# A Comprehensive Review on the Advancements and Applications of Point-of-Care Ultrasound in Lung Disease.

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## Abstract

In the past, it was believed that ultrasound assessment of the lungs was not possible due to the presence of air, which hindered the visualization of the lung tissue. However, over time, various artifacts generated by ultrasound interactions with different structures within the chest, including tissues, air, and fluid, have been studied and increasingly utilized to evaluate and comprehend pulmonary diseases. The objective of this review article is to assess the effectiveness of point-of-care ultrasound (POCUS) in patients with lung disease. POCUS has emerged as a valuable tool in managing patients with lung disease. It enables real-time visualization of lung structures, evaluation of lung pathology, and guidance for various procedures. POCUS has demonstrated promise in diagnosing and monitoring conditions like pneumonia, pleural effusion, and pneumothorax. Furthermore, it has been utilized to assist in interventions such as thoracentesis and chest tube placement, resulting in improved patient outcomes. This review article offers a comprehensive overview of the current evidence regarding the use of POCUS in patients with lung disease. It emphasizes the potential advantages of POCUS in enhancing diagnostic accuracy, facilitating timely interventions, and reducing the necessity for more invasive procedures. The findings of this review article contribute to the expanding body of literature supporting the integration of POCUS into routine clinical practice for patients with lung disease.

**Keywords:** Lung air artifacts, lung pathology, critically ill patients, lung ultrasound scan, point-of-care-ultrasound

## Introduction

The management of critically ill patients necessitates the utilization of imaging techniques to optimize appropriate clinical decisions. In recent years, lung ultrasound has become an integral component of the daily examination conducted by physicians in intensive care units, sub-intensive care units, and general medical wards. The availability of hand-held ultrasound machines in wards where they were previously unavailable has facilitated the widespread use of ultrasound, both for clinical examination and as a guide for procedures **(Longhitano Y, et al. 2023).** Point-of-care ultrasound (POCUS) refers to the utilization of portable ultrasonography at the patient's bedside, allowing for immediate performance and interpretation **(Moore CL AND Copel JA. 2011)**.

Over the past few years, point- of-care ultrasound has been rapidly integrated into clinical practice and is expected to continue expanding its role in medicine in the coming decades. Studies have demonstrated that point-of-care ultrasound enhances the safety of procedures, expedites diagnoses, and increases confidence in clinical decision- making. Furthermore, point-of-care ultrasound is one of the few technologies that brings healthcare providers closer to patients, enabling them to be present at the bedside. This proximity enhances the satisfaction of both providers and patients **(Arntfield, et al. 2015).**

The use of sonographic evaluation of the thorax has become more common in everyday medical practice. In the past, the lungs were thought to be unsuitable for ultrasound assessment because of the presence of air, which made it difficult to see the parenchyma. However, researchers have now studied and utilized various artifacts produced by ultrasound interactions with thoracic structures such as tissues, air, and fluid. These artifacts are increasingly being used to assess and comprehend pulmonary pathologies **(Gargani L .2019).**

Numerous studies have provided evidence of the diagnostic accuracy of POCUS in different lung diseases. For example, POCUS has demonstrated a high level of sensitivity and specificity in detecting pneumonia, especially in children. In a study conducted by Pereda et al. (2015) **(Pereda, et al., 2015)**, POCUS successfully identified lung consolidations with a sensitivity of 94% and a specificity of 96% in children suspected of having pneumonia. Similarly, POCUS has proven to be effective in diagnosing pneumothorax, with a sensitivity ranging from 86% to 98% and a specificity of 99%.

POCUS plays a crucial role in the diagnosis and monitoring of pleural effusions, which occur when fluid accumulates in the pleural space due to various factors such as infection, cancer, or heart failure. By enabling clinicians to visualize and measure the size of the effusion, POCUS assists in making informed decisions regarding drainage or further intervention. Multiple studies have confirmed the accuracy and reliability of POCUS in detecting pleural effusions, establishing it as a valuable tool in the management of these patients **(L. Demi, T. Egan, and M. Muller 2020) ( Ding et al., 2019)**

Moreover, POCUS has demonstrated its value in evaluating lung consolidation, which refers to the solidification of lung tissue caused by conditions like pneumonia or atelectasis. By providing real-time visualization of lung consolidation, POCUS aids in identifying the affected area and guiding clinicians in selecting appropriate treatment options. Research has consistently shown that POCUS exhibits high sensitivity and specificity in detecting lung consolidation, making it a valuable tool for early diagnosis and monitoring of these conditions **(Ye et al., 2020)**

### The characteristics of the lungs in ultrasound physics

LUS utilizes a pulse-echo principle to create images of the lungs. In this process, an acoustic pulse is emitted from a transducer and directed towards the lung tissue. The transducer then receives the reflected echoes, which are subsequently processed to generate a diagnosable image **(Ye Q, Zhou J and Wu H. 2020).** The visual characteristics of LU are determined by the presence of air and fluid in the lungs, which is influenced by the phenomenon of acoustic impedance (Z). Acoustic impedance refers to the resistance of particles in a medium to mechanical vibrations. This resistance increases in proportion to the density of the medium and the propagation velocity of ultrasound (US) in the medium. When US encounters a large and flat boundary between mediums with different impedances, a portion of the sound is transmitted across the boundary while the rest is reflected, creating an echo. The magnitude of reflection is directly proportional to the difference in Z. Fluid, which possesses a constant Z, does not produce any echoes and therefore appears black on the image. Soft tissues, on the other hand, have similar Z values, resulting in minimal reflection. Interfaces between bone and soft tissue reflect approximately 40% of US energy. Soft tissue and air, however, reflect 99.9% of US energy, making this interface nearly impenetrable to US. Consequently, structures located beneath the pleura in an air-filled lung cannot be visualized, and only artifacts will be observed. LU relies on the interpretation of these artifacts in cases where the lung is predominantly filled with air. The nature of these artifacts varies depending on the ratio of air to fluid. If the lung is predominantly filled with fluid, it can be directly visualized. Pneumothorax, characterized by the presence of only air below the parietal pleura, and pleural effusion, characterized by the presence of only fluid, represent the two extremes. Between these extremes, there exists a range of normal lung (98% air), interstitial syndrome (IS; 95% air), alveolar. Syndrome (10% air), and atelectasis (5% air), each exhibiting distinct US appearances, ranging from specific artifacts to the visualization of actual structures **(Lichtenstein DA and Meziere GA 2008).**

### Transducer selection:

The 3.5-5.0 MHz convex phased-array transducer is the most commonly used and versatile transducer for lung ultrasound imaging. It is commonly found in multipurpose point-of-care ultrasound machines. This transducer is preferred due to its lower frequency, which allows for better visualization of deep structures, particularly in obese patients. On the other hand, linear transducers, typically used for vascular access, have limitations in terms of penetrating deeper structures. This becomes a challenge when trying to visualize consolidation, atelectasis, and pleural effusions located at the lung bases. However, linear transducers are still useful for analyzing the pleural line in the anterior chest to rule out pneumothorax after vascular access procedures or to assess pathology near the chest wall. Another recommended probe for lung ultrasound is the curvilinear probe with a frequency range of 3-5 MHz. This probe provides excellent imaging of lung sliding, interstitial syndrome, effusions, consolidated lung, and the diaphragm. Its large sector width and good penetration make it a versatile option. However, when scanning postero-laterally, some angulation is required to avoid the .ribs due to the probe's large footprint **(Gargani L .2019).**

**Patient's position:**

Thoracic ultrasound can be conducted while the patient is in an upright position. The presence of pleural effusions in the thorax is influenced by the patient's posture due to the effect of gravity on fluid distribution. However, other patterns of the pleural line are not significantly affected by patient positioning, except for interstitial syndrome. In interstitial syndrome, the interlobular septa at the lung bases may widen due to gravity-dependent fluid, which can be more pronounced in an upright patient but less prominent in a supine patient.

**Ultrasound protocols:**

It is advisable to conduct LUS exams using a standardized approach whenever feasible. This approach aids in the interpretation, monitoring, and reproducibility of the results (.A Miller 2016). In the context of monitoring acute respiratory distress syndrome (ARDS), the recommended protocol is the 12-zones protocol. This protocol divides each lung into anterior, lateral, and posterior zones, resulting in six zones per lung. The upper and lower zones are separated by the nipple line, while the parasternal line, anterior axillary line, posterior axillary line, and paraspinal line define the vertical boundaries of the zones. Although it can be challenging to scan the posterior zones in supine critically ill patients, we still recommend scanning the most posterolateral zones possible. This is because pleural effusions, pneumonia, or atelectasis often manifest in these zones in supine patients. For a more universal scanning protocol, the 8-zones protocol can be used.

Unlike the 12-zones protocol, it does not involve assessing the posterior zones. The 8-zones protocol is more standardized for patients with heart failure and is also useful for the differential diagnosis of respiratory failure/acute dyspnea (**Volpicelli G , et al. 2006 ).**

**Anatomy:**

The thoracic cage is covered by the chest wall, which consists of the skin, subcutaneous tissue, and muscles. The outer layer of the pleura is located on the inner side of the rib, separated from the inner layer by a thin layer of pleural fluid. This fluid helps to lubricate movement between the two layers during respiration. On LUS, both layers of the pleura appear as a single hyper echoic bright line and are approximately 5µm thick. The alveoli, which are millions of airspaces within lobules, are situated beneath the visceral pleura.

However, they are not normally visible on ultrasound due to their resolution being below the ultrasound threshold. The thickening of the interlobular septa, which divide the lobules, is a characteristic feature of interstitial syndrome (B-lines) on LUS. It is important to note that LUS provides a regional assessment of each lung, whereas CXR provides a global assessment of both lungs. Therefore, a systematic approach to LUS scanning is crucial in order to enhance the diagnostic accuracy of the scan.

**Ultrasound appearance:**

All indications in LU originate from the pleural line, except for subcutaneous Emphysema, which will eliminate it (as there is air above it). Rib shadows will be visible (as the sound is reflected back to the probe), and in between them, the bright white pleural line can be observed approximately 0.5 cm below the rib line. Ensure that this is centered in your image, and you will observe the 'bat sign' with the ribs resembling wings. Air below the pleural line reflects most ultrasound waves back to the transducer. The pleural line itself acts as a reflector, causing some of the ultrasound waves to bounce back and forth between the pleura and transducer, resulting in artifacts known as A lines. These A lines appear as horizontal lines below the pleura, with the same spacing as the distance between the probe and the pleural line. Since they indicate the presence of air below the pleura, they can be observed in both normal lungs and pneumothorax cases.

Rotating the probe transversely will

eliminate the rib shadows, allowing for a clearer view of the pleural line. However, it is important to note that an inexperienced user may mistake a rib for the pleural line and incorrectly diagnose the absence of lung sliding (**A Miller, 2016).**

**Usage of point of care ultrasound for lung pathology**

### 1. Pneumonia

During the initial stages of pneumonia, LUS can detect focal B-lines with intact lung sliding. As the condition progresses, subpleural small consolidations and/or large lobar consolidation may become visible. Consolidation refers to a region of lung that has lost air and appears as a tissue-like echogenic structure. The "shred sign" is characterized by the irregular and rough edge of the deaerated lung, which is separated from the partially deaerated lung. A specific indicator of pneumonia is the presence of "dynamic air-bronchograms," which are mobile hyperechogenic particles (air bubbles) that .move back and forth within the bronchioles during respiration **(Luke Flower & Pradeep Madhivathanan, 2022)**

### 2. Plueral effusion:

Fluid accumulation in the chest can be easily overlooked when using chest radiography, as up to 500 ml of fluid may not be detected. However, the use of ultrasound (US) has proven to be highly sensitive and specific, with a success rate of nearly 100%. US can reveal the presence of septations within the fluid and aid in distinguishing between transudates and exudates. In patients in the intensive care unit (ICU), effusions tend to collect caudad (towards the feet) and posteriorly (towards the back) due to the force of gravity. These effusions can be easily identified in the space between the diaphragm and the lung, specifically in the postero-lateral region. An important characteristic of effusions is that the lung will float on top of the accumulated fluid.

To visualize the effusion, the quad sign can be observed. This sign appears as a rectangular shape, usually with anechoic (echo-free) properties, and is bordered by the ribs cephalad (towards the head) and caudad (towards the feet), as well as the parietal and visceral pleura at the top and bottom. It is crucial not to mistake an A line for the visceral pleura, as this can lead to misinterpretation. Additionally, the movement of the lung with respiration can be observed using 2D or M-mode imaging, known as the sinusoid sign. This movement helps differentiate between pleural thickening and an effusion.

Color Doppler imaging is another useful tool in identifying fluid movement within an effusion. When the diaphragm is visible, a significant effusion will be observed surrounding the basal lung and separating it from the diaphragm. In some cases, a collapsed or consolidated lung base may be seen floating within the effusion.

When it comes to determining the size of a pleural effusion, there are various published techniques; however, they often differ significantly, as accurately measuring the volume of an effusion using US is challenging. Instead, it is more practical and clinically relevant to classify the effusion volume as small, moderate, or large. As a general guideline, an effusion .depth of greater than 4-5 cm at its widest point typically indicates a volume exceeding 1000 ml **(A Miller 2016)**

### 3. Pneumothorax :

Episodic occurrences of pneumothoraces in the intensive care unit (ICU) necessitate their inclusion in the list of potential diagnoses for mechanically ventilated patients who experience sudden deterioration, as well as for patients undergoing procedures like central venous access. The identification of a pneumothorax can be conclusively achieved by identifying the "lung point," which is the region where a transient manifestation of lung-sliding or B-lines replaces an area of absent lung sliding during inhalation. This discovery exhibits a specificity of 100% and a sensitivity of 66% (Lichtenstein DA, Menu Y, 1995. Lichtenstein D, Meziere G and Biderman P, Gepner A 200).

### 4. Consoldation:

Ultrasonography is a valuable tool for visualizing the consolidated lung, as it allows for clear imaging without any interference from a tissue-air interface. This lack of interference enables the identification of various conditions such as pneumonia, atelectasis, tumor, or pulmonary infarct. However, it is crucial to integrate the clinical presentation to determine the underlying cause of the consolidation. When observed through ultrasonography, consolidation appears as a uniformly dark and dense area, resembling the texture of a liver (hepatization). Within this consolidated area, one may also observe anatomical features like vascularization and branches of the bronchial tree. In cases where the airway remains open, hyperechoic spots may be visible within the lung tissue due to the presence of air in the bronchial tree. These hyperechoic spots can manifest as either points or linear images, known as air bronchograms (Lichtenstein D, Meziere G and Biderman P, Gepner A, 2000). (Guevarra, K, Greenstein, Y. 2020 ) ( Mathis, G 1997).

## 5. Aclactasia:

Basilar resorptive atelectasis is a common occurrence in patients who are on ventilators due to lung hypoinflation or in patients with obstruction in the proximal bronchial tubes. This condition is characterized by a loss of lung volume and the presence of "static" air bronchograms. These air bronchograms indicate the presence of trapped air bubbles within the bronchioles and can be observed in up to 40% of patients with pneumonia. It is important to consider the clinical context when interpreting these findings. In cases where there is compressive atelectasis caused by a pleural effusion, there is a loss of lung volume and the lung appears to float within the effusion. During respirations, the lung tip displays sinusoidal movements, indicating a simple pleural effusion. However, in cases of higher-viscosity parapneumonic effusions, there is a loss of sinusoidal movements. When examining the diaphragm, a mirror image of the liver or spleen may be observed due to a delay in sound waves returning to the transducer after reflecting off the diaphragm. This is considered a normal finding and confirms that there is aerated lung tissue adjacent to the diaphragm. Additionally, a positive curtain sign, negative spine sign, and mirror image of the liver/spleen above the diaphragm are all normal findings. However, in the presence of a lower lobe pneumonia or pleural effusion, the vertebral bodies are typically visualized extending above the diaphragm, indicating a positive spine sign.) **(Nilam J Soni, Robert Arntfield and Pierre Kory 2019).**

**Table (1):** Summarize point of care ultrasound finding of lung pathology

| Lung Pathology | Ultrasound Findings |
|---|---|
| Pneumonia | At the initial stages, intact lung sliding is observed along with focal B-lines. As the condition progresses, subpleural small consolidations and/or large lobar consolidation may become evident. Moreover, the presence of "dynamic air-bronchograms" is indicative of pneumonia. |
| Pleural Effusion | -Accurate and precise identification of fluid buildup - Existence of partitions within the fluid - Effusion depth surpassing 4-5 cm signifies a volume surpassing 1000 ml |
| Pneumothorax | - The identification of the "lung point" demonstrates a specificity of 100% and a sensitivity of 66%. |
| Consolidation | - Achieving high-quality imaging without any disruption caused by the tissue-air interface - A distinct and compact region that closely resembles the texture of the liver - The existence of blood vessels and branches of the bronchial tree - Bright spots indicating the presence of air bronchograms |
| Atelectasis | Take into account the clinical context while analyzing the results, as it is crucial in understanding the significance of the loss of lung volume and the presence of "static" air bronchograms. - In compressive atelectasis، it is important to note the mirror image of the liver/spleen above the diaphragm. - When evaluating these findings, it is essential to consider the overall clinical picture. |

## Limitation of lung ultrasound:

Nevertheless, despite its numerous advantages, there are certain limitations to the use of POCUS in patients with lung disease. Firstly, the technique's reliance on the operator means that the quality of imaging and interpretation may vary between operators. This emphasizes the importance of adequate training and certification in POCUS to ensure accurate and reliable results. Additionally, POCUS has limitations in certain patient populations, such as those with severe obesity or extensive subcutaneous emphysema, where visualization may be challenging. These limitations should be considered when implementing POCUS in clinical practice.

## Conclusions

Point-of-care ultrasound (POCUS) has emerged as an invaluable tool in the management of lung disease. It enables clinicians to visualize lung structures and assess lung pathology in real-time, providing quick and accurate imaging. POCUS has demonstrated high sensitivity and specificity in detecting common findings associated with lung disease, including pleural effusions, consolidations, and pneumothorax. Moreover, it offers a non-invasive alternative to traditional methods like chest X-rays and CT scans for evaluating lung function. The portability and affordability of POCUS make it particularly promising for revolutionizing lung disease management in resource-limited settings. Future research should prioritize validating the diagnostic accuracy of POCUS and exploring its potential in monitoring disease progression and treatment response.

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