may be associated with fewer complications, such as pneumothorax, hemothorax, and chylothorax. The axillary vein is usually easier to compress than the subclavian vein and allows an easier recognition of clots. There is, however, the additional potential complication of causing a brachial plexus injury, particularly if a far lateral approach is used.30 One distinct disadvantage of the axillary approach is the unique dependence on ultrasound to ensure localization and subsequent cannulation; landmark techniques are not as effective as with the other common sites used to access the central venous system. Figure 18.8 shows proper transducer placement for viewing the axillary vein transversely. As with internal jugular and subclavian access approaches, a quick postprocedure scan of the chest should be performed to ensure sliding pleura, which essentially eliminates the possibility of pneumothorax.27

**Femoral Vein**

Femoral cannulation remains a popular approach because of its relatively low incidence of life-threatening complications. However, several clinically important complications may occur that lead to significant morbidity. Accidental (or intentional for that matter) femoral arterial cannulation, especially in coagulopathic patients, may cause life-threatening retroperitoneal hemorrhage and hematoma. Inadvertent stimulation of the femoral nerve with the cannulation needle can cause intense pain. A puncture site that is
too proximal can also result in inadvertent puncture of intraperitoneal structures. Ultrasound can help avoid some of these important complications.

Like internal jugular, subclavian, and axillary cannulation, the first step in successful femoral access is achieving proper orientation. The ultrasound machine should be placed in a location that encourages operator comfort. The entire area should be scanned, with identification of all vascular structures, including the femoral artery, common femoral vein, and saphenous or profunda femoris vessels if possible. Once the vein is identified, it should be evaluated for the presence of clot. Additionally, a longitudinal view of the vein should be obtained as it dives under the inguinal ligament, and the ligament itself should be marked on the skin. If a femoral hernia is not present, this step ensures that an intraperitoneal puncture will not occur (Fig. 18.9). All other steps are identical to those listed earlier for the internal jugular vein.

Common Pitfalls
The most common pitfalls encountered in ultrasound-guided vascular access are easily avoided. These include not understanding the relationship between transducer frequency and both depth of penetration and image resolution, incomplete understanding of the basics of color Doppler and how the angle of the incident ultrasound beam can alter the Doppler signal (and color), poor technique in terms of always keeping the needle tip in view during image-guided cannulation, not paying attention to equipment setup to maximize comfort and ergonomics during the procedure, and not scanning the entire vessel to exclude the presence of thrombus. These pitfalls can be avoided by proper training and subsequent practice.

LUMBAR PUNCTURE

Introduction
Lumbar puncture, first described by Heinrich Quincke, has been performed for over a century. Typically, the procedure is performed after proper positioning of the patient and careful palpation of anatomic landmarks to help locate an appropriate site for needle insertion. However, successful lumbar puncture can be difficult to achieve in certain patient populations (e.g., the morbidly obese), presumably because of obscuration of palpable anatomic landmarks such as the spinous processes. In recent years, there has been a renewed interest in augmenting the landmark-based technique with ultrasound.

The first reported use of ultrasound to help guide lumbar puncture was published in 1971 in the Russian literature. Since that time, the technique remained relatively dormant until the last decade, when it was resurrected by anesthesiologists for use in guiding spinal and epidural blocks. In fact, most of the data currently available have been reported in the anesthesia literature; incorporation of ultrasound guidance into critical care and generalist practice has been a more recent development. The main advantages of adding ultrasound guidance to the landmark-based technique are shown in Table 18.3.

Anatomic Review and Physical Examination Correlation with Ultrasound Anatomy and Physiology

Normal lumbar spinal anatomy is shown in Figure 18.10. As can be seen, the needle used for lumbar puncture must traverse the skin, subcutaneous tissues, and
supraspinous ligament; then it must navigate through the spinous processes and the interspinous ligament before traversing the ligamentum flavum before it enters the dural space and, finally, the subarachnoid space. Success is inherently dependent on proper needle position and angulation. Since the conus medullaris rarely extends beyond L3 in most studies, the most common site of insertion is the L3-L4 interspace. Figure 18.11 shows a transverse view through the lumbar spine at the level of L4. Note the easily distinguishable tip of the spinous process as well as the transverse processes. This transverse view facilitates identification of the midline, which can be surprisingly difficult to identify by palpation in some patients. Figure 18.12 shows a longitudinal view of the L3-L4 level. Note the appearance of the spinous processes as well as the presence of the ligamentum flavum, which overlies the dura. In one study, the depth of the dural reflection correlated very well with needle depth during insertion.38

**Technique**

A linear array transducer works well for most patients. In our institution, we use the same 6- to 13-MHz linear array transducer used for vascular access procedures. Alternatively, a curvilinear 5-MHz transducer could be substituted. The patient is positioned appropriately, either sitting upright, leaning forward, or on the side in the lateral recumbent position (particularly if pressure measurements will be obtained). Puncture can be guided either statically or dynamically. In static guidance, an appropriate site is marked on the skin by first finding the L3-L4 level by the usual technique (palpation of the iliac crest), then marking the exact midline with a transverse ultrasound view, followed by locating and marking the appropriate interspace with a longitudinal view. Once the two marks are made, the insertion site will be the center of the “+”; it helps to make a skin indentation with a sterile instrument in case the “+” is removed during sterile preparation of

<table>
<thead>
<tr>
<th>TABLE 18.3. Advantages of Using Ultrasound Guidance for Lumbar Puncture</th>
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<tbody>
<tr>
<td>Allows visualization of the interspace and the exact midline as well as the target (ligamentum flavum)</td>
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<tr>
<td>Allows one to easily see the required needle trajectory between the spinous processes</td>
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<tr>
<td>Allows one to gauge the required needle depth prior to needle insertion</td>
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<tr>
<td>Reduces failure rate</td>
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<tr>
<td>Reduces procedure time</td>
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**Figure 18.10.** Normal spinal anatomy.

**Figure 18.11.** Transverse ultrasound view through the spine, clearly showing the tips of the spinous processes as well as the transverse processes.
the skin (see Fig 18.13). If dynamic guidance is employed, all the above steps are done, followed by needle insertion under ultrasound guidance; the needle tip can be seen to enter the area of the dural sac. As mentioned earlier, one can measure the distance from the skin to the dural reflection on the image; this has been found to correspond well to the required depth of the needle to obtain fluid. Once learned, this technique can improve success rates up to 92% as reported in one series.38

Common Pitfalls
This technique is relatively resistant to error. However, heavy ligamentous calcification can obscure underlying anatomy, so particular care is needed in these patients. Fortunately, calcification rarely impairs the operator’s ability to identify the midline or an appropriate interspace for needle insertion. Another very common pitfall, much more difficult to overcome, is the presence of posterior spinal hardware. There are more advanced techniques to obtain spinal fluid in these patients, but this is beyond the scope of this book.

THORACENTESIS
Introduction
Ultrasound-guided thoracentesis is a very useful procedure, especially in the critical care setting when visualization of pleural effusions in supine mechanically ventilated patients becomes difficult. In fact, ultrasound-guided thoracentesis was found to be a safe procedure with a lower risk of pneumothorax in comparison to blind thoracentesis in both mechanically ventilated and nonventilated patients.4,39 Furthermore, it has been found to be a helpful adjunct when used to evaluate unsuccessful thoracentesis.40

Evaluation of the pleural space and pleural fluid with ultrasound is useful to help determine the nature of the effusion and help differentiate between transudative and exudative effusions. A transudative pleural effusion is usually anechoic, while an exudative effusion may have complex septation, echogenic material, or the presence of pleural thickening41 (Figs. 18.14 and 18.15).

In addition to providing useful information about the type of fluid present, ultrasound can help with the
quantitative evaluation of the pleural fluid. In most circumstances, this is not essential information, and, therefore, we will not discuss techniques to quantify pleural fluid any further.

**Anatomic Review and Physical Examination Correlation with Ultrasound Anatomy and Physiology**

The pleural space can be thought of as being roughly conical in shape, bordered by the chest wall anteriorly, laterally, and posteriorly; the mediastinum medially; and the diaphragm inferiorly. From a sonographic viewpoint, only the anterior, lateral, and posterior borders are accessible. Fluid, if it is free flowing, accumulates dependently, inferiorly and posteriorly in the upright chest and posterolaterally when the patient is supine. When fluid is present in the thorax, it is always bordered by three structures: the chest wall, the diaphragm, and the lung. Knowledge regarding the location and appearance of intra-abdominal structures, such as the spleen, liver, and kidneys, is absolutely necessary to be able to perform ultrasound-guided thoracentesis safely. The liver is shown in Figures 18.16A and 18.16B as a relatively homogenous structure bordered superiorly by the diaphragm and inferiorly by the kidneys. The kidneys are usually very easy to recognize, having an outer cortex and inner medulla. The potential space in between the liver and the right kidney (hepatorenal recess), as well as that between the spleen and the left kidney (splenorenal recess), can occasionally be confused with the pleural space (Figure 18.17), especially when large amounts of intra-abdominal fluid are present (Figure 18.18).

Figure 18.14. Anechoic appearance indicates an uncomplicated transudative pleural effusion. X marks the spot.

Figure 18.15. Complicated parapneumonic effusion with septation (arrow).

Figure 18.16. Appearance of the liver, spleen, and kidneys in relation to the diaphragm. (A) The different appearance of the liver from the chest ultrasound window may be confused with a pleural effusion. (B) Normal appearance of the liver and kidney from the chest ultrasound window.
Pleural fluid usually appears homogenously black if the effusion is simple. Complex effusions may appear “speckled” or otherwise inhomogeneous. Occasionally, a spider-web appearance will be encountered, which indicates loculation. Dynamic characters are almost universally present, which include a moving diaphragm, moving lung, and movement within the effusion itself.

**Technique**

1. The patient is positioned appropriately. The best position for thoracentesis is with the patient sitting upright with arms elevated and extended in front, especially for nonloculated effusions. However, when ultrasound is utilized, thoracentesis becomes feasible even in the lateral and supine positions, which is helpful in assessing critically ill mechanically ventilated patients because it would be difficult to place them upright without significant ancillary support.

2. A 3.5- to 5-MHz curvilinear ultrasound probe is used in a longitudinal orientation (perpendicular position of the ultrasound probe in relation to the underlying rib) to identify the location, quantity, and quality of the fluid, if present.

3. One should scan below the effusion to identify the diaphragm, the spleen on the left side, and the liver on the right side. **Pay particular attention in order to not confuse fluid in the hepatorenal recess or the splenorenal recess with pleural fluid.**

4. The operator confirms that there is enough fluid to create a safe distance between the planned site of entry and vital organs, remembering that the diaphragm is dome shaped; if one plans to advance the needle close to it, he or she may inadvertently penetrate through it if the needle is advanced too far.

5. The operator confirms the presence of the pleural effusion by identifying at least three borders and at least two dynamic characters; usually the pleural fluid is bordered by the diaphragm inferiorly, the chest wall anteriorly, and the lung posteriorly (or medially) (Fig. 18.18).

6. M mode can be used to confirm the presence of pleural fluid using the sinusoid sign, especially with minimal pleural effusion (Fig. 18.19).
7. Once the position of the effusion is identified, a transverse position of the ultrasound probe is used to evaluate both the proper puncture site and the presence of any superficial vascular structures.

8. The operator plans the needle trajectory based on the location of fluid, the presence and distance of any underlying structures, and the angle of incidence of the ultrasound transducer during the examination. In general, once a good view is obtained with the transducer, the operator mentally note the position and angle of the probe; this will be the position and angle of the needle during insertion.

9. The operator cleans the site of entry with ChloraPrep and steriley drapes it. One may use a sterile cover for the ultrasound probe to rescan the area again to confirm the optimum site of entry.

10. Using a 25- to 30-gauge needle, the operator infiltrates the skin with local anesthetic using 1% or 2% lidocaine. Using a 22-gauge, 1.5-inch needle, the operator infiltrates local anesthetic to the subcutaneous tissues and intercostal space. The catheter is inserted through the planned tract until pleural fluid is obtained and is then advanced into the pleural space while the inner needle is pulled back.

11. Once the procedure is done, the catheter is withdrawn from the pleural space.

12. Postprocedure ultrasound evaluation of the pleural space is recommended. One needs to evaluate first for the resolution of the pleural effusion and for the presence of any residual fluid, and secondly for postprocedure complications such as pneumothorax. One study looking at the comparison between chest x-ray and chest ultrasound for postinterventional pneumothorax showed that transthoracic ultrasound had a sensitivity and specificity of 100% to rule out postinterventional pneumothorax. About 16% of cases with postprocedure pneumothorax were missed with chest x-ray.

A freehand technique in which real-time ultrasound guided thoracentesis is utilized (so-called dynamic guidance) is highly recommended for small pockets of pleural fluid or in patients on mechanical ventilation. This technique requires significant hand-eye coordination, however. The advantage is that needle insertion is visualized with ultrasound, so the operator can see the needle tip as it is advanced.

**Pitfalls**

There really are no pitfalls unique to ultrasound-guided thoracentesis. However, all the usual pitfalls of traditional thoracentesis exist, which include dry tap, re-expansion pulmonary edema, and pneumothorax. The most common causes for dry tap when ultrasound guidance is used are either poor angle selection or the presence of a complicated effusion with interpleural septation. Feller-Kopman et al found that re-expansion pulmonary edema occurred more often if the patient experienced chest discomfort during the procedure, there was rapid removal of pleural fluid, or the end-expiratory pleural pressure was noted to be less than \(-20 \text{ cm H}_2\text{O}\).  

**PARACENTESIS**

**Introduction**

Paracentesis is a very commonly performed procedure, typically indicated as part of the initial evaluation of patients with new-onset ascites or patients with a known history of ascites who develop clinical deterioration. Using ultrasound guidance for paracentesis has been shown to decrease the duration, increase the ease, and improve the accuracy of the procedure, partly by avoiding unnecessary procedures in patients with minimal or no ascites. Other advantages of ultrasound use to guide paracentesis are that it can detect as little as 10 mL of free fluid with a specificity of 100%, help identify the character of the fluid, and be used to determine an appropriate point of entry (Fig. 18.20). Theoretically, ultrasound

**Figure 18.20.** M mode of a small effusion showing the sinusoid sign (arrow).
guidance can help avoid puncture of vital organs, such as the liver, kidney, and spleen.

**Anatomic Review and Physical Examination Correlation with Ultrasound Anatomy and Physiology**

The peritoneal space is bordered by the diaphragm superiorly, the abdominal wall anteriorly and laterally, and the retroperitoneum posteriorly. Inferiorly, the peritoneal space is contiguous with the pelvis and is bordered by the pelvic floor. The abdomen presents a fairly unique challenge in that one of its resident organs, the bowel, is highly mobile. In addition, several intra-abdominal organs are highly subject to changes in intrathoracic pressure and can change position during respiration. Another challenge is that in morbidly obese patients, it is very difficult to appreciate the classic fluid wave on physical examination maneuvers. Therefore, it is quite advantageous for medical providers to know basic abdominal ultrasonographic anatomy (see Chapter 10). For our purposes, remember that the liver is separated from the right kidney by a potential space known as the hepatorenal recess. This space can fill with fluid and occasionally be mistaken for pleural fluid, with the liver being mistaken for lung. On the left side, the spleen is likewise separated from the left kidney by the splenorenal recess. The kidneys, probably the most recognizable structure on ultrasound, are located retroperitoneally and are most easily imaged from a posterolateral transducer position. Bowel, especially in patients with large fluid collections, can be seen as multiple free-floating loops. A particularly important structure to be able to recognize is the urinary bladder, which, if full, can be mistaken for ascites. The bladder typically has easily identifiable walls and may have a visible balloon if catheterized.

**Technique**

1. Prior to the procedure the patient is asked to empty the urinary bladder to decrease the risk of bladder perforation. Also, any coagulopathy needs to be corrected prior to commencing.52
2. Most of the time the procedure is performed while the patient is supine, although it can also be done with the patient in the sitting position.44
3. Curved array transducers are preferred for evaluation of the abdomen and to identify the quality and the quantity of ascitic fluid. Ultrasound is able to reveal as little as 100 mL of ascitic fluid53 and can, therefore, determine a safe site of entry.

4. The left lower quadrant approach is considered to be a safe starting point. One may use color flow Doppler to evaluate for cutaneous veins at the proposed site of entry and to help avoid the inferior epigastric artery.
5. The operator performs a careful evaluation of the entire abdomen, paying particular attention to the position of the liver, spleen, bowels, and bladder; this step is key to avoiding complications.
6. The operator selects an appropriate site for needle insertion.
7. Once the site of entry is identified, the area is then cleaned and draped.
8. The transducer is sheathed in a sterile probe cover.
9. Prior to the procedure, ultrasound is used again to confirm the location of the ascitic fluid as well as the expected needle depth at which fluid should be encountered.
10. The operator introduces the needle into the peritoneal fluid using a “Z-line technique” to decrease the risk of postprocedure leak.
11. Using a free-hand technique with real-time ultrasound (dynamic guidance), the operator should try to keep the needle and the ultrasound beam in the same plane. Again, this is the key point for successful thoracentesis, paracentesis, and the longitudinal approach for central line placement (Figs. 18.21 [see also color insert] and 18.22).54,55
12. If dynamic guidance is used, the operator should be able to see both the needle and the catheter entering the peritoneal space in real time (Fig. 18.23).
13. Once fluid is obtained, the operator sets the transducer aside and proceeds with fluid evacuation.

**Pitfalls**

As with thoracentesis, the pitfalls associated with ultrasound guidance for paracentesis are the same as with the traditional technique. Large-volume paracentesis (>10 liters) is usually avoided, as it may lead to severe hypotension.52 Damage to blood vessels can occur, with postprocedure hemorrhage that can occur from 6 to 48 hours after the procedure.56 However, careful evaluation of superficial veins and arteries with ultrasound can help avoid bloody paracentesis and even inferior epigastric artery aneurysm. Of course, areas of previous scars and areas of intra-abdominal adhesion should be avoided.
It is the responsibility of the physician to select the appropriate code for the services rendered. *Current Procedural Terminology* (CPT) code 76604 can be used for diagnostic ultrasound of the chest and code 76700 for diagnostic ultrasound of the abdomen, while CPT code 76942 can be used for ultrasound-guided thoracentesis.57

There are two separate payment components that can be requested: the professional fee and the facility fee. The professional fee is the physician's fee for the medical services provided. The facility fee is the fee charged to offset the cost of equipment and maintenance. For most ultrasound-guided procedures, the additional professional fee attributable to ultrasound guidance is nominal. However, the facility fee can be

**Figure 18.21.** Diagram comparing transverse and longitudinal approach, illustrating the need for the visualization of the needle tip (see color insert). In plane B needle appears in the center of the vessel while the tip has penetrated the posterior wall. *(Adapted with permission)*

**Figure 18.22.** Longitudinal view of the internal jugular vein with the needle seen in the vessel lumen *(white arrow).*

**Figure 18.23.** The arrow demonstrates the tip of the paracentesis needle in the peritoneal cavity during real-time guidance for paracentesis.
quite large. One caveat is that the person or group charging the facility must own the equipment. If these procedures are going to be billed to the patient, adequate documentation that ultrasound was indeed used must be permanently stored in the medical record. Adequate documentation, for example, would include a static photo of the vein before and after cannulation, showing the needle or guidewire in the vessel lumen. Video loops of the procedures may also be stored on a computer for access should an audit be performed.

**FUTURE DEVELOPMENTS**

Ultrasound guidance has been used for many years and with excellent success in interventional radiology suites. As these techniques become disseminated to nonradiologist practitioners, the limits of what is "standard" change. Already, nephrologists are learning to perform ultrasound-guided renal biopsy, general internists are performing ultrasound-guided liver biopsy, and critical care practitioners are aspirating abdominal abscesses. Standardized training programs will emerge, with clearly defined training requirements, to enable practitioners of varied backgrounds to acquire the skills they need to perform these procedures at the point of care. Data will very likely emerge proving that ultrasound guidance improves the outcome of the vast majority of procedures, including those discussed in this chapter, and early adapters will have a distinct advantage.

**References**


