REVIEW ARTICLE

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Lung Ultrasound in the Intensive Care Unit

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The use of ultrasound (US) for vascular access in the intensive care unit (ICU) is commonplace and, in fact, has become the standard of practice when inserting internal jugular venous catheters.[1,2] Physicians in many countries outside the United States have expanded the role of US to include several different diagnostic modalities for multiple organ systems. Algorithms for rapid diagnosis during acute clinical decompensation have been developed based on a growing body of literature supporting the benefits of using US in this role.[3–8]

Additional examples of US use for point-of-care in the ICU for diagnosis include the focused assessed transthoracic echo (FATE) exam, the focused assessment with sonography for trauma (FAST) exam, the deep venous thrombosis exam, and the lung US. This particular review focuses on the use of transthoracic US to diagnose lung pathologies, including pneumothorax and pleural effusion, and includes studies outlining the value of US in diagnosing lung pathology.[3,9,10]

Historically, the lungs have been imaged using portable anteroposterior (AP) chest x-rays (CXRs) in the ICU because of the risk of transporting critically ill patients for posteroanterior (PA) and lateral CXRs.[11,12] US images have higher fidelity and better visualization of the pleural space compared with supine CXR.[9,13,14] Pleural space abnormalities detected by sonography and not visualized readily by x-rays have been designated as a sonographic syndrome, "pleural syndrome."[15] These sonographic pleural abnormalities can involve fluid (effusion), air (pneumothorax), blood (hemothorax), or combinations of these (eg, hemothorax/pneumothorax). A supine PA CXR may not find even a large pneumothorax, because air tends to rise to the most nondependent area of the chest, which in supine patients is the anterior chest wall.[16,17] On a supine AP CXR, up to 55% of pneumothoraces may be occult.[16]

Conversely, gravity forces pleural fluid to the most dependent parts of the chest. In the supine position, pleural fluid then is spread throughout the posterior surface of the chest; this often presents a challenge in quantifying the amount of fluid present on a radiographic film. Another challenge is that because of its radiographic density, pleural fluid can be difficult to distinguish from other lung processes, including atelectasis and consolidation. These processes can occur simultaneously; thus, a patient can present with pleural fluid and another coexisting disease process. This can lead to confusing clinical pictures.

Computed tomography (CT) scans can help distinguish these processes, including their combined presentations; however, this diagnostic testing requires patient transport to the scanner with additional diagnostic procedure costs. In contrast, US is a technology that is rapid, available at the point-of-care, easily accessible, and inexpensive. In the diagnosis of a pneumothorax, US has demonstrated near-equivalent diagnostic ability compared with CT scans, with a reported sensitivity of 86% to 100% and a specificity of 94% to 100%; this is superior to chest radiographs, with a sensitivity and specificity ranging from 28% to 75% and 50% to 100%, respectively ($p < 0.05$).[13,18,19] Another advantage of US imaging of pleural effusions is that US can provide procedural guidance if further drainage or other interventions are required for therapy. Of the multitude of ICU US applications, rapid diagnosis and treatment of pneumothoraces and pleural effusions are perhaps two of the most valuable. The purpose of this review is to focus on the use of US as a diagnostic technique for pneumothoraces and pleural effusions. In addition, the practical advantages of real-time US guidance for chest tube drainage of pleural effusions will be discussed. To provide a better understanding of US techniques, a brief description of the basics of equipment and US imaging follows.

US EQUIPMENT

In generating a US image, the piezoelectric crystals of the transducer emit a short burst of US when an electric current is applied. This burst of US travels along a line, generating echoes from the structures along its path. The short burst then is followed by a period of "listening" for return echoes as they travel back to the transducer. Because the velocity of US through soft tissue is relatively constant, the time elapsed for the return echo can be used to determine the structures' distance/depth with respect to the transducer. Reflection serves as the basis for US imaging. The strongest reflections—those involving the largest amplitude—occur at tissue interfaces. Most US emissions are not reflected back to the transducer because of the differences in the acoustic impedance. This refers to the amount of sound pressure generated by the vibration of molecules in adjacent tissues at a given frequency. This difference in acoustic impedance is termed the "reflection coefficient". The echo signals are processed to produce luminescence. Blood and other fluids have relatively similar

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impedances, producing few reflections, and thus generate an echo-free or hypoechoic appearance. The structure will appear black or dark variations of grey.[20] On the other hand, the pleura generate a large change in acoustic impedance compared with the adjacent muscle and will appear hyperechoic and produce a white structure. Metals, such as wires, also will appear hyperechoic due to the acoustic impedance difference with the surrounding tissues. The process described above with signal processing and luminance serves as the basis for a brightness mode (B-mode) of US imaging. B-mode can be displayed as one- (M-mode), two-, or three-dimensional.[20] M-mode refers to the image produced when US pulses are emitted in quick succession from a single point to easily demonstrate the movement of adjacent tissues along the beam. The transducer position is held constant; therefore, only those structures along the beam will be displayed. The distance then is plotted against time, and easily demonstrates the movement of the adjacent tissues. This is useful in cardiac exams when there are subtle wall motion abnormalities or in evaluating "lung sliding" for a pneumothorax.

The structures of interest for this review (ie, the pleura, superficial lung parenchyma, and the potential spaces between) can be visualized using several different US probes and at several frequencies. Generally, as the US passes through the tissue, the intensity is reduced/attenuated through refraction, scatter, or absorption of the energy. Absorption is frequency-dependent—the higher the frequency, the greater the absorption. High frequencies (7-12 MHz) allow for improved tissue resolution; however, the tissue penetration is limited (Table 1).[20] Low frequencies (2-6 MHz) allow for optimal tissue penetration, but at the expense of picture resolution.[21] In general, however, the lung and pleural space are relatively shallow. Therefore, in most situations, it is appropriate to opt for a probe of high frequency that allows for higher resolution images. The shape of the probe can make a difference in allowing for optimal contact with the patient's skin on the thorax.

Given these fundamental principles, the probe with the most utility for the purposes of this review is the linear array vascular probe that is standard in most US packages. In linear array probes, the elements are arranged linearly and the US beam is created by exciting a portion of these elements. Successive elements are excited in a lateral fashion across the face of the array. The produced image is rectangular and the width of the probe. These probes are available in a range of frequencies, depending on the manufacturer, but they generally are designed for high-resolution imaging of relatively shallow structures. Most high-frequency linear array transducers used for vessel cannulation or lung US have a maximum penetration depth of 8 cm. Larger patients with extreme subcutaneous adipose tissue can present challenges for visualization with this probe. Generally, the depth of penetration should be adjusted until the area of interest is in the center of the screen. Therefore, if the patient's subcutaneous tissue is judged to be greater than 5 or 6 cm, it may be prudent to select a lower-frequency transducer, realizing that picture resolution will decrease.

PNEUMOTHORAX DIAGNOSIS

Body Position and Probe Placement

One of the great advantages of using US for diagnosing a pneumothorax in ICU patients is portability of the device. The US machine can be brought to the bedside, avoiding the hazards associated with patient transport. US can be used with the patient in any position, but in general, the supine position provides an adequate exam surface area for the diagnosis of a clinically significant pneumothorax. A complete US examination would include visualization of the posterior lung fields, but to accomplish this, the clinician would have to sit the patient up and then slide the probe to different positions across the patient's back.

However, it has been reported that, by and large, clinically significant pneumothoraces will rise in the pleura to the most nondependent area of the chest.[17] Therefore, in the supine

Table 1. Common Manufacturers of Linear Array Transducers and Transducer Characteristics

Common Transducers						
	System	Tranducer	Array Type	Frequency	Application	
Zonare Mountain View, CA	ZS3	L8-3	Linear	3-8 MHz	Superficial*/Vascular	
		L10-5		5-10 MHz		
		P4-1c	Phased	1-4 MHz	Cardiac	
		C4-1	Curvilinear	1-4 MHz	Abdominal	
		C6-2		2-6 MHz		
Sonosite Bothel, WA	X-Porte	L25xp	Linear	6-13 MHz	Superficial*/Vascular	
		HFL50xp		6-15 MHz		
		P21xp	Phased	1-5 MHz	Cardiac	
		C60xp	Curvilinear	2-5 MHz	Abdominal	
Philips Andover, MA	CX50	L12-5	Linear	5-12 MHz	Superficial*/Vascular	
		L12-3		3-12 MHz		
		S5-1	Sector	1-5 MHz	Cardiac	
		C5-1	Curvilinear	1-5 MHz	Abdominal	
		C9-3io		3-9 MHz		

*Superficial - Depth < 8cm