



Lung Ultrasound in Evaluation of Pneumonia

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 Invited paper

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The Sound Judgment Series consists of invited articles highlighting the clinical value of using ultrasound first in specific clinical diagnoses where ultrasound has shown comparative or superior value. The series is meant to serve as an educational tool for medical and sonography students and clinical practitioners and may help integrate ultrasound into clinical practice.

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Abbreviations

ARDS, acute respiratory distress syndrome; CT, computed tomography

During the last 20 years, ultrasound has been shown to be highly effective in evaluating a range of pathologic pulmonary conditions. One of the most widely studied and practiced applications is the evaluation of pneumonia with ultrasound. Ultrasound interrogation of the thorax for detection of pneumonia has been explored most in critical care and emergency department settings. However, recently, the application has spread to general practice and even prehospital settings. A number of scanning approaches exist, ranging from highly involved research scanning tools to rapid and focused surveillance scans. The most widely accepted protocol is performed rapidly and easily and has proved to be sensitive and specific in adult and pediatric patients. Multiple studies have shown lung ultrasound imaging to be more accurate than chest radiography and in some cases rivals the accuracy of computed tomography (CT), such as in the diagnosis of lung abscesses. This article reviews clinical scenarios in which the lung ultrasound examination is useful in suspected pneumonia, describes pathologic findings, and presents a commonly accepted scanning protocol.

Overview and Clinical Problem

The diagnosis of pneumonia, once thought to be accomplished simply by physical examination, history taking, and specific auscultatory findings, has recently become highly dependent on imaging. There is, in general, a method behind this apparent clinical madness. Despite a long-held belief that physical examination findings and proper auscultation are sufficient to rule in, or out, the presence of pneumonia, multiple pressures in clinical practice have driven increased use of chest radiography and occasionally CT. The physical examination has proved to be unreliable for detection of pneumonia, even in expert hands.¹ Studies comparing examinations by expert physicians to chest radiography have verified the failure of auscultation as a diagnostic method in evaluation of pneumonia, yet physicians are under an increasing burden to be more accurate, and missing pneumonia is seen as a substantial liability. Additionally, the common approach in general private practice of prescribing antibiotics to any patient presenting with a cough and fever contributes to increasing antibiotic resistance and is actively combated by the US Centers for Disease Control and Prevention.

When faced with a patient with any combination of fever, cough, shortness of breath, and hypoxia, clinicians think they have little option but to obtain an imaging study or empirically prescribe antibiotics. In hospital settings, patients may receive chest radiography routinely, not only for most presentations to the emergency department with a cough but also in hospital wards and intensive care units. In the latter two locations, chest radiography may be a daily occurrence for some patients. However, one of the most clinically frustrating aspects of searching for pneumonia with chest radiography is the relatively low accuracy of this traditional imaging standby. Clinicians frequently discover pneumonia on CT that was not seen on chest radiography while searching for other pathologic conditions such as pulmonary embolisms. Additionally, common chest radiography is associated with considerable practical delays in most settings where a trained technologist obtains an image and then processes it, both frequently away from the immediate clinical setting. Point-of-care ultrasound imaging, performed at the patient's bedside, decreases the delays of chest radiography in diagnosis of pneumonia. Studies showing the efficacy of lung ultrasound in detecting and ruling out pneumonia date back approximately 20 years. Originally unrecognized by most in the medical community, ultrasound imaging has proved superior to chest radiography in almost every setting ranging from intensive care units to emergency departments and outpatient clinics.^{2,3} The term "lung ultrasound" is the most widely accepted one but is effectively equivalent to "thoracic ultrasound" and "pleural ultrasound," both of which have occasionally been used in the literature.

Ultrasound Use

Performing the examination is easy and can be accomplished after focused training. The original descriptions used a micro-convex ultrasound transducer in the 5-MHz range. Little or no image postprocessing was available at the time, and much of the science of lung ultrasound was built on artifacts noted when the ultrasonic waves hit the pleural surface. In recent years, a variety of ultrasound transducer types have been used to image the lung. The most common, in addition to the micro-convex type, are linear and phased array cardiac transducers, typically ranging from 10 to 5 and 5 to 2.5 MHz, respectively. The linear arrays, much like a curved linear abdominal probe, have difficulty getting in between ribs, substantially limiting imaging in some patients. However, the pleura and near-pleural abnormalities are seen much better than with the micro-convex and phased array transducers, which are

probably best suited for general lung applications such as pneumonia screening in most patients. In the adult patient, the field depth is typically set at 16 to 18 cm, commonly found on most machine presets. Image postprocessing settings such as tissue harmonics and multibeam functions are best turned off if possible. Such settings may eliminate artifacts and could impede diagnosis. The ultrasound transducer is moved until a rib interspace is located. The probe is then panned horizontally and vertically to the extent possible to allow the broadest sweep through the area being imaged. The transducer indicator is pointed cephalad and then to the patient's right, allowing for the best ultrasound penetration between ribs. Holding the transducer perpendicular to the chest wall and panning of the beam are accomplished with subtle movements and angle variations. For the most consistent and accurate results, the operator should use a methodical scan to map out the entire thorax. The micro-convex and phased array transducers are ideal for manipulating the ultrasonic beam in the rib interspaces. One exception is the young pediatric patient, for whom linear array or high-resolution micro-convex transducers are best suited to the small body size.

When evaluating for pneumonia, the ultrasound transducer is typically applied to 4 different windows on each hemithorax. In a reclined or semireclined patient, the 8 regions include the upper and lower regions of the anterior hemithorax and upper and lower regions of the lateral hemithorax (Figure 1). An entire region is surveyed by angling and sliding the ultrasound transducer as needed. The pleural surface of the lung acts as an acoustic reflector, reflecting nearly 80% of the ultrasonic beam it encounters. As seen with other anatomic structures with high impedance, horizontal reverberation artifacts are readily created and are known as A-lines in the lung ultrasound lexicon (Figure 2). The healthy, well-aerated, and inflated lung has a density of approximately 0.32 g/mL and is not acoustically penetrated by medical ultrasound to an appreciable

Figure 1. The scanning position for the lateral chest is shown. A phased array cardiac transducer was used for this 8-point pneumonia survey.



degree.⁴ When the fluid content of the lung increases, substantial impedance differences are encountered in close proximity, leading to generation of additional artifacts termed B-lines, which are frequently seen in pulmonary edema. These artifacts are classically described as discrete laser-like vertical hyperechoic entities, which appear to arise at the pleural line and extend to the bottom of the ultrasound image without fading. Debate still exists about their exact source.

The key to ultrasound visualization of pneumonia in the lungs is relative loss of aeration of a portion of the lung and a concomitant increase in the fluid content, which is seen in lung consolidation. Once this consolidation reaches the pleura, it can be seen with ultrasound. Although some very early pneumonias must be so localized as to not abut the lung pleura, most make contact at some point inside the chest in clinically symptomatic patients and can thus be imaged with ultrasound. Current literature suggests that most pneumonias in critically ill patients (up to 98%) will contact the pleura.⁵ On a standard ultrasound examination, lung consolidation from pneumonia is often described as having a tissue-like pattern and is referred to as “hepatization” to illustrate its gray scale density and general appearance (Figure 3). Boundaries of a consolidated lung segment are defined by the pleural line, the adjacent aerated lung, and any effusion that may be present. The boundary created by adjacent aerated lung will naturally appear irregular. An exception is when an entire lobe is affected, in which case the boundary will be regular and well defined. A dendrite-like air bronchogram and a large number scatter artifacts from air are frequently traceable up to the pleura (Figure 4). In real time, air can be seen moving through bronchi, and this finding is known as a dynamic air bronchogram (Video 1). On color or power Doppler

Figure 2. Arrows show multiple bright repeating horizontal lines, known as A-lines.

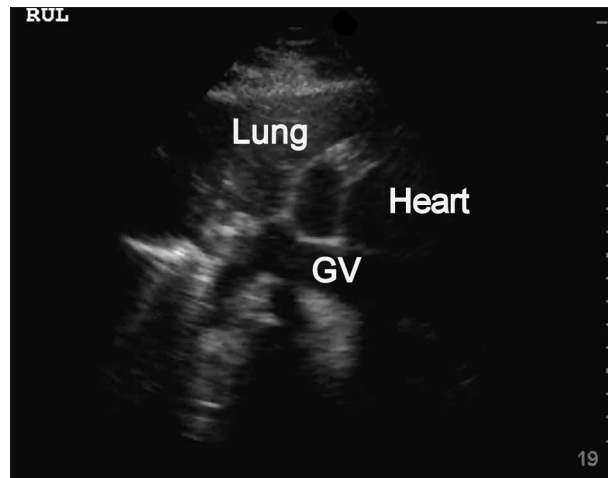
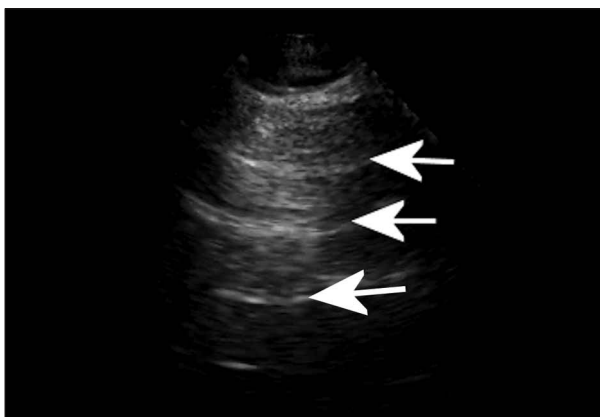


Figure 3. This image shows a solid organ–appearing structure in the near field. In actuality, the scan was performed through the lateral thorax. The lung is consolidated in a case of pneumonia and has an echo texture similar to that of the liver (Lung). Adjacent to it, the heart is shown, which is not possible through healthy lung. Several vessels are shown near the heart with a great vessel (GV).

imaging, vascular flow in cases of pneumonia is seen as a classic branching pattern in the infected/consolidated lung. Table 1 summarizes the typical ultrasound findings associated with pneumonia.

The sensitivity of B-mode ultrasound imaging is about 90%.⁵ Consolidation and dynamic air bronchograms have the highest specificity for pneumonia. Several studies showed that ultrasound imaging outperformed chest radiography with CT of the chest as a reference standard.^{2,6–10}

Figure 4. This image shows air bronchograms. The liver is shown on the right side of the screen with the diaphragm just to the left. The content of the thorax above the diaphragm is easily visualized (Lung) and appears to have a liver-like echo texture. Arrows point to bright branching signals within the consolidated lung, which represent the air bronchograms.

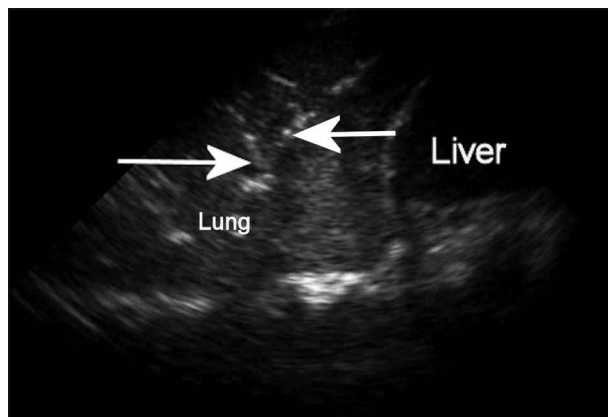


Table 1. Most Common Ultrasound Findings Associated With Pneumonia

Hypoechoic areas of varying size and shape
Irregular and serrated margins
Heterogeneous echo texture
Air bronchograms
Dynamic air bronchograms
Pleural effusion
Vascular flow in consolidated lung on color or power Doppler imaging
Hepatization of lung tissue similar to appearance of the liver

Interestingly, lung ultrasound has grown to such an extent that an evidence-based consensus conference was held in 2010 and 2011, grading supporting evidence and bringing together dozens of published experts from multiple countries around the world.¹¹ The consensus conference found lung ultrasound to have broad utility in evaluating patients for pneumonia, lung contusions, pneumothorax, pulmonary edema, pulmonary embolisms, and other pathologic conditions. In general, ultrasound imaging performed better than plain radiography.

Discussion

Lung ultrasound imaging for the detection of pneumonia is highly accurate but like most diagnostic tests is not perfect. It is important for the sonologist to realize that lung consolidation can result from several different pathologic conditions. These include not only pneumonia but also acute respiratory distress syndrome (ARDS), lung contusions, and atelectasis. Although differentiating between pneumonia and atelectasis is probably the most difficult on the basis of clinical grounds, it is easily accomplished with ultrasound. Atelectatic lung segments (clinically the most commonly encountered mimickers) will show the absence of regional blood flow in the affected area of the lung on color or power Doppler interrogation. Patients with ARDS and lung contusions are often obviously clinically but will show the presence of blood flow on Doppler imaging. Lung contusions are typically encountered in patients with blunt trauma and will show abolishment of lung sliding; in some cases, they have even been mistaken for pneumothorax. However, contusions will also show localized signs of pulmonary edema and asymmetry between the left and right lungs, which can help differentiate them from pneumonia. On the other hand, ARDS will almost always show pleural line irregularities and will frequently show subpleural consolidation. These signs can allow clinicians to distinguish between major causes of lung consolidation on ultrasound imaging. As with any ultra-

sound application, operator competency is critical, and error can occur if the operator is not properly trained and experienced. Fortunately, it appears that lung ultrasound imaging has a favorable learning curve. However, misdiagnosis of pneumonia or, worse, failing to detect pneumonia could negatively affect the patient.

The use of lung ultrasound in the evaluation of pneumonia is growing rapidly and in each clinical setting shows increased efficiency as accurate bedside diagnosis is made possible. Although many traditional imaging applications are still indicated and will be used indefinitely for patients with possible pneumonia, lung ultrasound can substantially decrease the practical delays associated with plain chest radiography and in some cases can obviate the need for chest CT when a definitive diagnosis is obtained on ultrasound imaging, avoiding a large radiation dose. In many cases when pneumonia is in the differential diagnosis, lung ultrasound should come first.

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