Pulmonary Ultrasound Examination for Edema, Effusion, and Thromboembolism

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ABSTRACT

Bedside, or point-of-care, ultrasound (US) has increasingly been used in various clinical settings to provide clinicians with rapid clinical information without the use of ionizing radiation. Lung US has been demonstrated as a valuable tool in the diagnosis and evaluation of pulmonary edema, pleural effusions, and pulmonary thromboembolism. Lung US enables the clinician to more quickly identify and initiate treatment for these potentially life-threatening conditions without the need for patient transportation to the radiology suite. Additionally, lung US can repeatedly be implemented to assess clinical changes without concern for repeated radiation exposure and is cost-effective given its ability to decrease the need for additional radiological and laboratory testing to confirm a suspected diagnosis. This review focuses on the application of lung US in the evaluation and management of pulmonary edema, pleural effusions, and pulmonary thromboembolism.

PULMONARY EDEMA

Introduction

Pulmonary edema is the phenomenon of fluid accumulation in the airspaces and parenchyma of the lung causing impairment of alveolar exchange capacity, ultimately leading to respiratory distress. For the past 2 decades, ultrasound (US) has been recognized as an important diagnostic tool for promptly and accurately recognizing pulmonary edema [1,2] because the interstitial and alveolar congestion present in pulmonary edema have direct, easily measurable ultrasonographic correlates. These correlates are known as "B-lines."

Typically, the lung is a poor transmitter of sound waves. When sound enters aerated lung parenchyma, it is scattered in all directions and little energy is reflected back to the transducer causing horizontal hyperintense lines seen at regular intervals below the pleura. These "A-lines" are reverberation artifacts caused by reflection between the skin and the pleural line, and their presence indicates aerated lung parenchyma and alveoli (see Fig. 1). The loss of A-lines suggests underlying increased density of lung from either interstitial fluid accumulation or consolidation [3]. B-lines are vertical hyperintense lines extending undiminished from the pleural line and which move with pleural sliding like spotlights. They are believed to be caused by the resonance phenomena of sound traveling through air-filled alveoli and edematous interlobular septa [4] (see Fig. 2). As extravascular lung water increases in the lungs, these lines become brighter and more numerous; ultimately, they coalesce [1].

Notably, these artifacts do not always apply specifically to pulmonary edema; rather they apply in varying degrees and, on the basis of clinical setting, to any state of parenchymal thickening in the lung, including pulmonary fibrosis, pneumonia, hemorrhage, etc. [5]. Typically focal processes such as pneumonia, contusion, atelectasis, and malignancy will be unilateral and therefore may be differentiated from more diffuse entities such as pulmonary edema. However, diffuse lung processes such as acute respiratory distress syndrome (ARDS) and pulmonary fibrosis are not well differentiated by B-lines alone. Whereas additional findings such as subpleural fluid collections and irregular pleural lines can help to distinguish pulmonary edema (thin regular pleural line) from an inflammatory process such as ARDS or fibrosis (subpleural fluid, irregular "lumpy bumpy" pleural lines), it is essential to appreciate the clinical context of the patient when performing and interpreting lung ultrasound for pulmonary edema [4].

Image Acquisition

There are several methods of scanning the lungs for signs of pulmonary edema that have been previously well described [3,6–8]. The indications for which scanning protocol is used depend on the urgency of the evaluation and in which clinical setting the examination is being performed. A 2-point positive approach can be used as a quick screen in the acutely dyspneic patient. Using a curvilinear or phased-array 2- to 5-MHz transducer on a supine or upright patient, the ultrasound should be placed between the third and fourth rib spaces in the mid-axillary line with the depth set to 18 cm. The probe marker should be toward the head, such that a longitudinal view is obtained. The presence of 3 or more B-lines is considered positive and a bilateral screen is suggestive of pulmonary edema in the acutely dyspneic patient [7]. A more complete lung evaluation suggested for emergency department patients that are not in extremis uses 8 quadrants as shown (Fig. 3). In this scanning protocol, 3 or more B-lines makes

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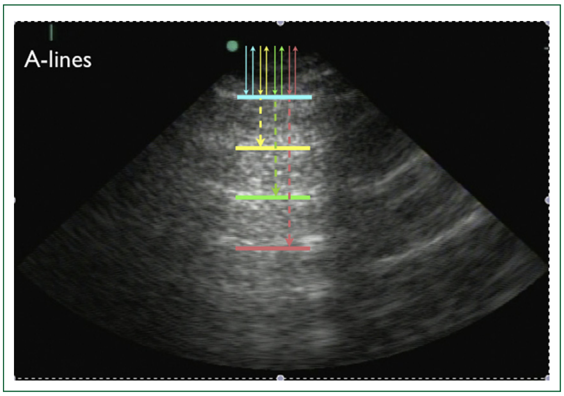

FIGURE 1. A lines—horizontal reverberation artifact caused by sound reflecting between the skin and pleura.

a quadrant positive and 2 quadrants per side must be positive to suggest pulmonary edema [8]. An even more complete evaluation uses 28 zones and has been used mostly to evaluate stable patients with congestive heart failure or as a research tool to more completely evaluate lung parenchyma [9]. This more complete scanning protocol has been shown to correlate with wedge pressure (i.e., more B-lines correlates with higher wedge pressure) [8,9] as well as to have prognostic significance (i.e., more B-lines correlates with higher 30-day mortality) [10].

Use in Clinical Setting

A number of studies have looked at the clinical efficacy of using lung US to diagnose and monitor pulmonary edema in an acute setting. The overall theme of much of the data is that lung ultrasound to evaluate for pulmonary edema in the appropriate context obviates the need for additional specialized laboratory or radiographic testing.

In a global health setting, laboratory tests or radiography are often unavailable, and when they are available, they require time and money to perform, making it difficult to obtain prompt results. N-terminus brain natriuretic peptide (BNP) is an accepted marker of atrial stretching reflecting increased left atrial pressures; multiple studies have noted its correlation with increased extravascular lung water [2,10,11]. However, a positive B-line lung US examination using the Volpicelli 8-zone technique was found to have a higher likelihood ratio for acute congestive heart failure over BNP (3.9 vs. 2.3), suggesting a higher sensitivity when compared to the lab result alone [2]. This relationship has been even more firmly established by the study showing the correlation between pulmonary wedge pressure and presence of B-lines ($r = 0.48$; $p < 0.01$) as mentioned [9].

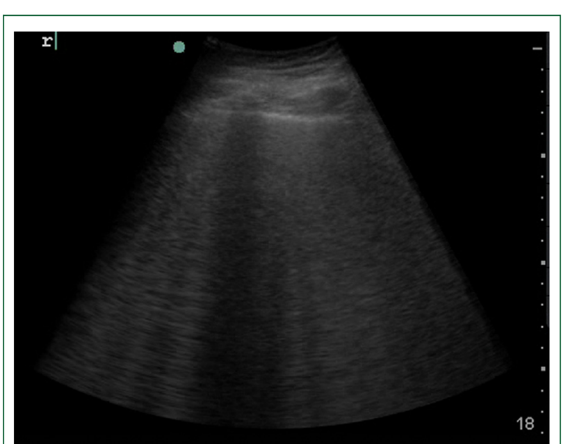

FIGURE 2. B lines—vertical artifact caused by increased extravascular lung water.

In a standard pulmonary edema evaluation, chest radiography is routinely ordered to document extravascular fluid. However, several studies have shown US to be similarly sensitive (85% US vs. 93% chest X-ray) [6] in diagnosing pulmonary edema compared with standard chest radiography, with more recent data suggesting the sensitivity and specificity of lung US is superior to chest radiography (US 99% vs. chest X-ray 97% sensitivity; US 61% vs. chest X-ray 32% specificity) [12]. Indeed, several studies have shown that lung US is an excellent method of more quickly and more accurately differentiating pulmonary edema in the setting of congestive heart failure exacerbation from the complications of chronic obstructive pulmonary disease [13–15].

In addition to the diagnostic advantage lung US provides, it has also been shown to be useful in monitoring the efficacy of interventions to treat pulmonary edema. This is an advantage over chest radiography, as the lag between symptoms and radiographic correlates of extravascular lung water is known to be 24 to 48 h. Several studies have demonstrated this superiority by observing the resolution of B-lines during hemodialysis [16]or after administration of continuous positive airway pressure [17] (Fig. 4). This data shows that frequent reassessment with lung US can provide real-time feedback about the efficacy of interventions.

More recent studies combine cardiac and lung ultrasound to produce composite markers of volume status and cardiac function [18]. This data is emerging and is yet of unclear clinical utility.

Future research in lung US evaluation for pulmonary edema aims to find ways to better differentiate pulmonary edema from ARDS [4] and other processes causing interstitial alveolar syndrome to help even more precisely to diagnose lung disease states.

In conclusion, lung US in the evaluation of pulmonary edema has been found to be as good or superior to traditional evaluations with chest radiography and equivalent to testing for elevated BNP. Additionally, there is evidence to support its use in monitoring the efficacy of interventions used to treat pulmonary edema and individual patient responses to treatment. The role of lung US in conjunction with cardiac US for discriminating different types of interstitial alveolar syndrome are currently active areas of research.