CHEST

Better With Ultrasound

Pleural Procedures in Critically Ill Patients

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VIDEO

Procedures designed to drain fluid or air from the pleural spaces can be technically challenging in patients who are critically ill, and are associated with significant complications. Many individual ultrasound techniques have been described, each with the goal of making pleural drainage procedures safer. This article presents a systemic approach for incorporating many of these tools into procedures such as diagnostic thoracentesis, therapeutic drainage, and pleural catheter insertion. A series of illustrative figures and narrated video presentations are included to demonstrate many of the described techniques.

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Procedures designed to drain fluid or air from the pleural spaces are commonly performed in critically ill patients and are associated with significant complications.[1] A series of individual ultrasound techniques have been described, each with the goal of making pleural drainage procedures safer. This article presents a systemic approach for incorporating these tools into common bedside procedures such as diagnostic thoracentesis, therapeutic drainage, and catheter insertion. The recommendations presented in this article are the opinions of the authors, and while they represent reasonable approaches to common problems it is important to note that there are many alternative and equally reasonable methods that may be favored by other providers.

Because of the limited mobility typical of critically ill patients, all techniques will be described on the basis of the supine position rather than the seated position, which is often favored in ambulatory patients. It is sometimes advantageous to rotate the patient slightly to the side opposite the effusion to allow better access to the hemithorax, but this may have the detrimental effect of causing the pleural fluid to shift away from the operator and toward the mediastinum. Pleural effusions will be described as small if they are less than 500 mL, moderate if between 500 and 1000 mL, and large if greater than 1,000 mL, although these cutoffs are not well agreed on.[2] The three commonly used ultrasound transducers will be described as "linear" (sometimes called "vascular," usually in the range of 10 to 12 MHz, most commonly used for insertion of central venous catheters), "phased array" (sometimes called "cardiac," usually in the range of 1 to 5 MHz, most commonly used

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ABBREVIATIONS: CVC = central venous catheter; CXR = chest x-ray; FAST = focused assessment with sonography in trauma

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for cardiac and thoracic ultrasound), and "curvilinear" (sometimes called "abdominal," usually in the range of 2 to 5 MHz, most commonly used for imaging the abdomen) for the sake of brevity and simplicity. To address the frequent discord with respect to the correct orientation of the ultrasound image on screen, this article will remain neutral. Although an indicator dot to the left side of the screen is standard for abdominal applications (radiology convention), some thoracic studies are done with the indicator dot to the right of the screen (cardiology convention) given that thoracic imaging often flows naturally from cardiac ultrasound in critically ill patients. Most providers favor the radiology convention and the authors encourage that practice, but either orientation is acceptable provided that the operator is sure of which direction is cranial and which is caudal.

General Advantages of Ultrasound

Specific to pleural-based procedures, ultrasound guidance has a number of advantages. To begin with, ultrasound detects pleural fluid with greater accuracy than chest radiography (CXR).[3] Although slightly less sensitive than CT scanning,[4] most effusions missed on ultrasound and detected on a CT scan are very small and likely to be clinically irrelevant. Furthermore, CT scanning has several other disadvantages including burden of transport, radiation risk, and inability to characterize dynamic signs within the effusion. Ultrasound can be used to estimate the size of an effusion,[5] as well as whether it is likely to be exudative.[6] It has been well documented to reduce the risk of pneumothorax,[7,8] and can yield a successful result in a large majority of attempts, even after a failed (non-ultrasound-guided) attempt.[9] Training and supervision requirements, although not well studied, appear to be modest.[8]

Complications Associated With Pleural Drainage

The commonly occurring complications associated with pleural-based procedures include the following:

1. *Dry tap*: Dry tap occurs when a pleural effusion is suspected but does not in fact exist, or when the needle is incorrectly placed. It occurs in about 8% of attempts[10] when ultrasound is not used, and is typically related to the poor performance characteristics of both physical examination[11,12] and CXR[13] in detecting pleural fluid.
2. *Subdiaphragmatic insertion*: Subdiaphragmatic needle insertion may result in injury to the diaphragm, liver, or spleen, with significant associated hemorrhage. Again, it is most often related to the poor performance characteristics of physical examination in judging the position of the diaphragm. This phenomenon is particularly common in critically ill patients, who typically have elevated hemidiaphragms due to atelectasis, abdominal distention, and supine positioning. Many dry taps are the result of subdiaphragmatic needle insertion,[9] more common when ultrasound is not used.
3. *Pneumothorax*: Pneumothorax is the most common complication[14] associated with pleural drainage; laceration of the lung parenchyma is usually related to excessive depth of needle insertion or erroneous landmarking. Some postprocedural pleural air collections represent ex-vacuo phenomena due to trapped lung rather than an injury to the lung parenchyma; the relative incidence of this problem appears to be approximately 4.5%.[15]
4. *Laceration of adjacent structures*: The most feared complication of pleural drainage, cardiac laceration, is thankfully rare. This complication, more common with trocar-based techniques, should occur less frequently with the use of Seldinger-based techniques as well as ultrasound.
5. *Intercostal artery laceration*: Intercostal artery laceration, a dangerous complication, can present insidiously and result in massive hemothorax. Classic chest tube insertion with direct digital rib palpation reduces the incidence, but Seldinger-based techniques remain at risk.

Overall Approach

An overall approach to pleural draining procedures is presented below, broken down into nine individual techniques. Choosing the specific techniques that relate to the procedure at hand and applying them in order will provide a reasonable initial approach to ultrasound guidance.

Technique 1: Locate the Diaphragm

This first technique should be performed before every pleural procedure, and is designed to avoid subdiaphragmatic catheter insertion. A systematic approach is essential as errors are more common in urgent situations or where typical anatomic landmarks are disturbed by the presence of pleural fluid, ascites, or in obese patients with cranially displaced hemidiaphragms. Mechanically ventilated patients, somewhat paradoxically, may also have elevated hemidiaphragms due to the significant atelectasis that arises when bedridden. In patients with large-volume ascites, the hemidiaphragm may be markedly elevated, causing the operator to erroneously attribute the hypoechoic space to a pleural effusion. The most straightforward approach to locating the diaphragm involves identification of a distinct and reliable subdiaphragmatic landmark: the kidney. The classic right and left upper quadrant views from the focused assessment with sonography in trauma (FAST) examination[16] are quickly achievable in nearly all patients. Once the kidney has been identified, sliding of the probe cranially to pass through the liver or spleen thereafter identifies the diaphragm. Either a phased-array or curvilinear transducer may be used. On the right side, begin by placing the transducer in the mid-axillary line at the level of the lower ribcage (roughly in line with the xiphoid process), with the indicator pointed to the patient's head (Fig 1A). The first image to be achieved is that of the hepato-renal interface with the diaphragm at the edge of the screen (Fig 1B). Continue sliding the transducer toward the patient's head until the diaphragm is centered on the screen (Fig 1C). At this point the apex of the diaphragm, its most cranial point, should be identified by sweeping through it anteriorly and posteriorly; this point can then be marked on the skin surface with a marker (Fig 1D) to guide the forthcoming pleural drainage procedure. Marking the skin is optional, but some operators find it helpful. The position of the diaphragm should always be marked at end expiration, when it is most cranial in position. When performing the procedure on the patient's left side, the initial transducer position is adjusted to the posterior rather than the anterior axillary line because of the position of the left kidney, which is typically more posterior and often more difficult to locate (Video 1).

Technique 2: Estimate the Size of the Effusion

Estimating the effusion size is essential in nearly all cases to confirm that it is indeed present and of the expected size, thus avoiding a dry or unnecessary tap. It may be omitted in circumstances such as penetrating thoracic trauma, where the diagnosis is obvious and speed is of the essence. In many cases rough "eyeball" estimation will suffice, although some operators prefer a more quantitative measurement.

Beginning with the previously obtained view with the diaphragm in the middle of the screen (Fig 1C), slide the transducer slightly farther toward the patient's head to bring the supradiaphragmatic area and associated pleural effusion to the center of the screen (Fig 2A). The

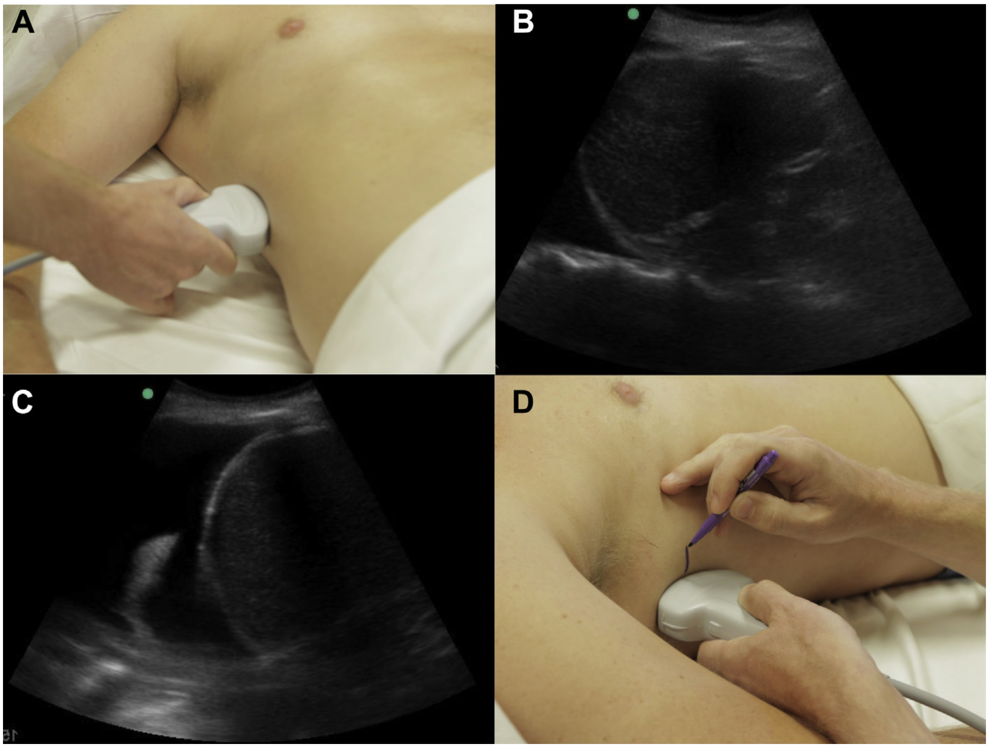

Figure 1 – *Locate the diaphragm. A, Initial transducer position to achieve the FAST view on the right side. B, The right FAST view, showing the kidney, liver, and diaphragm. C, Bringing the diaphragm to the center of the screen. D, Marking the location of the most cranial aspect of the diaphragm with a skin pen, an optional step that some find helpful. FAST = focused assessment with sonography in trauma.*

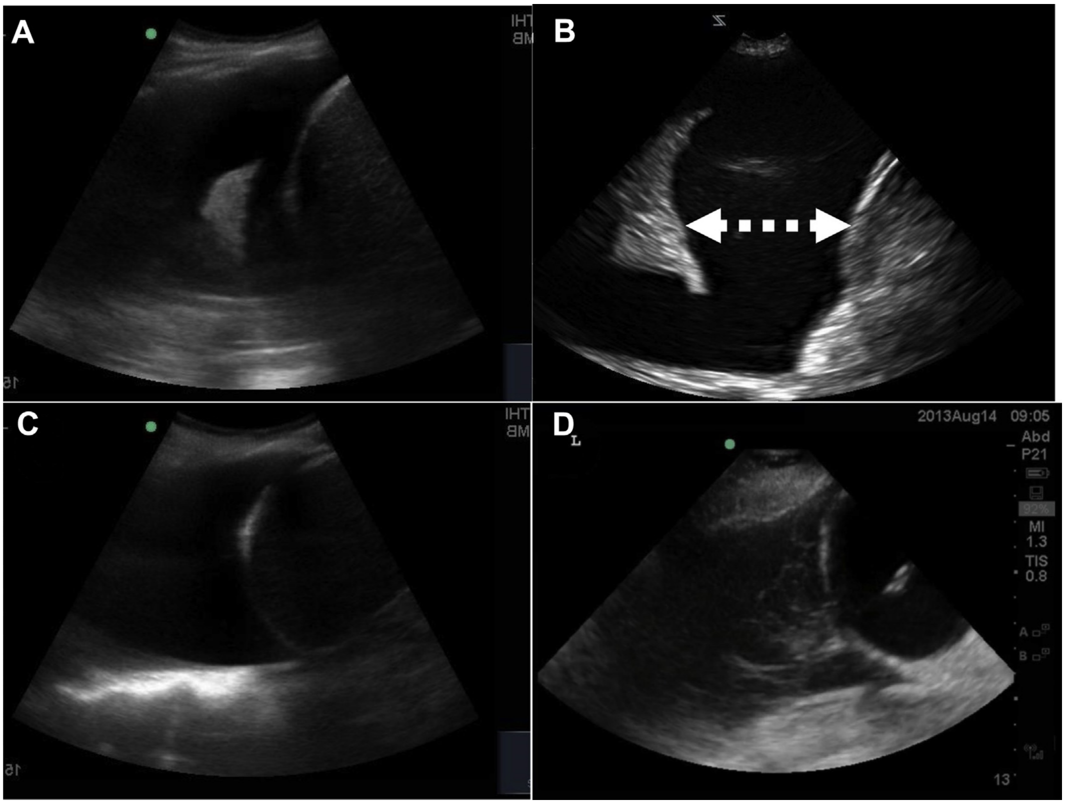

Figure 2 – *Estimate the size of the effusion. A, The pleural effusion well centered on the screen. B, Estimating the size of the effusion by measuring the horizontal distance (dashed arrow) between the most cranial aspect of the diaphragm and the adjacent atelectatic lung. C, A uniformly hypoechoic effusion, which could be either transudative or exudative. D, An effusion with hyperechoic material, definitively exudative.*

effusion, where present, must always be confirmed by the following three-step process:

1. Locate the effusion, a hypoechoic collection immediately above the diaphragm.
2. Identify typical anatomic boundaries including the diaphragm, the chest wall (at the top of the screen), and the adjacent lung (Fig 2A).
3. Visualize at least one of the following dynamic signs:
   a. Diaphragmatic descent with inspiration
   b. Caudal movement of the lung with inspiration
   c. Movement of hyperechoic structures or debris within the hypoechoic effusion, where they exist

The most straightforward manner in which to estimate the size of a pleural collection is to measure the horizontal distance from the most cranial aspect of the diaphragm in the mid-axillary line to the nearest segment of the lung (Fig 2B). This distance, in millimeters, is multiplied by 20 to yield the approximate volume of fluid in milliliters. This technique is described in detail elsewhere,[5] and other techniques exist.[17] Great care must be taken to avoid over- or underestimating the size of the effusion; altering the transducer angle slightly from the horizontal will have a great impact on the distance measured. Angling more anteriorly will underestimate the effusion size, while angling posteriorly will overestimate. Alternatively, many operators do not routinely attempt to quantify effusion size, preferring to focus on clinically relevant questions such as whether the effusion is safe to tap for diagnostic and/or therapeutic purposes. In this case, identification of a path to the fluid collection, unobstructed by the lung or other structures, is the primary concern. As experience accrues, rough estimation of effusion size into small/medium/large categories can be done reliably without measurement. The safety of such an approach, even in mechanically ventilated patients, has been demonstrated.[8]

Next, the ultrasound characteristics of the effusion should be examined. While uniform, hypoechoic effusions (Fig 2C) can be either transudative or exudative; the presence of more hyperechoic material within the effusion indicates an exudative effusion (Fig 2D).[6] Knowing the approximate size of an effusion and whether it is likely to be exudative allows for an informed decision regarding the potential risks and benefits of pleural drainage (Video 2).

Technique 3: Locate the Intercostal Artery

Intercostal arteries vary in position considerably from person to person, and tend to move into a more vulnerable position as one moves more posteriorly along an individual rib.[18] Locating the position of the artery by ultrasound to ensure that it is in a typical protected position can be done quickly in most patients.[19] While this technique is not essential, when time permits it is recommended to reduce the risk of intercostal artery injury. Given that elderly patients are particularly prone to tortuous intercostal arteries,[20] this population should be given special attention.

Begin by placing the linear transducer at the point where the drainage procedure will occur; the classic "triangle of safety"[21] should be kept in mind and adhered to, unless information derived by an experienced operator using ultrasound allows for a location outside the triangle to be selected. The transducer should be oriented perpendicularly to the ribs. Transducer and screen marker orientation are variable and depend on operator and institutional preference. In the examples used for this article (Fig 3 and Video 3) the transducer indicator is pointed to the patient's feet and the screen marker is positioned on the right side of the screen. Many institutions use the opposite convention; either is acceptable so long as the user is clear on which direction on the ultrasound screen is cranial and which is caudal.

The superiorly located rib is identified as a circular echo-poor structure that casts a posterior shadow (Fig 3B). Depth should be adjusted such that the rib itself occupies nearly the entirety of the screen, typically 2 cm in the average-sized patient. Next, the artery itself should be located with the help of color Doppler. A color Doppler box is positioned at the inferior margin of the rib, and the pulse repetition frequency is lowered to the point where pulsatile blood flow within the artery is detectable (Fig 3C). Finally, the position of the artery at the proposed point of pleural drainage is noted and judged for safety. An intercostal artery that is tucked directly under the rib notch is safest, followed by arteries that are located very close to the rib. Where arteries deviate toward the middle of the intercostal space they are at increased risk of laceration, and a new procedural site should be considered (Fig 3D).

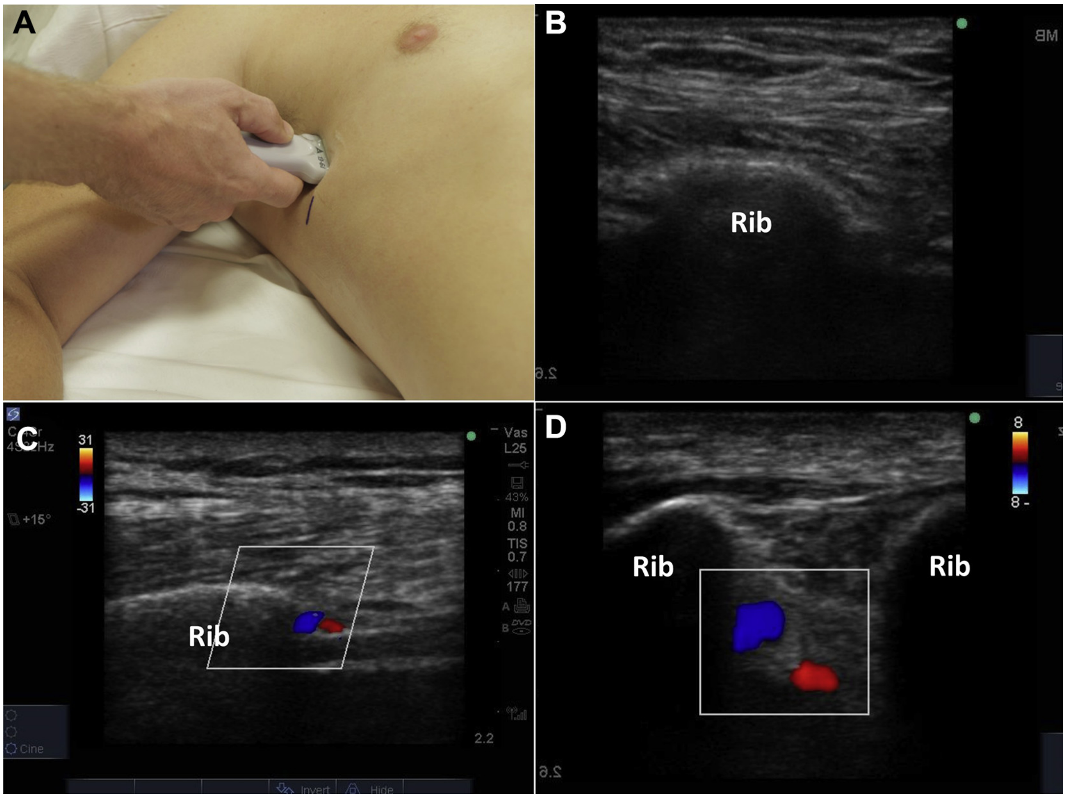

Figure 3 – *Locate the intercostal artery. A, Correct transducer position required to locate the intercostal artery (IA). In this example the transducer indicator is pointing to the patient's feet. B, The initial view with the rib centered on the screen. Note that with the transducer in this orientation, the patient's head is to the left of the screen. C, Finding the IA with color Doppler; here the artery is in a safe position, tucked right to the underside of the rib. D, An IA in a more dangerous position, away from the rib notch and into the middle of the intercostal space.*

Technique 4: Measure Minimal and Maximal Distances

The structure most likely to be injured by a pleural drainage procedure is the lung. To reduce the incidence of lung injury, the size of the effusion may be estimated, as described above. In addition, the anticipated point of needle entry and its likely trajectory should be carefully mapped, with particular attention paid to two particular distances (Fig 4). First, the depth of penetration required to reach the pleural fluid serves as a safety check; when pleural fluid is not obtained at the expected distance the angle of needle insertion should be reconsidered. Second, the depth required to reach the atelectatic lung should be measured and never exceeded. This is especially important for attempts at draining smaller effusions, and for patients who are obese or edematous (Video 4).

Technique 5: Perform an Ultrasound-Assisted Pleural Drainage

The term "ultrasound-assisted" describes a technique where ultrasound is used initially to gather information, but the actual procedure itself is performed without real-time ultrasound guidance. This is analogous to using ultrasound to identify the position of the jugular vein and marking that location on the skin, but subsequently performing the central venous catheter (CVC) insertion by a landmark-based technique.

For the majority of pleural procedures an ultrasound-assisted technique is preferred,[22] as (real-time) ultrasound-guided techniques have several important disadvantages. The requirement to hold an ultrasound transducer adds a level of complexity and robs the operator of the ability to freely use the off-hand to feel the rib margin and guide the needle over it. The added effort and complexity is rarely justified as moderate or large effusions are easy to access provided the preprocedure scan is done correctly. The needle is often difficult to identify in real time, and just like in CVC insertion the needle tip and mid-point appear identical. Most importantly, the focus on real-time needle guidance can be distracting; the needle may be inserted to an excessive depth as the operator is focused on the ultrasound screen, or an intercostal artery may be lacerated as the operator fails to focus on the position of the needle relative to the intercostal space. It is generally preferable, therefore, to focus on an accurate preprocedure ultrasound assessment and then concentrate on needle depth and avoidance of the intercostal artery during the procedure itself.

With the most caudal aspect of the diaphragm marked (technique 1), an adequate-sized effusion identified (technique 2), and an appropriate intercostal space located (technique 3), the operator should measure the distance required to enter into the pleural fluid (minimal distance) and the distance required to reach the lung or heart (maximal distance; see technique 4). The ultrasound transducer should then be set aside. Once the sterile field has been prepared and local anesthetic administered the needle is inserted without direct ultrasound guidance, with a focus on maintaining close contact with the superior margin of the inferior rib to avoid intercostal artery laceration while carefully controlling needle depth. Digital palpation of the ribs and intercostal space during needle advancement is also important in achieving these goals.

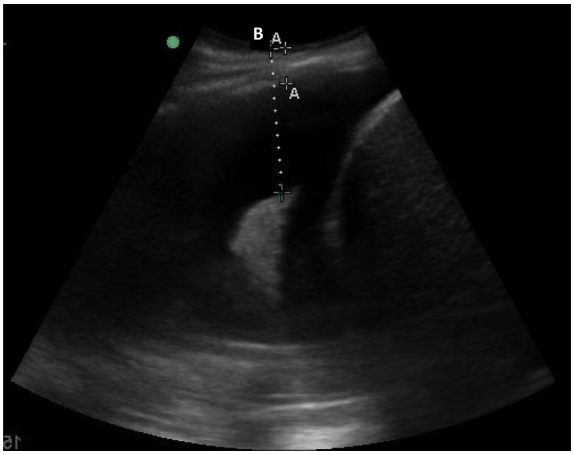

Figure 4 – *Measure minimal and maximal distances. Distance "A" represents the minimal distance required to reach the pleural fluid, and distance "B" represents the distance required to strike the lung.*

Technique 6: Perform an Ultrasound-Guided Pleural Drainage

In certain rare circumstances, it may be preferable to perform needle insertion under real-time ultrasound guidance. The main indication here is typically sampling of a small pleural effusion for diagnostic purposes, as therapeutic drainage of such small effusions typically does not yield significant benefit to the patient.[23] The smallest effusion size that can be safely sampled is not known, and depends on patient factors as well as operator skill and experience. It has been recommended that fluid pockets less than 15 mm in minimal diameter are not safe to sample,[24] but this cutoff is arbitrary. Some sources also recommend that the effusion be visible in at least one intercostal space above and below the intended procedure site, at a minimum.[25]

As discussed above, real-time needle guidance is discouraged in most cases. It should be considered an advanced technique and reserved for operators who are comfortable with chest drainage, pleural ultrasound techniques in general, and dynamic needle guidance specifically.

For real-time ultrasound guidance the procedure should unfold exactly as described above (technique 5) until the point of needle insertion. Here, either a linear (for thin patients) or phased-array (for larger patients) transducer may be used, but it must be appreciated that tracking a needle in real time with the lower frequency phased-array transducer can be quite difficult. The priority, as with blind techniques, is to avoid the intercostal artery and control the depth of insertion. The needle should be inserted in a position so as to strike the rib inferior to the desired intercostal space. The ultrasound transducer is then brought into contact with the skin just above the needle, and angled inferiorly in such a manner as to locate the needle tip (Fig 5). The needle can then be redirected slightly more superiorly in order to slip over the superior surface of the rib and toward the effusion, with the goal of keeping the needle in contact with the rib in order to avoid the neurovascular bundle. In slipping over the rib it is important not to point the needle cranially, however, as this can cause it to be advanced toward the bundle. Needle trajectory should be confirmed by ultrasound, ensuring that the pleural fluid will be reached at the expected depth and other structures will be avoided. Finally, the needle can be advanced slowly under direct visualization.

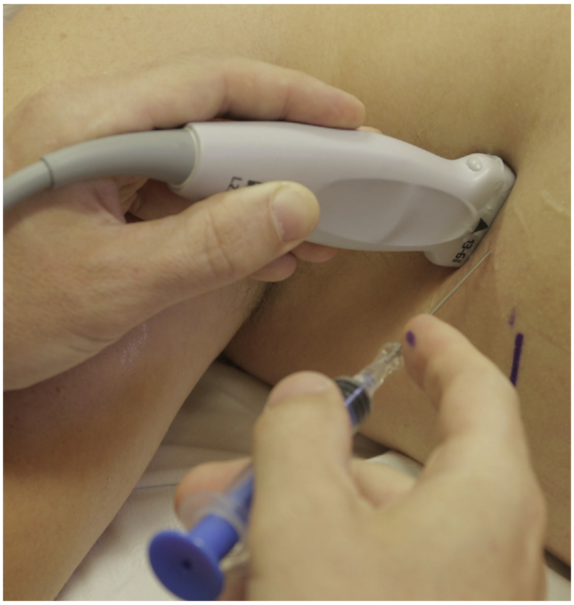

Figure 5 – *Perform ultrasound-guided pleural drainage. The needle is inserted over the rib margin, with the transducer in position to follow the needle trajectory.*

As in CVC insertion, depth control is paramount. Because the mid-portion and tip of the needle look identical on ultrasound, and because the ultrasound screen is very distracting, it is common to lose control of needle depth.[26] Minimum and maximum depths, as measured by technique 4, must be carefully adhered to. The needle should be advanced by a creeping technique:

1. Check the needle depth by manual inspection, looking directly at the needle as it enters the skin.
2. Check the needle depth by ultrasound, sweeping the probe along its length and identifying the needle tip. To be sure of the location of the tip it is necessary to move the plane of the ultrasound beam past the tip, and then to sweep back toward it. The first bright structure encountered can then be confirmed to be the needle tip, a process that can be aided by jiggling the needle slightly to identify needle movement.
3. Check the needle trajectory, ensuring that it is on course to intersect the intended target.
4. If steps 1 through 3 are favorable, advance the needle a few millimeters.
5. Repeat the process until the pleural fluid collection is reached.

Technique 7: Check the Position of the Wire Prior to Dilating

For Seldinger-based techniques such as pigtail catheter insertion, the position of the guidewire should be confirmed by ultrasound prior to proceeding with dilation. The guidewire will be seen as a hyperechoic linear structure within the hypoechoic effusion (Fig 6), and can be traced from the insertion point at the skin surface to the center of the effusion. This technique is analogous to CVC insertion where the position of the guidewire is confirmed within the vein prior to dilating. The optimal transducer to use for this purpose will depend on operator experience and patient size; many operators are most comfortable locating guidewires with the linear transducer (as in CVC insertion), but this may be difficult in larger patients. Where greater depth of penetration is sought, the phased-array transducer may be preferred.

Technique 8: Rule Out a Postprocedure Pneumothorax

With respect to the diagnosis of a pneumothorax, lung sliding is a straightforward and commonly used

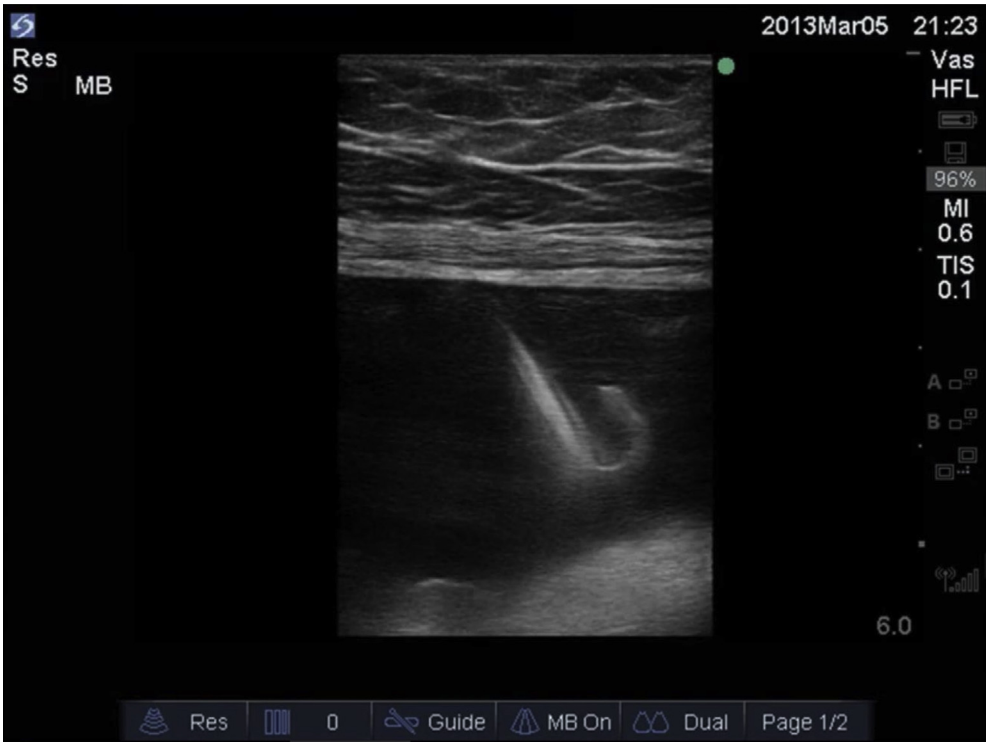

Figure 6 – *Check the position of the wire prior to dilating. Here the wire is seen safely within the hypoechoic effusion, and the operator may proceed to dilation.*

ultrasound sign that is well described elsewhere[27]; the presence of lung sliding rules out pneumothorax at that particular point with 100% sensitivity (see Video 3 at time index 1:30 for an example of lung sliding). As such, it is recommended that the ipsilateral side be checked for the presence of lung sliding at the level of the second intercostal space in the mid-clavicular line while the patient is supine both before and after all procedures. If lung sliding (or other equivalent sign such as lung pulse or visible B-lines) is present on the postprocedure scan, then the procedure has not been complicated by a pneumothorax. While CXR is widely used after thoracentesis to exclude postprocedural pneumothorax, lung ultrasound has been shown to be superior[28] and thus is preferred at some centers.

Some patients, especially those with pleural pathology, do not have lung sliding even in the absence of a pneumothorax. Such patients typically have adherence of the visceral and parietal pleural surfaces due to inflammation, and thus the pleura is not free to "slide." As such, it is recommended that lung sliding be checked preprocedure; if it is absent then this technique will not be useful to exclude a postprocedure pneumothorax and should be omitted, usually in favor of a CXR.

Technique 9: Use of Ultrasound When Draining a Pneumothorax

When the decision to drain a pneumothorax has been made, ultrasound can help make the procedure safer. Where time permits, locating the diaphragm (technique 1) will reduce the risk of catheter malposition. Otherwise, the remainder of the techniques described above typically do not apply.

Beyond lung sliding (described above), a second sign, the lung point, is useful to rule-in a pneumothorax by locating the point where the visceral and parietal layers of the pleura are driven apart by air; it is described in detail elsewhere.[29] Where a lung point is found, it can be of use in estimating the size of a pneumothorax, with a more posterior lung point indicating a larger pneumothorax.[30] Furthermore, a pneumothorax can be shown to be increasing in size if the lung point is found to be moving posteriorly over time.[30] An example of a lung point can be seen in Video 5.

Use of lung sliding and the lung point can be combined in interesting ways. When a percutaneous procedure such as pigtail insertion is being contemplated to drain a pneumothorax, the two signs can serve as a safety check. The site of catheter insertion should be at the level of an intercostal space where lung sliding is absent, indicating that the two pleural layers are indeed separated by air. If lung sliding is present it means that the two pleural layers are in direct opposition, and thus that there is no pneumothorax at that point; here the pigtail should be inserted more anteriorly or the diagnosis of pneumothorax reconsidered. If a lung point can be found it indicates the exact point where the pneumothorax starts; therefore drainage should occur anteriorly to this point in a supine patient. To summarize, the site selected for pneumothorax drainage should be (1) above the diaphragm, (2) anterior and superior (cranial) to the lung point, and (3) at the level of an intercostal space where lung sliding is absent.

Locating the intercostal artery (technique 3) may be useful here, when time permits. With respect to ultrasound-guided vs ultrasound-assisted techniques, drainage of pneumothorax should be done by an ultrasound-assisted technique only, as the presence of air in the pleural space interferes with direct needle visualization.

Conclusion

Specific ultrasound techniques are available to help with respect to the diagnosis and management of pleural effusions and pneumothoraces. By applying these techniques in a stepwise fashion, as shown in Video 6 and as described in this article, the process of pleural drainage may be made more effective and safer.

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Additional information: The Videos can be found in the Supplemental Materials section of the online article.

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