Ultrasound-Guided Procedures in the Emergency Department—Diagnostic and Therapeutic Asset

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KEYWORDS

• Ultrasound • Procedures • Pericardiocentesis • Abscess • Lumbar puncture
• Paracentesis • Arthrocentesis • Thoracentesis

KEY POINTS

- Correct orientation of the probe is paramount for procedural ultrasound (ie, aligning the probe marker with the on-screen logo).
- Ultrasound is a diagnostic modality that can aid in the therapeutic intervention of some serious conditions such as pericardial tamponade, pleural effusions, and massive ascites.
- It is important for the user to pay close attention to the trajectory of the needle in all ultrasound-guided procedures. This ensures accuracy and reduces error.

ULTRASOUND-GUIDED PERICARDIOCENTESIS

Background

When patients are suspected of having a life-threatening pericardial effusion and cardiac tamponade, prompt diagnosis and treatment are imperative to improve chances of survival. Making the diagnosis of a pericardial effusion is often difficult based on

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clinical findings alone. Bedside ultrasound can be used to determine if a pericardial effusion is present, to estimate the size of the fluid collection, to assess for cardiac tamponade, and to help guide an emergent pericardiocentesis.[1–7]

Indications and Contraindications

A bedside cardiac ultrasound should be performed when there is clinical suspicion for a pericardial effusion. If an effusion is noted on ultrasound, the heart should be assessed for any evidence of right atrial or right ventricular collapse. Diastolic collapse of the right atrium is the first sonographic sign encountered with increased pericardial pressures from a growing effusion. Once intrapericardial pressures exceed right ventricular pressures, end-diastolic right ventricular collapse is noted, and cardiac output is compromised. Right atrial and right ventricular collapses are best seen in the apical 4-chamber view of the heart.

Anatomy and Imaging

The pericardium is a thin, 2-layered structure that surrounds the heart. The outer layer is called the parietal pericardium. It is normally separated from the inner visceral pericardium by 25 to 50 mL of physiologic fluid. A pericardial effusion develops when infectious, serous, hemorrhagic, serosanguinous, or chylous fluid accumulates in between the parietal and visceral pericardium.

To determine if a pericardial effusion is present, 3 common cardiac views are used: the subxiphoid 4-chamber view, the parasternal long-axis view, and the apical 4-chamber view (**Fig. 1**). Although the parasternal short-axis view of the heart is typically obtained in most bedside cardiac ultrasound examinations, it is not one of the common views used during an ultrasound-guided pericardiocentesis.

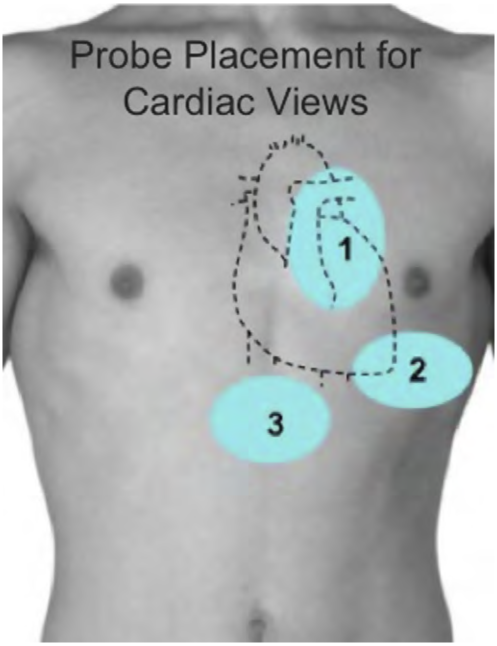

Fig. 1. Probe placement for standard cardiac views: (1) parasternal, (2) apical, and (3) subxiphoid.

Technique

Once the pericardial effusion has been localized on ultrasound, it is important to determine which approach will maximize chances of a successful pericardiocentesis, while minimizing the amount of damage inflicted on adjacent organs. If time permits, begin by prepping and draping the patient and the ultrasound transducer in a sterile fashion. Next, attempt to visualize the pericardial effusion with the subxiphoid, parasternal, or apical view of the heart (**Figs. 2–4**). Find an area where much pericardial fluid has accumulated close to the skin, and scan for a spot where there are no overlying organs obstructing the needle path to the heart.

In most situations, begin the scan with a low frequency (5–1 MHz) transducer to assess the heart and surrounding effusion. If the procedure is being performed with the needle entering the chest via the parasternal or apical approach, switching to a high-frequency transducer may provide better visualization of the needle and its trajectory into the pericardial sac (**Fig. 5**). With the apical or parasternal approach, the distance from the skin to the anterior pericardial sac is only a few centimeters, so using a high-frequency transducer enables better image resolution of the needle as it advances into the pericardial sac.

For the subxiphoid approach, place the probe just caudal to the xiphoid process and angle the face of the probe toward the patient's left shoulder. Insert the pericardiocentesis needle just cephalad to the transducer so that it bisects the ultrasound beams as it enters the pericardial space. The needle should be inserted at a 30° to 45° angle and directed toward the patient's left shoulder. Note that entering the thoracic cavity through the subxiphoid approach can put the patient at risk of liver or intestinal puncture.

During the parasternal approach, a long-axis view of the heart and pericardial effusion is obtained by placing the probe in the 3rd or 4th intercostal space, just left of the sternum. Insert the pericardiocentesis needle just lateral to the end of the transducer closest to the apex of the heart and direct the needle toward the patient's spine. Angle the ultrasound beams so that they bisect the needle as it enters the anterior pericardial sac (**Fig. 6**). With the anterior intercostal approach, there is a small risk of puncturing the internal mammary artery or accidentally lacerating the left anterior descending branch of the coronary artery.

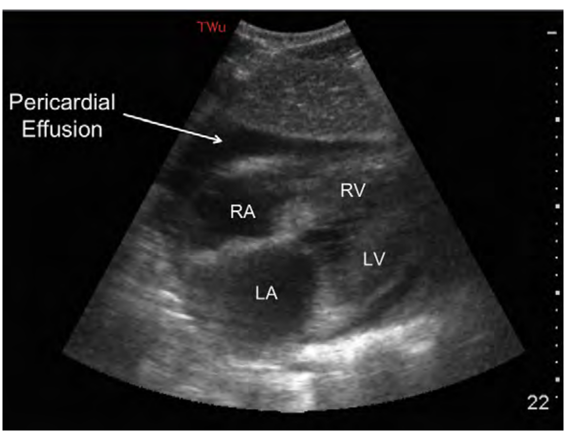

Fig. 2. Subxiphoid view of a pericardial effusion.

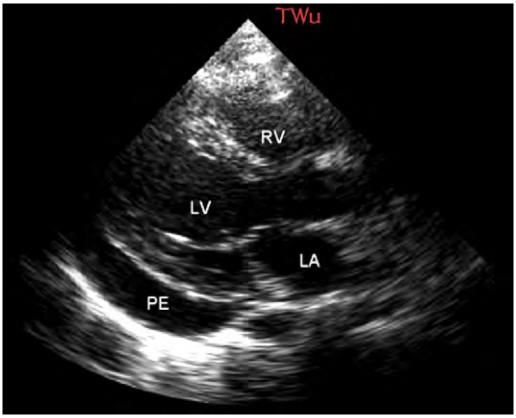

Fig. 3. Parasternal view of a pericardial effusion.

Under ultrasound guidance, the para-apical approach is becoming the most commonly used method for performing an emergent pericardiocentesis. In many patients, the largest collection of pericardial fluid is often seen collecting around the apex of the heart. Once an apical 4-chamber view of the heart is captured, the pericardiocentesis needle is inserted just lateral to the transducer (**Fig. 7**). The trajectory of the needle should be visualized as it enters the pericardial sac anterolaterally near the apex of the heart (**Fig. 8**). If lung is visualized overlying the apex of the heart (**Fig. 9**), movement of the probe in the medial and caudal direction may provide a more optimal needle entry site.

Once the pericardial sac has been entered, rapid injection of a few milliliters of saline will create bubbles in the pericardial sac that can be visualized on ultrasound. Agitated saline can help confirm needle placement before the Seldinger technique is used to introduce a catheter for serial drainage. If saline bubbles are noted in the cardiac chambers or in the subcutaneous tissues, reposition the needle under ultrasound guidance.

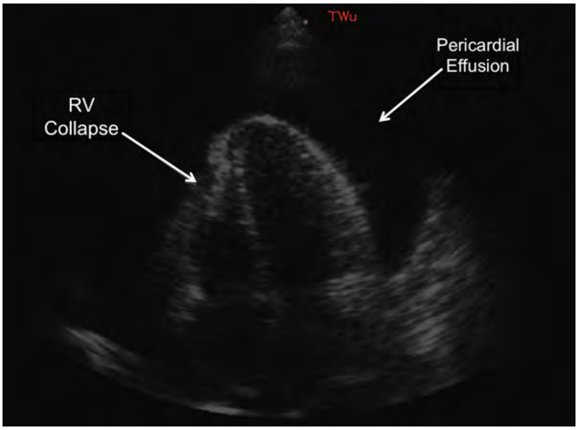

Fig. 4. Apical view of a pericardial effusion.

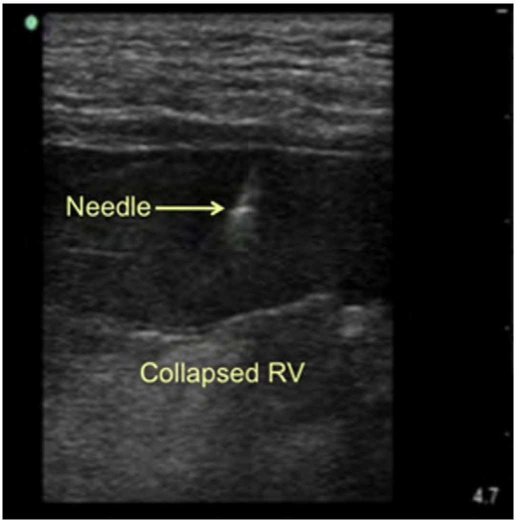

Fig. 5. Pericardiocentesis using ultrasound guidance with a high-frequency linear array transducer. RV, right ventricle.

Pitfalls

- Although there are no absolute contraindications for performing a bedside ultrasound-guided pericardiocentesis, it is important that hemodynamically stable patients with a large pericardial effusion should have their pericardiocentesis or pericardial window performed in the operating room by the most experienced personnel available.
- A pericardiocentesis performed using anatomic landmark guidance can put the patient at risk for inadvertent injury to the liver, cardiac chambers, coronary arteries, internal mammary artery, intercostal arteries, stomach, intestines, and lung. Knowledge of the surrounding anatomy and ultrasound guidance can help minimize these risks.

Fig. 6. Parasternal approach to a pericardiocentesis.

Fig. 7. Para-apical approach to a pericardiocentesis.

- Determine how deep the pericardial effusion is from the site of needle entry using the depth markers on the side of the ultrasound screen. Attempt the pericardiocentesis with a needle long enough to enter the pericardial effusion and permit wire insertion for a catheter placement in case serial drainage of the effusion is required.
- During the pericardiocentesis, it is important that the ultrasound beams are aimed to bisect the needle tip as it approaches the pericardial sac. You may need to fan or slide the probe away from the puncture site to maintain visualization of the needle tip as you advance the needle deeper into the patient.
- The optimal entry site may be some place between or around the 3 standard approaches noted in this article. Be flexible with your approach and scan around the heart to find the best for successful aspiration based on the patient in front of you.
- Do not be fooled by large anterior fat pads. Remember that most significant effusions will be seen circumferentially around the heart, and not just anteriorly. Additionally, fat pads tend to move in concert with the ventricular contractions and remain the same size, whereas pericardial effusions appear larger with each cardiac contraction as the ventricular wall constricts within the fluid.

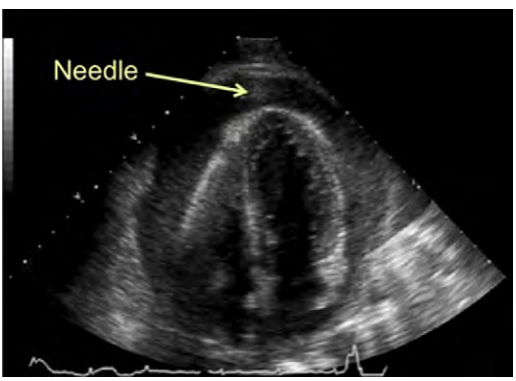

Fig. 8. Pericardiocentesis via the apical approach.

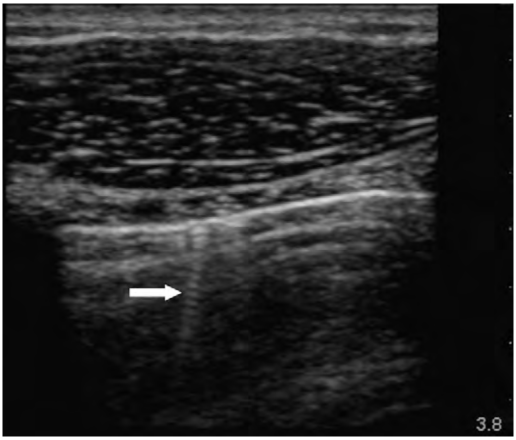

Fig. 9. White arrow demonstrates comet tail artifact between the 2 pleural surfaces.

- To maximize the collection of pericardial fluid available for aspiration, gently roll the patient over toward his or her left side. The pericardial fluid should settle near the apex of the heart for an ultrasound-guided para-apical pericardiocentesis attempt.

ULTRASOUND-GUIDED THORACENTESIS AND PARACENTESIS

Background

Thoracentesis and paracentesis are necessary for both diagnostic and therapeutic reasons. Both procedures are performed at the bedside by the clinician, traditionally using either physical examination findings or radiology-performed imaging to guide skin puncture. Point of care ultrasound not only can make the diagnosis of pleural effusions and ascites more accurately than physical examination and portable radiographs but also can help to guide the needle placement and can speak to the feasibility of the procedure in general. Indeed, there is ample evidence that ultrasound allows for real-time, accurate guidance and has the ability to decrease complications.[8,9]

Indications

Pleural effusions can be either unilateral or bilateral and can stem from multiple processes including heart failure, malignancy, infection, and hemorrhage. When an effusion accumulates enough volume, it can cause mass effect on the lung and diaphragm, leading to shortness of breath, pleurisy, and sometimes chest pain. Although chest radiography can demonstrate the presence of an effusion, it does not show the extent of diaphragm excursion or depth of the fluid pocket and cannot reveal lung/pleural adhesions—all of which can be seen with bedside ultrasound. In addition, chest radiography can be misleading if the patient is supine, whereas ultrasound is very accurate in supine patients. This can be particularly helpful in ventilated patients.[10] Thoracentesis can sample the pleural fluid for analysis, providing a diagnosis. Furthermore, removal of a volume of fluid will improve the patient's ventilatory mechanics and provide symptomatic relief.

Ascitic fluid is often the result of hepatic disease, which leads to portal hypertension and a hypoproteinemic state. Malignancy and hemorrhage are 2 other causes of abdominal free fluid. When much fluid accumulates, it can lead to a mass effect on the abdominal wall and on the diaphragm. This causes abdominal discomfort and can also lead to shortness of breath and decreased exercise tolerance. In rare cases, when abdominal pressures build high enough, right heart filling can be impaired as a result of compression of the inferior vena cava. Furthermore, ascitic fluid can become infected as a result of bowel flora translocation, thus leading to spontaneous bacterial peritonitis. Spontaneous bacterial peritonitis may be suspected when patients with known ascites present with signs of infection including, fever, leukocytosis, abdominal pain, and altered mental status. Diagnostic paracentesis and analysis of the fluid are essential to making this diagnosis. Large-volume paracentesis can provide symptomatic relief for patients. Bedside ultrasound can confirm the presence or absence of abdominal free fluid and can help to identify a fluid pocket of adequate depth for sampling. Furthermore, large vessels in the abdominal wall can be visualized and avoided. Finally, omental and bowel adhesions to the peritoneum can be identified.

Anatomy and Imaging

The pleural cavity is formed by a continuous membranous lining that surrounds and adheres to the lung parenchyma (visceral pleura) and the interior of the chest wall (parietal pleura). Normally, the pleural cavity has a scant lubricating layer of fluid that is too small to be visualized directly with ultrasound. As the visceral and parietal layers rub against one another with lung expansion, the surfaces slide against one another (ie, lung sliding). Furthermore, in normal lungs, there may be a "comet tail artifact," which is thought to represent reverberation artifact created by small microbubbles of fluid between the 2 pleural surfaces (**Fig. 10**). Pleural fluid can be seen above the liver or spleen in the mid-axillary line with the patient supine (**Fig. 11**) and is noted when there is a loss of the mirror image artifact (normally caused by the reflection of the diaphragm and the lack of sound reflection from the aerated lung) or when there is the continuation of the spinal shadow above the diaphragm when there is fluid in the thoracic cavity that can transmit ultrasound. It is also possible to see fluid in the posterior mid scapular line with the patient upright-seated position, and this is demonstrated as a black anechoic space separating the visceral and parietal pleura (**Fig. 12**). Below each rib runs the intercostal neurovascular bundle; because this is

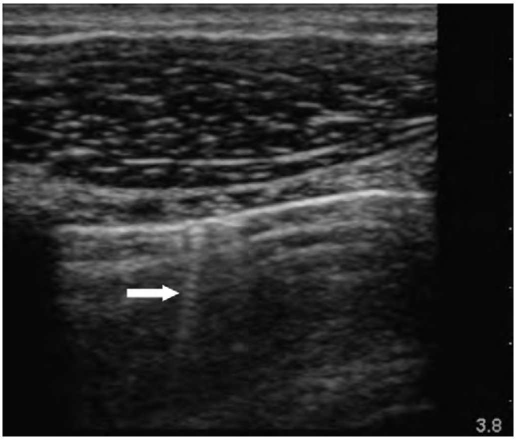

Fig. 10. Comet trail reverberation artifact artifact demonstrated by arrow.

Fig. 11. Pleural fluid in mid-axillary line with patient in supine position.

hidden under the curvature of each rib, it will not normally be visualized sonographically.

The abdominal contents are covered by a membranous layer that adheres to the interior of the abdominal wall called the peritoneum. Running just above the peritoneal layer is the inferior epigastric artery—this should be identified and avoided when ultrasound is used to guide needle placement (**Fig. 13**). Free fluid in the abdomen is gravity dependent and will accumulate in the recesses between organs, specifically the hepatorenal (Morrison), splenorenal, and retrovesicular spaces. A minimum of about 250 mL of fluid can be sonographically visualized.[11] As the volume increases, the rest of the abdomen will fill with fluid and the peritoneum will be lifted off of the bowels.

Fig. 12. Pleural fluid obtain by placing patient in upright position, with anechoic pace between visceral from parietal pleura.

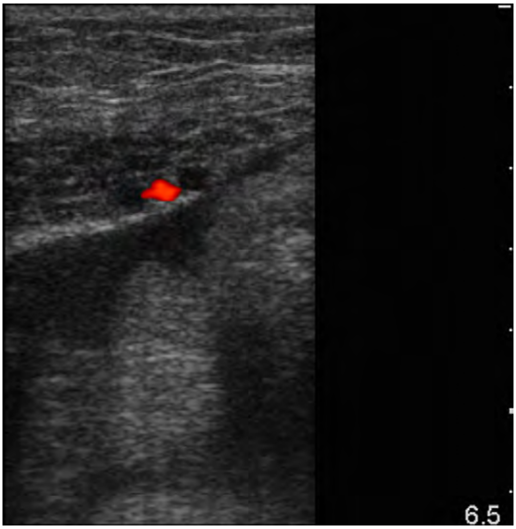

Fig. 13. Doppler image demonstrating inferior epigastric artery.

The fluid will appear as an anechoic region between the peritoneum and solid organs (**Fig. 14**).

Technique

Thoracentesis and paracentesis can be performed by aspirating fluid with a medium-gauge needle and syringe. More commonly, catheter-introducer kits are used; these kits will include either a plastic or a metal catheter sheathed over a longer introducer needle.

Both thoracentesis and paracentesis can be performed with ultrasound imaging, occurring preprocedurally or in real-time guidance. With either technique, the patient should be positioned with the ultrasound directly visible in the operator's line of sight (**Fig. 15**). It is important not to change the patient's position after marking the point of entry, because this can shift the pocket of fluid and move bowel into the path of the needle trajectory.

Fig. 14. Fluid appears anechoic (*black*) between the viscera in the peritoneal cavity.

Fig. 15. Ultrasound system position, visible to the operator's line of sight.

When performing thoracentesis, first review relevant cell counts and coagulation factors and any prior imaging. The patient should ideally be placed in a seated position. This position will allow the gravity-dependent fluid to accumulate caudally and will also increase the distance between the pleural lining and the lung. Furthermore, large effusions tend to cause orthopnea, and as such, some patients may be unable to tolerate a supine or prone position. A high-frequency linear probe or a low-frequency curvilinear probe can be used for this procedure depending on operator preference and patient body habitus. As with any ultrasound application, the high-frequency linear probe will provide superior picture quality of the superficial structures but may be insufficient to visualize the lung parenchyma. The effusion and the diaphragm should be visualized and the skin marked. After sterile prep and drape, the skin should be anesthetized. The needle should be directed toward the rib, orthogonal to the skin surface, and the soft tissue should be infiltrated as the needle is passed. To ensure that the intercostal neurovascular bundle inferior to the rib is not injured, the tip of the needle should first touch the rib periosteum and then should be directed slightly cephalad until the rib is passed. This will ensure the track is immediately superior to the rib. After the pleural space is entered, the anesthetic needle can be withdrawn. A small skin incision is then made with a scalpel so that the larger introducer needle can be passed. While holding suction with the dominant hand, pass through the soft tissue along the same track. Once pleural fluid is expressed, advance the catheter off of the introducer needle, taking care to not advance the needle any farther into the body cavity. Once the catheter is within the effusion, the needle can be withdrawn completely and fluid can be removed. After the sampling is complete, the catheter can be withdrawn. Having the patient perform the Valsalva movement during this time will increase the intrathoracic pressure and reduce the chance of pneuomothorax.

When performing paracentesis, first review relevant laboratory data, including platelet count and coagulation factors. The patient can be placed in a right or left lateral decubitus position to maximize the fluid pocket. Begin by looking at the lower quadrants and identify the largest collection. The omentum and bowel loops should be visible in the far field. Next, scan the overlying abdominal wall for the epigastric vessels. Depending on body habitus, it may be helpful to switch to a high frequency (5–10 MHz) linear probe for vessel identification. The skin can then be marked for puncture, taking care to select an area away from the vessels. Sterilely prep and drape the skin. Perform soft tissue anesthesia with a smaller-gauge needle. Following this, a small skin incision can be made to help pass the larger introducer needle. In patients with tense ascites, it is often prudent to ensure that the puncture to the peritoneal cavity and the skin puncture not be in parallel, to prevent fistula formation. Holding suction with the dominant hand, pass the introducer needle through the soft tissue. Once fluid is expressed, thread the catheter into the peritoneum, taking care to not advance the needle any farther. Once the catheter is in place, the needle can be withdrawn and the fluid sampled.

Pitfalls

- When performing paracentesis, be sure to scan in multiple orientations when identifying the inferior epigastric arteries. If the probe axis is parallel to the vessel, the vessel may have similar appearance to a soft tissue plane. Additionally, if color Doppler is being used to identify vascular structures and if the probe is exactly perpendicular to the vessel, no color signal will be generated.
- When performing thoracentesis or paracentesis, the parietal pleura/peritoneal layer has the most innervation and may be the greatest source of discomfort when passing the catheter. When anesthetizing with the smaller-gauge needle after the fluid pocket is entered, consider withdrawing the needle slightly so that it is in close proximity to the membranous layer and depositing several milliliters of anesthetic agent.
- When performing skin puncture with the catheter-introducer needle for paracentesis, the nondominant hand can be used to hold skin tension orthogonal to the puncture site. This will create a “z-track,” which will decrease postprocedural leaking.
- Both procedures have “traditional” landmarks and positioning, which do not necessarily apply when ultrasound is used. A large pleural effusion can be accessed with the patient recumbent if visualized in real-time. Abdominal free fluid can also be tapped with a patient supine as opposed to in a decubitus position.
- The lung and diaphragm are dynamic structures. Make sure you observe the full extent of excursion with the respiratory cycle.
- The intercostal neurovascular bundle is typically hidden inferior and proximal to the rib and usually cannot be visualized. The typical approach of needle insertion just cephalad to the rib will avoid vessel injury. However, anatomy can vary and thus it is important to examine the planned procedural site closely for anomalous vessels.
- Removal of large volumes may cause fluid shifts that can lead to patient instability. The traditional recommendation is to use caution when draining more than 1 L via thoracentesis, because this may lead to reexpansion pulmonary edema. However, there are recent studies that do not show an increased risk.[12,13] Removal of 8 L via paracentesis is considered large volume and this may lead to tachycardia and hypotension. Intravascular replacement with crystalloid and/or colloid is advisable.[14]

ULTRASOUND-GUIDED ARTHROCENTESIS

Background

When a patient presents with a painful and swollen joint, prompt diagnosis and evaluation are needed to distinguish a bursitis from a hemarthrosis, osteoarthritis, cellulitis, or a septic arthritis. A patient's history and physical examination may be limited in providing the information necessary to make an accurate diagnosis. Moreover, the physical examination alone may fail to suggest a joint effusion because of limited range of motion. Bedside ultrasound has proved to be superior to the physical examination in the detection of an effusion.[15]

When an effusion is identified, aspiration of synovial fluid may be necessary, such as when septic arthritis is a diagnostic concern.[16] Additionally, arthrocentesis may be of therapeutic benefit as occurs in the setting of hemarthrosis or inflammatory arthritis, allowing a decrease in the pressure within the synovial space and pain relief.[17] Bedside ultrasound can be used for assistance during diagnostic or therapeutic arthrocentesis.

Indications and Contraindications

A bedside ultrasound should be performed when a join effusion is suspected. Ultrasound has been found to be helpful in identifying effusions in smaller joints.[18] In larger joints, bedside ultrasound does not increase the likelihood of successful drainage, but it does result in more fluid drainage compared with the landmark technique.[19]

Bedside ultrasound by itself cannot distinguish the type of fluid present within the joint. Hemarthrosis, septic joint, and chronic inflammation may all have similar sonographic characteristics. An acute traumatic hemarthrosis appears hypoechoic but may be complicated by free-floating material (clot, fibrin, fat etc), making it appear more heterogeneous. Fluid within a septic joint may appear anechoic, often with internal echoes (providing a particulate appearance). Chronically inflamed joints as in degenerative arthritis may contain fluid that is hypoechoic or anechoic in appearance, making it difficult to distinguish from a septic effusion. Infectious arthritis is unique in that it classically presents with an increase in intra-articular fluid without an increase in synovial thickenss.[20]

There are no absolute contraindications to performing a bedside ultrasound to evaluate for the presence of an effusion. Once identified, bedside ultrasound may aid in dynamic arthrocentesis, thus decreasing potential complications.[21,22] This section will focus on ultrasound-assisted evaluation of the knee and elbow.

Anatomy and Imaging

Knee

A knee effusion may not be readily detectable on physical examination because of a patient's body habitus, the size of the effusion, or pain limiting knee flexion during the examination. Slight knee flexion will aid in beside ultrasound examination. This may be accomplished by placing a towel roll beneath the popliteal fossa.

The suprapatellar bursa extends approximately 6 cm superior to the patella, deep to the quadriceps tendon and in communication with the knee joint. A joint effusion is detected with increased distension of the suprapatellar recess with hypoechoic or anechoic fluid deep to the suprapatellar recess. To determine if a knee effusion is present, 6 common views may be used (**Fig. 16**A–D).

Technique

A high-frequency linear probe should be used with sterile water–based lubricant as a suggested conducting medium. A reference comparison view of the unaffected joint should be performed.

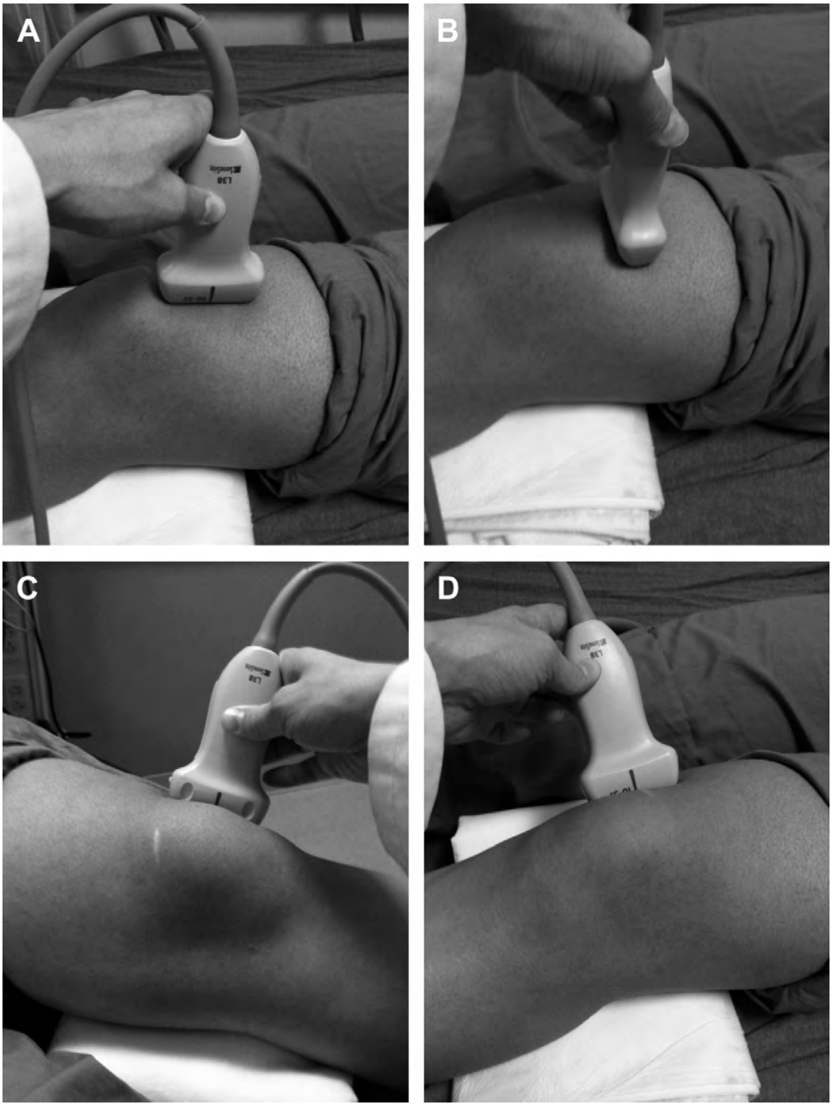

Fig. 16. Probe placement for standard knee views: (*A*) suprapatellar sagittal, (*B*) suprapatellar transverse, (*C*) lateral, and (*D*) medial.

As with all musculoskeletal bedside ultrasound applications, the sonographer should be sure to place and maintain the probe perpendicular to the anatomic structure of interest so as to avoid anisotropy and consequent misidentification of anatomic structures and misinterpretation of sonographic findings.[23]

The suprapatellar bursa should be imaged in the transverse and sagittal planes. With the patella serving as a landmark, take the image laterally for the lateral recess and medially for the medial recess (**Fig. 17**A–D).

In the static technique, identify the largest fluid pocket and mark to designate the optimal site for aspiration. Note the depth of the pocket and the optimal angle of approach. The ultrasound can be used to directly visualize and guide the needle

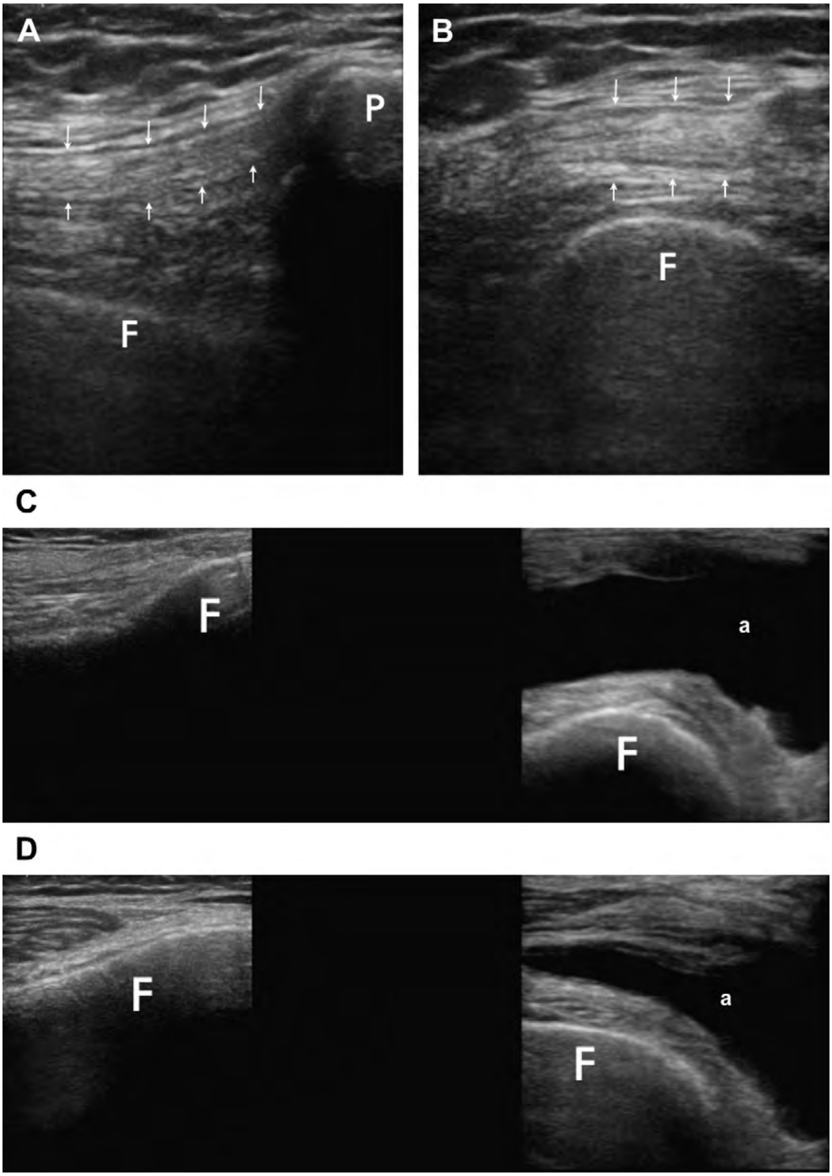

Fig. 17. (*A*) Normal knee. (*B*) Suprapatellar sagittal. (*C*) Suprapatellar transverse. (*D*) Coronal imaging at the lateral joint line or lateral recess (*left*) and (*right*) knee effusion seen as a hypoechoic collection of fluid in the suprapatellar bursa visualized along the lateral recess. Coronal imaging at the medial joint line or medial recess (*left*) and knee effusion (*right*) seen as a hypoechoic collection of fluid in the supra-patellar bursa visualized along the medial recess. F, femur; P, patella; arrows, quadriceps tendon. [a] Joint effusion.

into the fluid pocket. In the dynamic technique, sheath the probe in a sterile fashion and use sterile lubricant. Regardless of the approach used, maintain aseptic technique throughout the procedure.[23]

Elbow

An effusion in the elbow joint may be located in the anterior or posterior recess. The joint capsule, which lies between the radial head and capitellum (the anterior recess), distends anteriorly in the presence of effusion. A small amount of fluid (1- to 2-mm fluid stripe) visualized and measured sonographically within the anterior recess may be physiologic.[21]

The olecranon fossa, or posterior recess, is located distal to the medial and lateral epicondyles, where the posterior surface of the humerus flattens and then becomes depressed. In the sagittal plane, the triceps tendon will appear just below the epidermis and dermis as a hyperechoic fibrillar structure. The olecranon fossa is typically filled with adipose tissue and is known as the posterior fat pad. Sonographically, this appears as mid-gray echogenic material within the fossa. If an effusion is present, anechoic fluid pushes the fat pad superiorly and posteriorly.[21,23]

Technique

Place the patient's elbow in extension and hand in supination for imaging of the anterior recess in a sagittal plane (**Figs. 18** and **19**). The radial head and capitellum align with the joint capsule between them. This capsule will be anteriorly displaced in the presence of a pathologic effusion.[21]

Place the patient's elbow in 90° flexion when performing ultrasound assisted examination of the posterior recess.[24] When the posterior recess is located, the posterior fat pad will be observed within the olecranon fossa (**Figs. 20** and **21**A, B). In the presence of fluid, the fat pad will be superiorly displaced (**Fig. 22**A, B).

With the probe in the transverse plane in the posterior recess, the largest area of fluid collection should be identified and marked. Rotate the probe so it is aligned with the long axis of the humerus (sagittally), noting the location of the deepest pocket, and make a second mark that intersects with the first. This intersection would be the site of aspiration. The joint should be approached from the lateral aspect. A medial approach could

Fig. 18. Probe placement for standard visualization of the anterior recess of the elbow in sagittal view.

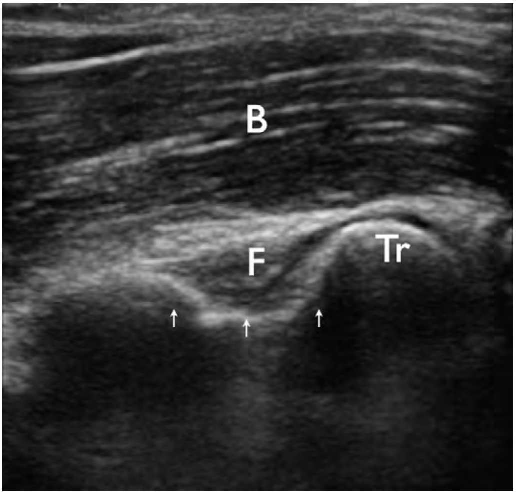

Fig. 19. Normal anterior elbow in sagittal view. B, brachialis muscle; F, anterior fat pad; Tr, trochlea; arrows, coronoid fossa.

result in triceps tendon, ulnar nerve, or superior ulnar collateral artery damage.[23,24] Direct the needle toward the patient's midline.[23] If real-time ultrasound guidance is performed, apply a sterile sheath to the probe and use sterile conducting medium.

Pearls and Pitfalls

- Comparison of the affected limb or joint with the unaffected side will aid in the identification of an effusion.
- Some pitfalls of ultrasound-assisted arthrocentesis are common to landmark-guided arthrocentesis. They pose the risk of iatrogenic infection.
- There is a risk of puncture of adjacent neurovascular structures. Ultrasound will aid in minimizing this risk, however, with the ability to distinguish vascular structures with color Doppler imaging.[23]
- Place the probe as perpendicular to the tendon or structure of interest as possible to avoid anisotropy.
- Gentle compression with the probe will aid in distinguishing a joint effusion from cartilage because fluid will compress and articular cartilage will not.[21]

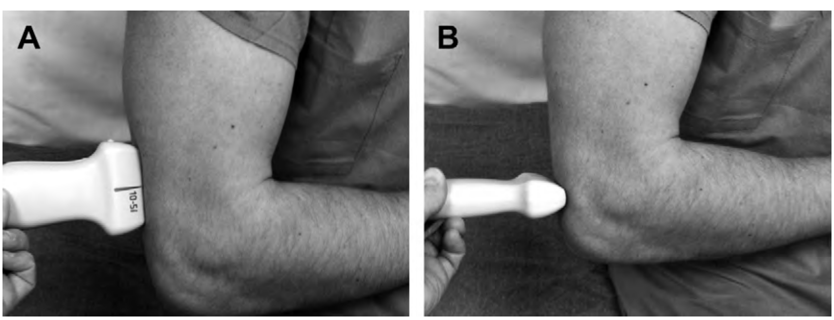

Fig. 20. Probe placement for standard posterior fossa elbow views: (*A*) sagittal and (*B*) transverse.

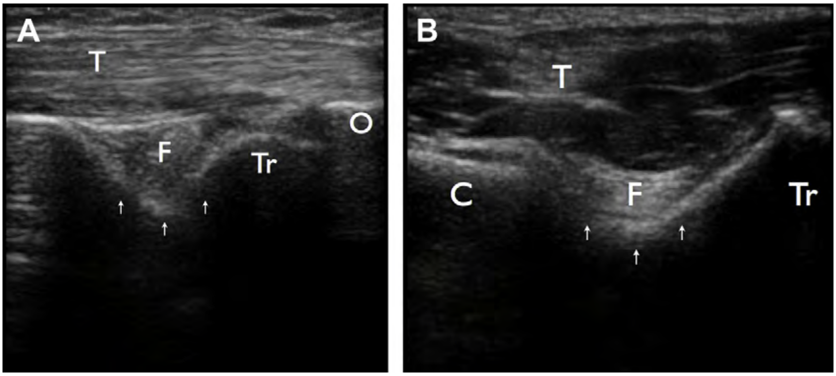

Fig. 21. Normal posterior elbow: (*A*) sagittal and (*B*) transverse. T, triceps; F, posterior fat pad; arrows, olecranon fossa; Tr, trochlea; O, olecranon; C, capitellum.

ULTRASOUND-GUIDED LUMBAR PUNCTURE

Background

Ultrasound-guided lumbar puncture was first described in the Russian literature in 1971.[25] Since then, multiple publications have reported on the utility of ultrasound to facilitate spinal anesthesia and lumbar puncture.[26–33] The literature has also documented that clinicians inaccurately identify lumbar interspaces with the standard palpation technique in 29% to 30% of cases.[34,35] Given this inaccuracy and given the increased risk of spinal cord injury, to access a lumbar interspace higher than the L3 vertebral body,[36] governing bodies in the anesthesia community recommend using assist devices such as ultrasound to select an accurate lumbar spinal access site.[37]

In addition to observational studies, there are a few small prospective, randomized controlled trials that compare ultrasound-guided lumbar puncture to landmark-guided lumbar puncture in the emergency department.[38,39] Although larger prospective cohort studies are needed to further define ultrasound's optimal use in lumbar

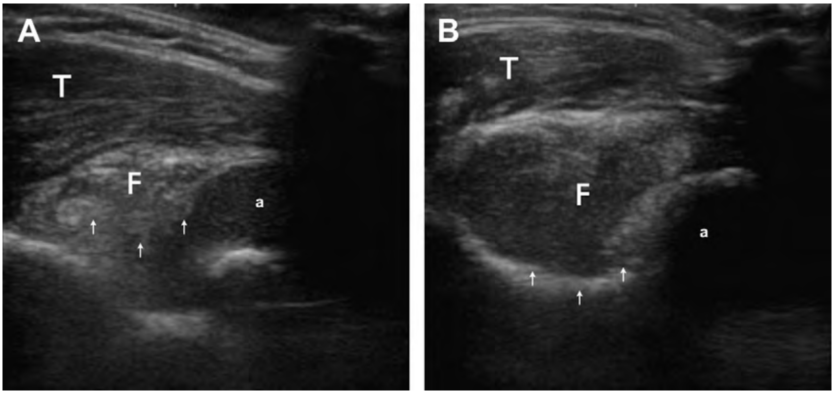

Fig. 22. Posterior recess joint effusion: (*A*). Sagittal and (*B*). Transverse. T, triceps; F, posterior fat pad; arrows, olecranon fossa; [a] joint fluid.

puncture, these early studies suggest a trend toward improved success with ultrasound use, especially in obese patients (ie, body mass index $\geq$30 kg/m^2), whose surface lumbar landmarks are difficult to palpate.

Ultrasound indications

In clinical cases when lumbar puncture is indicated, the literature suggests that ultrasound use should be considered when certain patient characteristics and clinical scenarios exist (**Box 1**).[29,32,33,39,40]

Anatomy

In spinal ultrasound imaging, the identification of bony landmarks is imperative. Bone is a very dense tissue and reflects virtually all of the ultrasound waves that encounter its surface. Given the reflective properties of bone, the ultrasound monitor will display a bony surface as a hyperechoic (white) image with an area of anechoic (black) "shadowing" directly behind the structure (**Fig. 23**). The procedurally important lumbar anatomic structures that often are visualized with ultrasound assessment include (1) the lumbar spine with its associated spinous process and transverse processes; (2) the sacral spine; (3) the lumbar interspace; and (4) the ligamentum flavum. The following sections discuss the imaging and identification of these structures using ultrasound.

Technique

Patient positioning Recent observational trials in adult and pediatric populations support the positioning of patients in a sitting position with legs supported in a hip-flexed position. This position increases the interspinous distance and may favor an improved success rate for lumbar puncture. Although patient positioning is determined by patient tolerability and comfort, to the extent possible, this described positioning is recommended.[41,42]

Probe selection Linear (high-frequency) probes allow for higher resolution of superficial structures, making these the most commonly used transducers for imaging of spinal anatomy. However, in patients with an obese habitus and correspondingly deeper spinal structures, a low-frequency phased-array or curvilinear probe may provide better assessment of structures. If using a low-frequency probe, adjust and decrease the depth settings on the machine so to optimize assessment of spinal structures.

Probe orientation In lumbar ultrasound imaging, 2 main probe orientations are used: the transverse view and the longitudinal view. The goal of imaging in the transverse view is to determine the anatomic lumbar spinal *midline* by identifying the spinous

Box 1
Patient examination characteristics and clinical scenarios in which ultrasound use should be considered to guide lumbar puncture

- Obese patients with a body mass index $\geq$30 kg/m^2
- Pregnant patients
- Patients with lumbar edema
- Patients with a history of difficult prior lumbar punctures or difficult spinal access
- Patients with an examination demonstrating difficult-to-palpate or difficult-to-visualize spinal anatomy

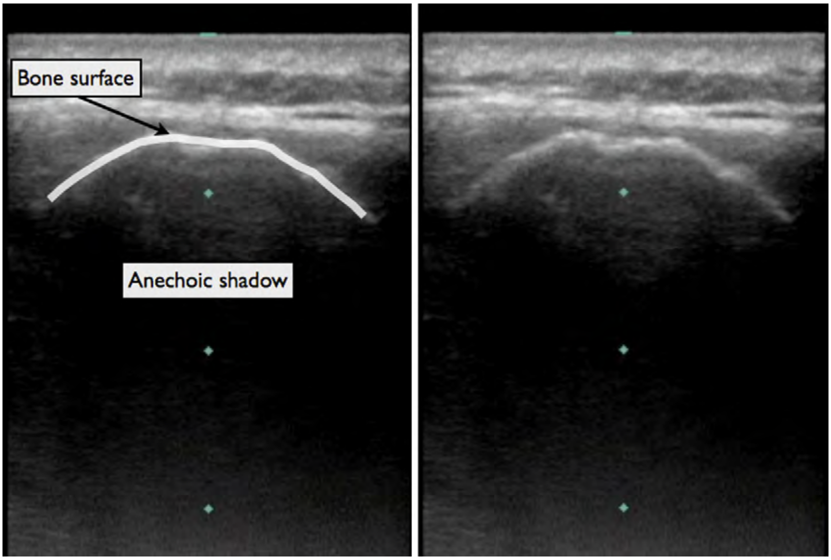

Fig. 23. On the left is a labeled bony spinous process, and on the right is an unlabeled structure. These images are obtained using ultrasound imaging in the longitudinal view.

processes. The goal of imaging in the longitudinal view is to locate the lumbar spinal *interspaces*.

Transverse view The transverse view is obtained by placing the probe perpendicular to the long axis of the spine (**Fig. 24**). The bony spinous process will often appear on the ultrasound monitor as a white hyperechoic convex rim with an associated anechoic shadow. Occasionally, the hyperechoic rim of the spinous process is not well visualized and only the anechoic shadow identifies the target structure. Often, paired hyperechoic structures may be visualized surrounding the spinous process, such as paired mammillary or transverse processes (**Fig. 25**). Identification of these symmetric structures surrounding the spinous process supports spinal midline

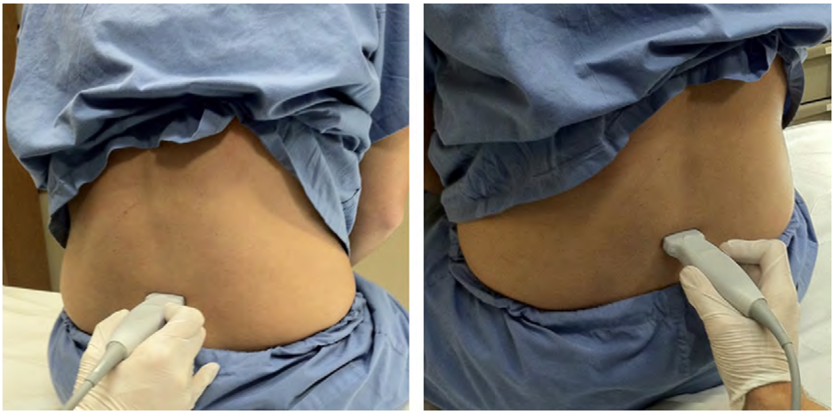

Fig. 24. Probe positioning in the transverse view.

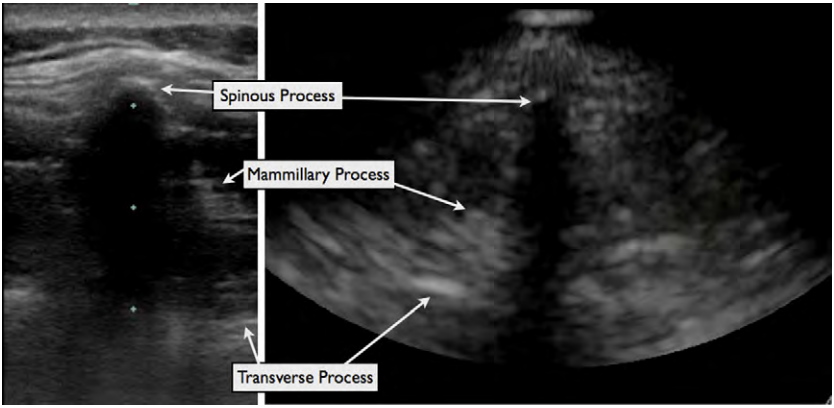

Fig. 25. The midline of the spine on ultrasound imaging in the transverse view. The left image is with use of a high-frequency probe, and the right image is with use of a low-frequency probe.

confirmation. Once identified, center the spinous process on the ultrasound display and then perform preprocedural labeling of the skin as directed in the following section.

Longitudinal View After the midline landmarks are identified with the transverse view, the longitudinal view should be performed with *continuous* reference to the marked and labeled midline. The longitudinal view is obtained by placing the probe's long axis parallel to the long axis of the spine (Fig. 26). Again, the key structure to identify is the spinous process. The spinous process should be the most superficial hyperechoic structure with an associated deep anechoic shadow. Care should be taken to confirm that the target structure is the spinous process and not a similar appearing deeper and lateral other bony structure. To confirm a structure is the spinous process, move the probe in a side-to-side direction away from and toward the identified spinal midline to confirm that the identified target structure is of the same general depth as the spinous processes identified on the transverse view. Once a spinous process is identified, move the probe cephalad and caudad to identify other contiguous spinous

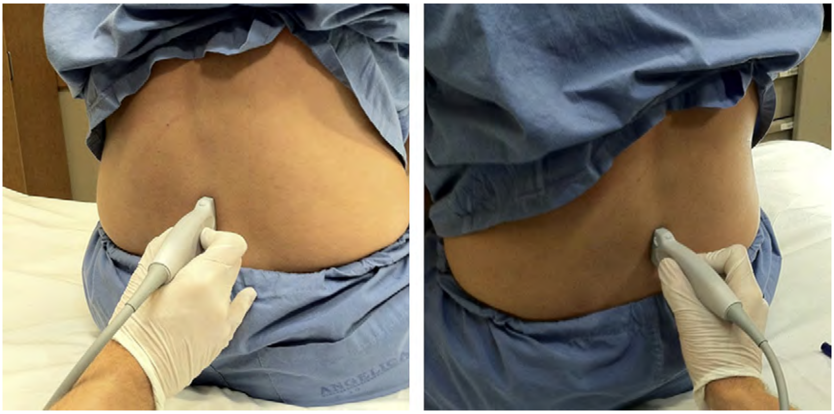

Fig. 26. Probe positioning in the longitudinal view.

processes. After another contiguous spinous process is identified, make fine adjustments with the probe to obtain an ultrasound image on the monitor that contains 2 contiguous spinous processes with a view between them into the spinal interspace. The goal with this view is to center the probe and image between the spinous processes and provide a direct ultrasonographic view into the hypoechoic (gray) interspace (**Fig. 27**). The spinal interspace is the optimal location for needle insertion during lumbar puncture; once it is identified, it should be marked and labeled as described in the following section.

Occasionally, deeper structures may be imaged within the spinal interspace, such as the ligamentum flavum. This structure typically appears as a hyperechoic linear structure within the depths of the interspace (**Fig. 28**). Unlike bone, this structure usually does not have an associated shadow. Sonographic depth assessment of this structure may provide a fairly accurate estimate of the spinal needle introduction depth needed to procure cerebrospinal fluid.

Exact lumbar interspace localization To perform the localization of an exact lumbar interspace, interrogate the midline spinal area of the lower back using the longitudinal view and attempt to localize the sacral bones. The sacral bones appear as fully continuous hyperechoic bony structures that do not have any associated interspaces. Once these bones are identified, move the probe cephalad until an interspace is identified (**Fig. 29**). The first visualized interspace should represent the L5-S1 interspace, with further cephalad movements of the probe allowing precise identification of additional interspaces.

Preprocedural labeling Preprocedural ultrasound guidance is only useful if accurate skin markings are made that clearly demarcate spinal anatomy and the access site. In the transverse view, the probe and monitor image should be centered over the midline spinous process. Once identified, use a surgical marking pen to make physical markings on the patient's skin adjacent to the midline of the probe (**Fig. 30**). For effective labeling and best adherence of ink to the skin, remove extraneous ultrasound gel from the skin with an alcohol wipe or towel before skin marking. In the longitudinal view, the probe and monitor image should be centered over the lumbar interspace

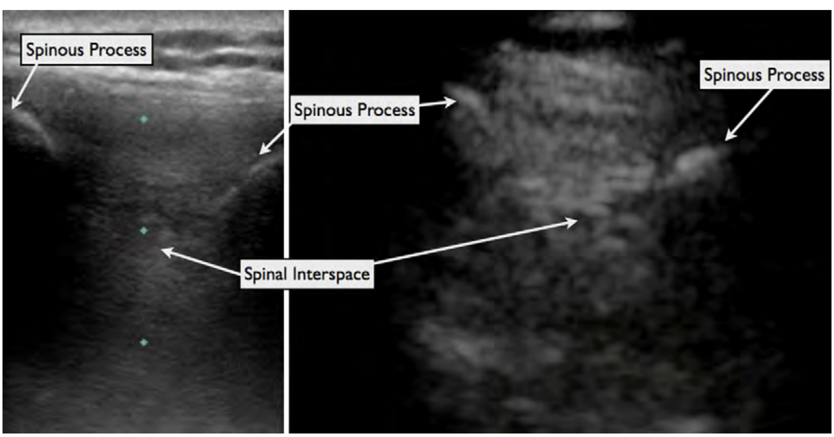

Fig. 27. The spinal interspace on ultrasound imaging in the longitudinal view. The left image is with use of a high-frequency probe, and the right image is with use of a low-frequency probe.

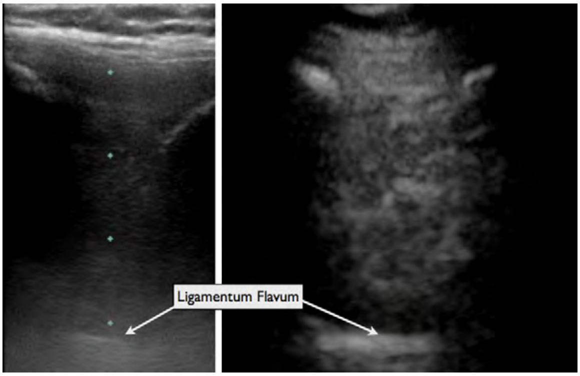

Fig. 28. Ultrasound appearance of the ligamentum flavum. The left image is with use of a high-frequency probe, and the right image is with use of a low-frequency probe.

with physical marks made adjacent to the midline of the probe (**Fig. 31**). Next, cross and connect the labeled markings made during the transverse and longitudinal views, which will effectively provide target "X" access points (**Fig. 32**). Once labeling is completed, standard aseptic site preparation may be performed and the spinal needle may be introduced at the identified "X" or a few millimeters below. Introduce the needle with a slight cephalad angulation so as to follow the contours of the spinous processes. Last, it is very important that patients maintain consistent positioning between the ultrasound-guided site labeling and the performance of the lumbar puncture. Even very small patient movements may change the correlation of the labeled skin surface marks and the underlying spinal structures.

Pitfalls

- The use of ultrasound to assess lumbar anatomy before lumbar puncture poses virtually no risk to patients. However, the inherent risk of the lumbar puncture procedure is the same as with the standard, landmark-guided procedure. Practitioners should also be mindful of the learning curve involved in becoming familiar with the technique and assessment of sonographic lumbar anatomy.

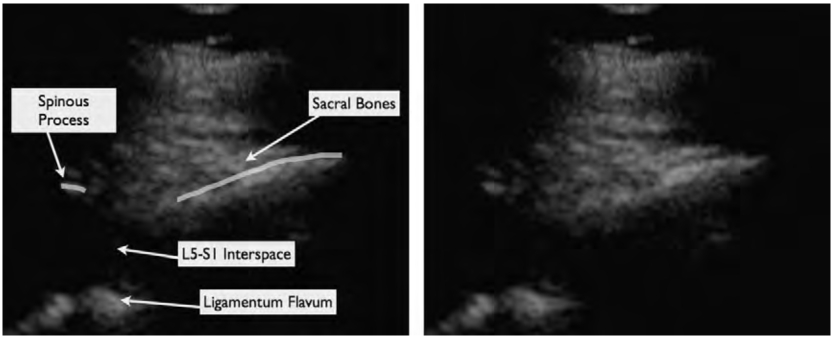

Fig. 29. When imaging with a low-frequency probe, the sacral bones and the L5-S1 interspace are identified. The left image is labeled, and the right image is not.

Fig. 30. Preprocedural labeling in the transverse view.

ULTRASOUND-GUIDED ABSCESS DRAINAGE

Background

Patients may present to the emergency department with a variety of infectious skin and soft tissue complaints ranging from simple cellulitis to purulent abscess. Making a clinical diagnosis about the nature and degree of a soft tissue infection may be difficult. This is reflected in the poor interrater agreement of the clinical examination findings and prediction of severity.[43,44] Bedside ultrasound has improved accuracy compared with physical examination findings alone in the detection of abscesses in adult and pediatric patient populations.[45–47] The information gained from soft tissue sonography can help determine not only whether a drainable subcutaneous fluid

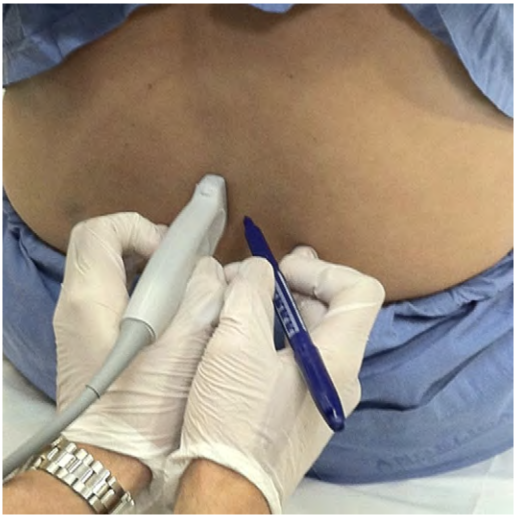

Fig. 31. Preprocedural labeling in the longitudinal view.

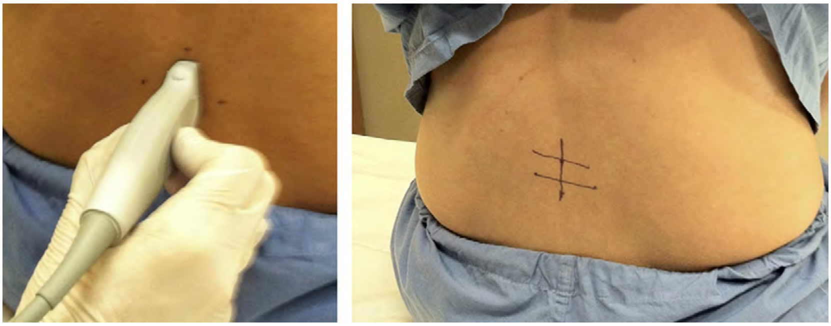

Fig. 32. After making physical markings on the patient's skin adjacent to the midline of the probe in both views, multiple access sites are mapped out by crossing and connecting the labeled markings.

collection exists but also the optimal drainage strategy and location, and it can be used to guide the eventual incision or aspiration.

Ultrasound Indications

A bedside soft tissue ultrasound should be performed on any soft tissue infection when there is a question of an underlying fluid collection. In cases when there is obvious abscess with fluctuance or drainage, the examination can help to delineate the extent of the underlying lesion and determine whether further invasive drainage is required. Low probability cases may reveal unexpected findings of an occult abscess. Once it is determined that drainage is required, the surrounding soft tissue should be assessed for structures such as local vasculature, nerves, or connective tissue that should be avoided during the incision and drainage.

Anatomy and Imaging

Normal soft tissue findings consist of a relatively thin layer of subcutaneous tissue with an organized echotexture. Deep to the subcutaneous tissue are hypoechoic muscle layers bordered by hyperechoic fascia. With cellulitis, the soft tissue appears diffusely thickened and echogenic, with a breakdown of the organized architecture (**Fig. 33**A). Eventually, with progressive edema, this creates a "cobblestone" appearance, with the presence of anechoic edema surrounding subcutaneous fat (see **Fig. 33**B). In contrast, an abscess appears as an ovoid collection of fluid (**Fig. 34**A). This collection may seem contiguous with surrounding cellulitic tissue or have a well-demarcated echogenic border (see **Fig. 34**B). Although a purulent collection often appears hypoechoic to anechoic, it may also appear isoechoic to hyperechoic compared with surrounding tissues.[48] Gentle downward pressure with the ultrasound transducer may reveal fluid moving within the collection.[49] The presence of posterior acoustic enhancement may also help to identify the liquid nature of an isoechoic or hyperechoic abscess cavity. Doppler may reveal hyperemia of the surrounding tissues and should reveal an absence of flow within the abscess cavity (**Fig. 35**).

Ultrasound Technique

Soft tissue ultrasonography is performed with a linear high-frequency transducer ($\geq$7.5 MHz). Assessing the lesion depends on the location, with infections on the trunk and extremities providing minimal obstruction, whereas those on joints, in folds, or between creases may be technically challenging. The scan should start from an

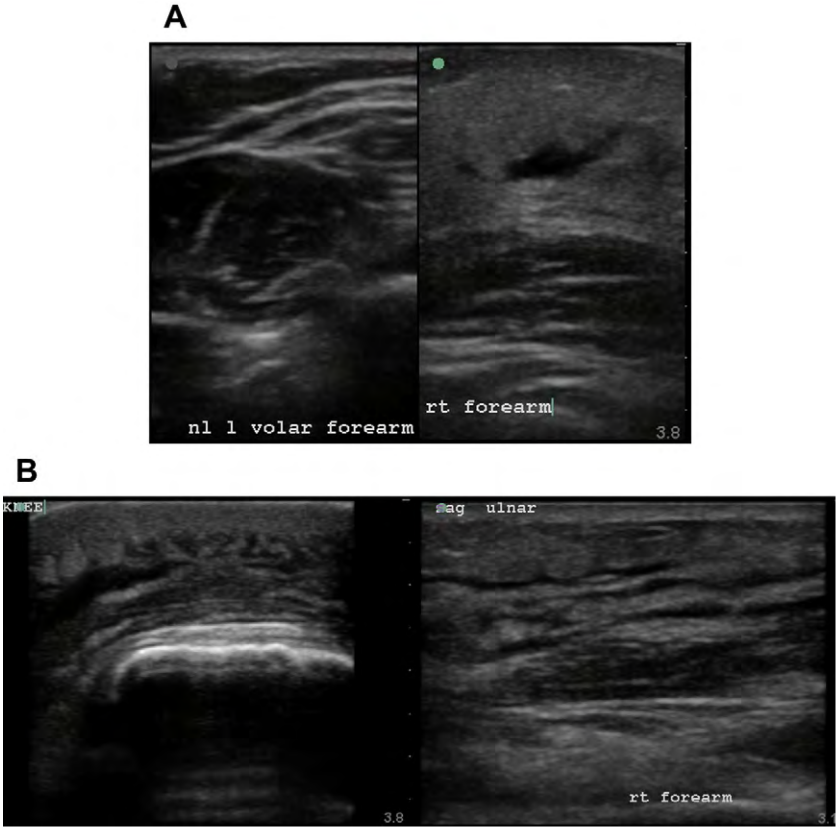

Fig. 33. (*A*) Comparison between normal soft tissue (*left*) and infected soft tissue with small fluid collection (*right*). Note the doubling of size of the subcutaneous tissue layer and the gray echogenicity. (*B*) Cobblestoning in cellulitis.

area of healthy tissue and pan across the lesion to the opposite side, repeating in an orthogonal plane. Measure the size and depth of the abscess, as well as the depth required for the incision. A sinus tract may extend to the surface, whereas the main abscess cavity lies not directly below but off at an angle.

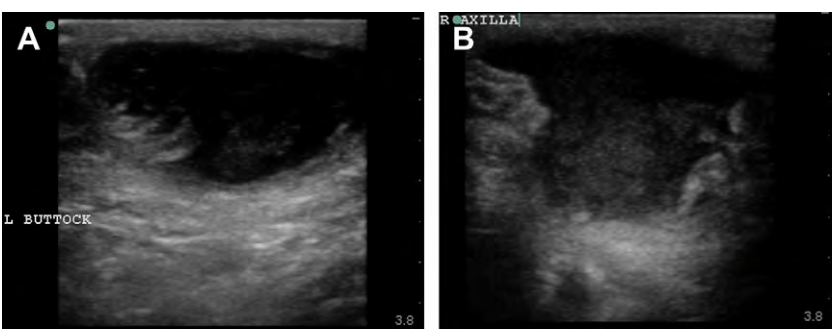

Fig. 34. (*A*) Abscess with well-demarcated borders and posterior acoustic enhancement, with some internal echoes. (*B*) Irregular shaped abscess with mixed echogenic contents.

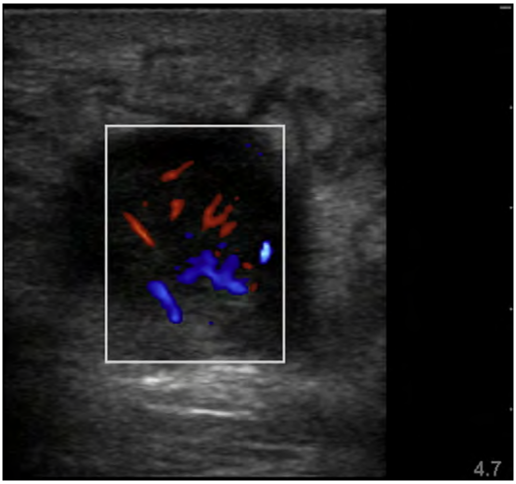

Fig. 35. Evaluated for an abscess, this shows a Doppler flow pattern consistent with adenitis. Also noted are the surrounding cellulitic changes (cobblestoning). An abscess should not have Doppler signal within the cavity.

Pitfalls

- There are no absolute contraindications for performing a soft tissue ultrasound, but care should be taken to ensure appropriate probe sterilization after performance on even a nonpurulent skin lesion.[50]
- Incomplete examination of the area may underestimate the extent of the abscess. Make sure the image has enough depth, and be sure to scan all the way through the lesion and not just in one area.
- Performing a blind incision and drainage procedure carries the inherent risks of injury to unseen adjacent structures, having an unsuccessful procedure because of inadequate localization, or having an unsuccessful procedure because of inadequate assessment of the abscess extent.

ULTRASOUND-GUIDED FOREIGN BODY REMOVAL

Background

Retained subcutaneous foreign bodies are of great concern to emergency physicians because of their ability to serve as a focus for wound infection. A focused evaluation including history and physical examination may not be adequate to rule out a foreign body. Anderson and colleagues[51] reported that 38% of foreign bodies were missed by the treating physician when imaging studies were not obtained.

Radiographs are most useful for detecting glass and metal larger than a few millimeters foreign bodies with sensitivities at greater than 95% when adequate penetration and multiple views are obtained. Radiographs are not useful for the detection of radiolucent objects such as rubber, plastic, and organic matter (wood, thorn, or cactus spines), with sensitivities ranging from 5% to 15%.[51]

The use of ultrasound for the detection of foreign bodies was introduced on 1978.[52] Detection of soft tissue foreign bodies has improved with faster scanners and processing applications. Studies have been performed in various tissue models such as cadavers and chicken thighs, with few small studies performed in humans.[53–55] Reported sensitivity ranges from 43% to 98%, and specificity ranges from 59% to

98%.[53–56] Ultrasound has been able to detect objects as small as 0.5 mm and as deep as 4 mm with improved sensitivity with increasing size of the foreign body.[55,57,58]

Ultrasound Indications

Ultrasound is recommended for the evaluation of radiolucent and radiopaque foreign bodies. Although metal and glass foreign bodies are visible on radiographs, ultrasound can give more precise information and the degree of soft tissue injuries. Ultrasound can determine not only the location of the foreign body but also the size, shape, and orientation. Real-time imaging allows the clinician to image nearby structures, such as blood vessels, that should be avoided during the removal. Surrounding muscle, tendons, ligaments, or neurovascular structures can also be evaluated for injury. Ultrasound reduces procedural time and surgical outcome.[59–61]

Anatomy and Imaging

Most foreign bodies appear echogenic on ultrasound with artifactual changes depending on the type of foreign body.[62] The degree of echogenicity is related to the differences in acoustic impedance at the interface of the foreign body and surrounding tissue. Metal and glass cause a comet tail or reverberation artifact (**Fig. 36**). Gravel has strong posterior shadowing similar to gallstones (**Fig. 37**A). Organic material such as wood, thorn, or plastic appears hyperechoic and may show posterior acoustic shadowing (see **Fig. 37**B). The artifact occurring depends primarily on the surface of the foreign body instead of the composition. Smooth and flat surfaces produce dirty shadowing or reverberation. Objects with irregular surfaces produce clean shadowing.[63] Additionally, organic materials may cause an inflammatory response with developing hemorrhage, edema, and hyperemia leading to a hypoechoic halo (**Fig. 38**). Presence of a hypoechoic halo and use of power Doppler to detect inflammatory changes can aid in foreign body detection.[57,64,65]

Technique

A high-frequency (≥7.5 MHz) linear array transducer is used for evaluation of soft tissue. Very superficial structures may be difficult to visualize because they lie outside the focal zone of the transducer. A standoff pad or water bath can be used to optimize the image by aligning the focal zone of the transducer with the area of interest. Water

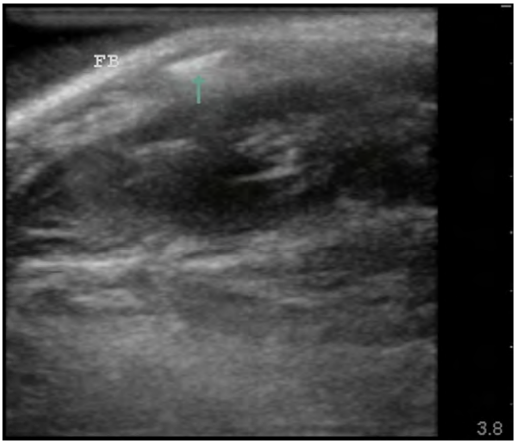

Fig. 36. Glass foreign body (*arrow*) with minimal reverberation artifact.

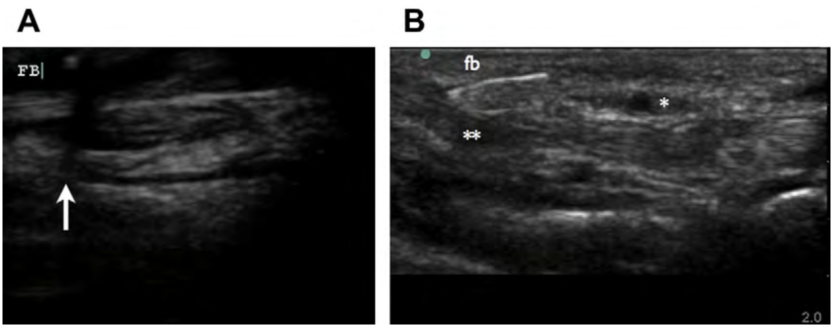

Fig. 37. (*A*) Foreign body (wood) with posterior acoustic shadowing (*arrow*). (*B*) Another wooden foreign body without shadowing. Note position adjacent to tendon (*double asterisk*) and artery (*asterisk*).

baths do not require the use of ultrasound gel and avoid compression of the soft tissue, which minimizes discomfort to the patient.[66]

It is important to scan slowly through that soft tissue as an object can be easily missed because of its similar appearance to the surrounding tissue and potential lack of shadowing. The area of interest should be scanned on both longitudinal and transverse planes. Objects are best viewed when the plane of the transducer beam is perpendicular to the surface of the foreign body. Rotating the transducer so the beam is oblique to the foreign body diminishes the echoes returning to the transducer.

Pitfalls

- Diagnostic pitfalls include misidentification of a structure. False-positive findings have been reported from the presence of calcifications, hematoma, scar tissue, trapped air, or sesamoid bone.[53,54,57] Careful scanning of the length of the object in multiple planes may differentiate a foreign body from artifact or bone.
- Limitations of ultrasound evaluation for soft tissue foreign body is primarily related to sonographer experience.
- Familiarity with ultrasound appearances of foreign bodies and their artifacts is essential.

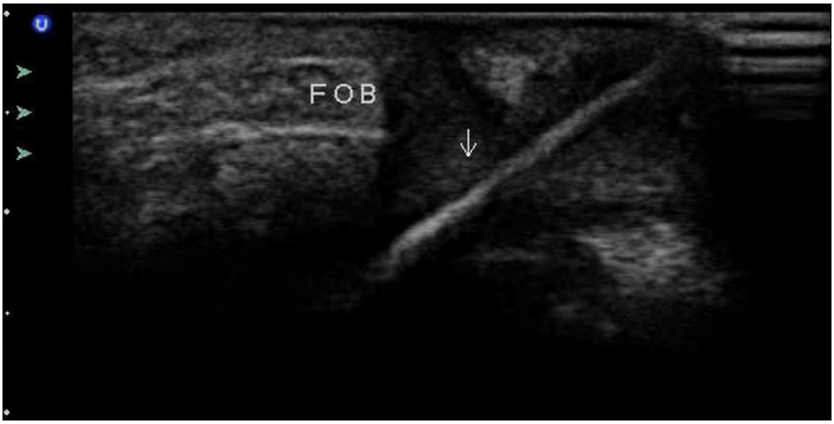

Fig. 38. Retained foreign body with associated abscess.

SUMMARY

Bedside ultrasound can be an effective tool for diagnosis of common conditions such as: ascities, joint, pleural and pericardial effusion. Prompt recognition and treatment of these conditions can be life saving in some cases, but it requires performing procedures that can be challenging. The use of this technology can help physicians identify best placement for needle insertion to improve success rates while decreasing complications. With adequate training and experience, physicians can incorporate this technology to their practice and help improve patient care.

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