My patient is short of breath: is there pleural fluid, and will PoCUS help drain it safely?

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Abstract

Pathological pleural fluid is common in patients presenting to the emergency department, occurring in as many as 17% of patients presenting with shortness of breath, and as many as 20% of patients with blunt thoracic trauma. A typical chest X-ray may fail to identify as much as 175 mL of pleural fluid in the erect position, and as much as 500 mL in the supine position. Point-of-care ultrasound (PoCUS) on the other hand can detect as little as 20 mL of pleural fluid, and has consistently been shown to have sensitivities and specificities for the detection of pleural fluid close to 100% in both the trauma and critically ill populations. In addition, ultrasound identifies pleural fluid more rapidly than chest X-ray. PoCUS can be used to guide thoracentesis, resulting in improved success rates with decreased complications. Here we describe the evidence supporting the use of PoCUS in the management of pleural fluid collections.

Keywords: Point of Care Ultrasound, PoCUS, Pleural Fluid, Needle guidance, Thoracentesis, Emergency Medicine

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Clinical questions

In patients presenting with shortness of breath, can I use point-of-care ultrasound (PoCUS) to identify pleural fluid and does it provide any advantage over chest X-ray (CXR)? Once detected, should I use PoCUS to guide thoracentesis?

Introduction

In healthy individuals, there is less than 10 mL of fluid in the pleural cavity, functioning as a lubricant between the visceral and parietal pleura.[1] Abnormal accumulation of fluid may result from a variety of disease processes, including malignancy, heart failure, pneumonia, empyema and traumatic bleeding. Excessive fluid in the pleural space can lead to reduced lung volume, abnormalities in oxygenation or ventilation, and act as a nidus for infection.

Pleural effusions are common in patients presenting with respiratory symptoms. In one study of 880 patients presenting to emergency departments (ED) in North America and Europe, with a chief complaint of shortness of breath, 17% were found to have pleural effusions.[2] As many as 62% of patients requiring admission to medical intensive care unit (ICU) have pleural effusions,[3] while 10–20%[4–10] of thoracic trauma patients have a haemothorax.

The presence of pleural fluid has traditionally been diagnosed through physical examination and CXR. Classical physical examination findings of pleural fluid – asymmetric chest expansion, dullness to percussion and diminished breath sounds – have extremely poor sensitivities and specificities for the diagnosis of pleural fluid and should not be relied on for diagnosis.[11,12] In addition, it can be extremely difficult to elicit these physical examination findings in critically ill or trauma patients.

Although CXR is the most commonly used modality to detect pleural effusion, it is only able to detect relatively large effusions. Studies have shown that approximately 175 mL of fluid is required to cause blunting of the costophrenic angles in an erect CXR, and sometimes as much as 500 mL.[13] Supine CXR, used in critically ill and trauma patients, is even poorer at detecting pleural effusions: able to detect 175–525 mL of pleural fluid.[14] The sensitivity and specificity of CXR for pleural fluid diagnosis is relatively poor. In ICU patients with coexisting lung pathology (which represents the majority of critically ill patients),

Figure 1 Probe position for pleural fluid detection in the supine patient

supine CXRs have a sensitivity of 39% and specificity of 85% for detection of pleural fluid.[14] Placing patients in the lateral decubitus position improves detection of pleural fluid.[15,16] However, this is often impractical in the critically ill patient. In thoracic trauma patients, the sensitivity and specificity of supine CXR is better, with sensitivities of 92–96% and specificities nearing 100%.[4,5]

The significance of pleural fluid to the patient's presentation is not always clear, and so early detection of pleural fluid is important to guide the decision to drain, either for diagnostic or therapeutic purposes.

Case example #1

A 25-year-old man presents following a high speed motor vehicle collision, in which he was the belted driver. He is brought into the ED by ambulance, supine, with cervical spine immobilization. He is haemodynamically stable and complaining of shortness of breath. After primary and secondary surveys are performed, as outlined by advanced trauma life support protocol,[17] ultrasound is used to examine the lungs, and determines the presence of a large fluid collection in the right chest. Based on this finding, a chest tube is placed; 1 L of blood is quickly drained, with resolution of the patient's symptoms. As the chest tube is being secured, the X-ray technician arrives with the portable X-ray machine to perform the X-ray that was called for on arrival of the patient.

Case example #2

A 70-year-old woman with a long smoking history presents to the emergency department complaining of a gradual onset of shortness of breath. Investigations show only a small pleural effusion on CXR. Suspecting that this is a malignant effusion, ultrasound-guided thoracentesis is performed. A sample is obtained without complication and sent for analysis.

Evidence

The use of ultrasound for the detection of pleural fluid was first described in 1967.[18] Since that time, ultrasound has been shown to be extremely sensitive for the detection of pleural fluid, with the ability to detect as little as 20 mL.[7,19,20]

The clinical sensitivity and specificity of PoCUS for the detection of pleural fluid has also been demonstrated. In the thoracic trauma population, PoCUS has consistently been shown to have a sensitivity between 92% and 100% and a specificity nearing 100% for haemothorax.[4–10] In the ICU population, PoCUS has demonstrated a sensitivity of 92% and specificity of 93% for the detection of pleural fluid,[14] even in the presence of severe pulmonary pathology.

In addition to an excellent sensitivity and specificity for detection of pleural fluid, PoCUS drastically reduces the time to clinical diagnosis when compared with CXR. In the trauma population, PoCUS has been shown to provide a diagnosis of haemothorax within one minute compared with 15 minutes by CXR.[4,6] The clinical impact of the use of PoCUS for the detection of pleural fluid is unclear, however, as it has not been studied in any clinical trials to date.

PoCUS can also aid thoracentesis. Use of PoCUS has been shown to increase the success of thoracentesis, while simultaneously decreasing the complication rate.[21–23] In a small randomized control trial with 52 patients, the failure rate in clinically-guided thoracentesis was 33% compared with 0% with ultrasound guidance.[21] Two large retrospective cohort studies with 342 and 523 patients showed that ultrasound guidance reduced the rate of pneumothorax from thoracentesis by more than half (from 18% to 3%, and from 10.3% to 4.9% respectively).[22,23] The benefits of ultrasound guidance for thoracentesis have led the British Thoracic Society to recommend the routine use of ultrasound guidance for thoracentesis.[24]

Image generation – how to get the right image

Probe selection and machine settings

When image interpretation requires deep image penetration, a phased array (cardiac) transducer or a low frequency (3–5 MHz) curvilinear (abdominal) transducer is preferable. For superficial effusions, a linear (vascular) transducer with higher frequency (5–10 MHz) is used. The machine can be set to abdominal pre-sets.

Patient position, surface anatomy and key landmarks

The examination may be done with the patient in the supine or erect positions, as determined by the clinical scenario. The transducer should be placed in the most dependent area, as that is where fluid will collect – inferior chest if the patient is in an erect position, and posterolaterally in the supine patient (Figure 1). Optimizing patient position enhances procedural success. Elective thoracentesis is often performed with the patient in the erect position, leaning forward, with arms crossed in front. This allows the effusion to collect at the lung bases. The ultrasound probe can then be placed on the back in the posterior axillary line to image the best location for drainage. Critically ill patients

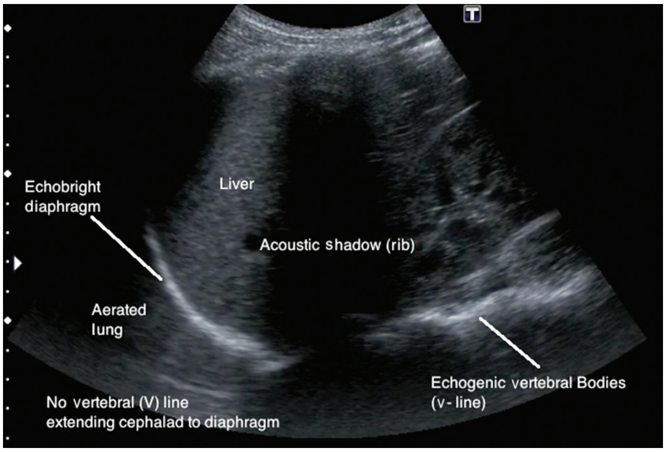

Figure 2 Identification of the diaphragm in relation to the liver. The diaphragm is found immediately superior to the liver on the right side and the spleen on the left side

are often required to remain in the supine position. A moderate effusion can still be well visualized by scanning the lateral chest wall at the posterior axillary line. The head of the bed may need to be raised, if possible, to visualize smaller effusions. Elevating the patient's arm over the head increases the distance between ribs, helping to improve image generation. Where this is not practical the ipsilateral arm can be pulled across the chest to the opposite side.

Greatest success is achieved when the transducer is placed immediately superior to the diaphragm.[25] The diaphragm is generally found at the level of the xiphoid process, and is perhaps most easily identified by its close relationship with the spleen and liver. The diaphragm is immediately superior to the spleen or liver and can easily be found using these organs as landmarks (Figure 2).

While effusions can be found at any level of the pleural cavity, the diaphragm is the best starting point to search for pleural fluid. One can examine more superior aspects of the pleural cavity for fluid using the pleural line as the landmark. When looking for pleural fluid, the most dependent areas of the chest are scanned as this is where fluid will collect, in contrast to pneumothorax, where the opposite is the case.

Image interpretation – is there fluid in the pleural cavity?

In the normal individual, air in the lung parenchyma scatters the ultrasound beam, creating a very indistinct image (Figure 2). The diaphragm appears brightly echogenic on expiration, as it lies directly adjacent to air filled lung parenchyma, causing scattered reflection, and will disappear during inspiration as aerated lung moves to lie between it and the probe. This loss of image during inspiration is known as the lung curtain (see Supplementary Video 1).

When pleural fluid is present, an anechoic (dark) area is seen superior to the diaphragm (Figure 3 and Supplementary Video 2). In areas where the diaphragm is not present, the fluid is seen between the pleural line and lung parenchyma (Figure 4, described in more detail with discussion of the quad sign later in the text).

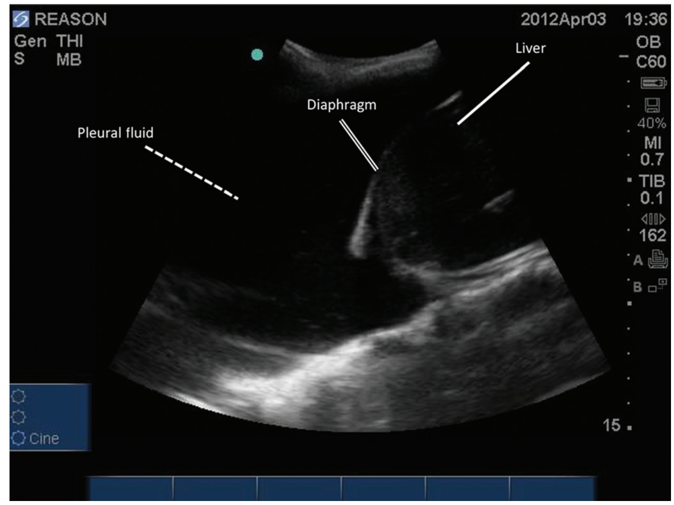

Figure 3 Pleural effusion seen as anechoic fluid (dashed line) superior to diaphragm. Note the location of the liver (solid white line), which is an easy landmark for the identification of the diaphragm (double line)

Pleural fluid greatly improves visualization of the diaphragm, which can be almost entirely seen in larger effusions. The diaphragm will however appear less echogenic, when anechoic pleural fluid is present. As pleural fluid will transmit echoes to the posterior wall of the thorax, these structures, including the vertebrae, will be visualized cephalad to the diaphragm. This is known as the vertebral (V) line, and helps distinguish pleural fluid from the loss of image, or dark lung curtain, seen with normal aerated lung (see Figure 5).[25]

Pleural fluid, especially when exudative, may be echoic, and can be mistaken for lung parenchyma. Therefore, two other signs have been described to help detect pleural fluid more accurately – the quad sign and the sinusoid sign.[25]

The quad sign refers to the visualization of an effusion between four regular borders – the pleural line, two rib shadows and the lung line (Figure 4).[26]

There are occasions where pleural thickening may appear hypoechoic and resemble a small pleural effusion. The sinusoidal sign may be useful to distinguish between this and fluid. The sinusoid sign is seen in M-mode and demonstrates the movement of lung parenchyma in and out of the effusion during respiration – towards the periphery in inspiration and *vice versa* in expiration. This gives the appearance of a sinusoidal wave as the lung parenchyma moves closer and farther away from the pleural line.[26]

Factors that hinder interpretation

Interpretation of PoCUS for pleural fluid can be hindered in the presence of alveolar consolidation, or rib shadows, which can give the appearance of fluid.[27]

Thoracentesis

PoCUS can guide thoracentesis once pleural fluid is found. Once pleural fluid is identified, the largest pocket of fluid should be found, and its depth noted (the British Thoracic Society recommends thoracentesis occur only when fluid

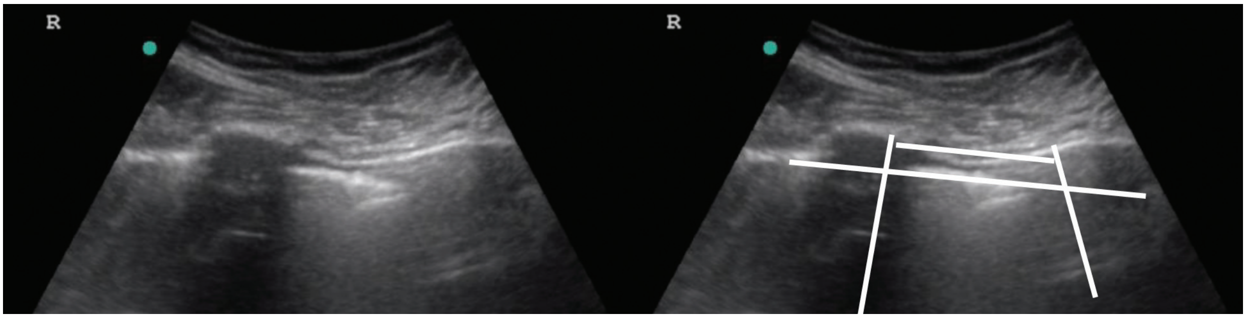

Figure 4 The quad sign. An anechoic pocket of fluid is seen contained between four borders – two rib shadows (vertical lines), the pleural line (short horizontal line) and the lung line (long horizontal line). Note that the fluid is seen deep to the plural line and superficial to the lung

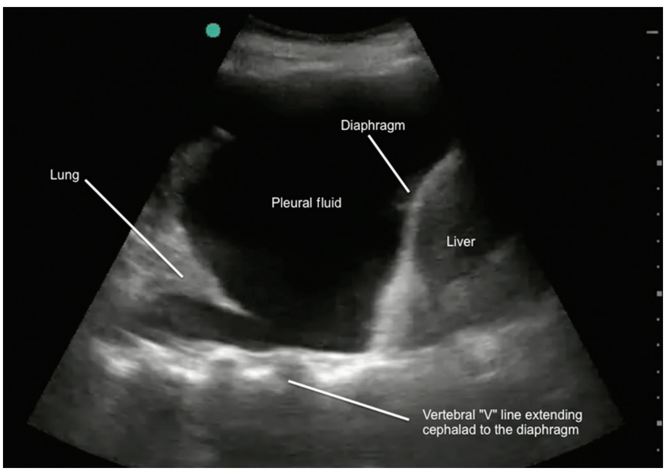

Figure 5 Visualization of the vertebral shadow above (cephalad) to the diaphragm, known as the vertebral (V) line, is indicative of pleural fluid

pockets greater than 10 mm are seen).[24] An ultrasound-guided thoracentesis may then proceed using a static or dynamic technique.

In the static technique, the effusion is identified using a curvilinear or phased array probe, a mark is placed on the skin over the location of the deepest area of fluid, away from the diaphragm and organs, with thoracentesis then proceeding in the usual way. The depth of the fluid is also noted and guides the depth of needle insertion. If the static technique is used, care should be taken to conduct the thoracentesis in the same position as the PoCUS was obtained, as movement of the patient will shift the fluid. There is evidence showing that the static technique may not decrease complication risk significantly compared with a blind approach when the scan is not performed at the bedside,[28] likely due to fluid shifts between the time of marking and aspiration.

The dynamic technique uses realtime ultrasound guidance. Once the patient is prepared for thoracentesis in the usual way, and the deepest area of fluid is marked as described above, a linear ultrasound probe is selected, covered with a sterile cover and the needle is then inserted under ultrasound visualization, either in or out of plane, and aspiration occurs in the usual way. For the in-plane approach (Figure 6a), the needle enters the skin at the side of the probe and traverses the ultrasound beam. This technique provides a larger needle artefact, which is easier to

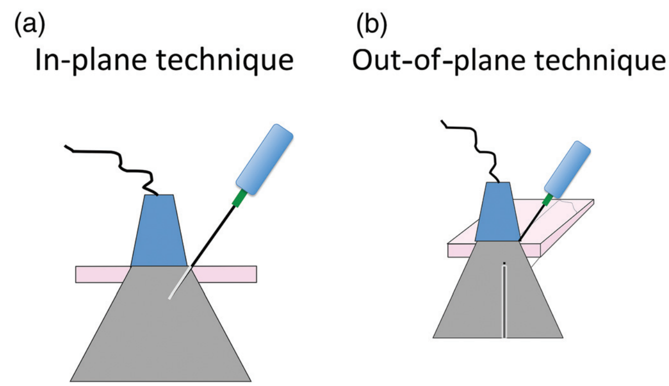

Figure 6 (a, b) The in-plane and out-of-plane techniques of ultrasound needle guidance

track. In areas where there are many confined structures, such as in the neck, it may be more difficult to see structures behind the needle. This is not a problem when performing thoracentesis. For the out-of-plane approach (Figure 6b) the needle enters the skin away from the probe and is aimed at the ultrasound beam. The needle tip intersects the ultrasound beam, which is already located over the optimal side for drainage. This is a technically more difficult manoeuver due to the reduced visual of the small needle tip.

Conclusion

PoCUS is a fast and sensitive modality for the detection of pleural fluid. The literature shows that compared with CXR, PoCUS can provide a diagnosis of pleural effusion faster, and with a superior sensitivity and specificity.

Once pleural effusion is found, PoCUS can also help to ensure the successful and safe performance of thoracentesis. The complication rate of thoracentesis performed under ultrasound guidance is less than half of that using the blind technique.

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Appendix

Supplementary Video 1 Ultrasound image of normal diaphragm and lung during respiration

http://dl.dropbox.com/u/21386908/Webvideos/Video%20clip%201%20normal%20lung.mov

Supplementary Video 2 Pleural effusion seen as anechoic fluid (dashed line) superior to diaphragm. Note the location of the liver (solid white line), which is an easy landmark for the identification of the diaphragm

http://dl.dropbox.com/u/21386908/Webvideos/Video%20clip%202.%20pleural%20effusion.mp4