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Review article

Application of transthoracic lung ultrasound in the diagnosis of pulmonary edema at ICU patients – Literature review

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ABSTRACT

Introduction: Pulmonary edema (PED) is one of the potential causes of acute respiratory failure at ICU patients. Transthoracic lung ultrasound (TUS) is a useful method of evaluating the condition of the respiratory system, because especially in the critically ill patients, this study should be simple, fast and easily accessible. Hence the study design is simplified and presented as a treatment protocol known by the acronym BLUE (Lung Bedside Ultrasound in Emergency). Study under this scheme reduces testing time for even 1 min, and at the same time allows for the diagnosis of the causes of acute respiratory failure.
Aim: The aim of this work is to describe the basics of actual techniques of medical ultrasound for diagnosis PED.
Material and methods: A literature review.
Results and discussion: We presented how to identify with ultrasonography the most common types of PED at ICU patients.
Conclusions: Medical ultrasound is a simple, fast, cheap and reproducible method of evaluating the respiratory system and seems to be one of the most promising imaging techniques for the diagnosis of lung diseases and monitoring of respiratory functions.
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1. Introduction

Pulmonary edema (PED) is defined as the accumulation of fluid in the extravascular space of the lungs as a result of the increase in hydrostatic pressure in the capillaries or weakening of the alveolar-capillary barrier.[1] Based on this definition, two main types of PED can be distinguished: cardiogenic and non-cardiogenic. Cardiogenic or hydrostatic PED develops as a result of the increase in pressure in the capillaries secondarily to the left ventricular heart failure. Non-cardiogenic or leakage-caused PED results from changes in permeability of the alveolar-capillary barrier, most often caused by its damage. Its example is PED in acute respiratory distress syndrome (ARDS).

2. Aim

The aim of this work is to describe actual techniques of medical ultrasound for diagnosis PED.

3. Material and methods

In the our study we focused on a review of actual literature for identifying with ultrasonography the most common causes PED at the ICU patients.

At the ICU patients micro-convex, convex and sector transducers are used for a lung ultrasound.[2] Scanning in the longitudinal planes has been recommended.[2,3] Protocol BLUE involves the assessment of the lungs in three points on both sides of the chest. Points 1 and 2 are the upper- and lower-BLUE points determined by two hands (without thumbs) that are juxtaposed below the lower edge of the clavicle. Point 3, which has been designated the 'Postero Lateral Alveolar and/or Pleural Syndrome (PLAPS) point', is

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at the junction of the posterior axillary line and a line extending from the lower-BLUE point. Lichtenstein has shown that his BLUE protocol has correctly confirmed the diagnosis of acute respiratory failure in 90.5% of cases.[3–5]

4. Results

A typical ultrasound image of the chest using the transducer in the longitudinal place includes subcutaneous tissue, muscles and pleural cavity that are visible starting from the top of the screen. In this type of image, identifying the ribs is the first step toward correctly localizing the pleural cavity. In adult patients, ribs appear as hyperechogenic structures with an acoustic shadow. Two adjacent ribs will form a so-called rib line. At a distance of approximately 0.5 cm below the rib line is a thin (generally less than 0.2 cm) hyperechogenic line which consists of parietal and visceral pleura, which make up the pleural line. Under non-pathological conditions the pleural line cannot be distinguished by means of ultrasound, however, it becomes visible in diseased states. Together, the pleural and rib line form an image called the bat sign. This is a fixed point that allows for locating the surface of the lung (Fig. 1).

On the boundary of the pleural cavity and aerated lung tissue, the A-line, B-line, Z-line, and lung sliding artifacts are visible.

A-lines are hyperechogenic lines parallel to the pleural cavity, repeated at the same distance. It is equal to the distance between the pleural line and the skin surface. These artifacts were named after the English word air (A – air) since they are produced by a reflection of the ultrasound on air contained in the lungs. In other words, these are multiple reflections of the pleural cavity.

The lung sliding sign is produced on the pleural line when the visceral pleura slides against the parietal pleura. In M-mode, the movement of the pleural cavity is visible as a homogenous granular structure, which resembles a grainy seashore (seashore sign). The A-line and lung sliding artifacts are major artifacts seen in normal interstitial syndrome.

B-lines are vertical, hyperechogenic lines spreading from the pleural line to the edge of the screen. They belong to the group of artifacts called comet tail artifacts, named for their characteristic appearance. They are dynamic findings that are synchronized with the movement of the pleural cavity, erase A-lines, and their echogenicity increases during inspiration.[5–7] They form due to the high gradient of acoustic impedance between the air and the fluid accumulated in subpleural interalveolar septa. In healthy lungs, they are not permanent, occur in only 28% of examinations, and are most often seen in the last two intercostal spaces above the diaphragm.[6] With the transducer in the longitudinal plane, the presence of B-lines or bb-lines between two ribs is typical in normal interstitial syndrome. However, the presence of three or more B-lines is seen when there is thickening or edema of the interalveolar septa and is not a typical normal finding.

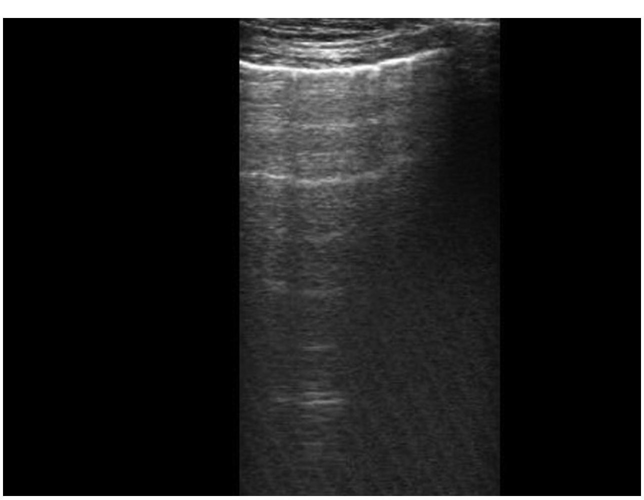

Fig. 1. Normal lung imaging.

5. Discussion

5.1. Ultrasound diagnosis of cardiogenic PED

From a pathophysiological point of view, there are two phases of cardiogenic PED[8]:

(1) interstitial edema and (2) alveolar flooding.

Diagnosis of cardiogenic PED is based on chest radiograph. In patients with congestive heart failure radiographic changes correlate with changes in hydrostatic pressure in the pulmonary capillaries. However, the development of these changes is delayed in relation to the increase in hydrostatic pressure and occurrence of clinical symptoms. Furthermore, radiography is not very accurate in detecting early stage of lung edema, which is interstitial edema.[9] Therefore, in patients in serious condition, catheters placed in the pulmonary artery are used to evaluate the hydrostatic pressure. The measurement of wedge pressure in the pulmonary artery correlates with radiological features of congestive heart failure.[1]

Recent studies report the usefulness of medical ultrasound in the diagnostics of cardiogenic PED.[6,10] Use of TUS in the diagnosis of PED has been confirmed by an international group of experts.[11]

The basis for its diagnosis is visualization of three or more B-line artifacts in the longitudinal planes at the all front or antero-lateral surface of the and it is called B+ pattern (7) B+ pattern artifacts include B7- and B3-lines. B7-lines are B-line artifacts spaced by 7 mm (±1 mm) and are ultrasound sign of changes occurring in the interstitial space of the lungs. They arise as a result of thickening or edema of subpleural interlobular septa (interstitial syndrome). The equivalents of B7-lines in radiography are Kerley's lines. The distance of 7 mm is an anatomical distance between two subpleurar interlobular septa in adult patients. In contrast, B3-lines are spaced from one another by 3 mm (±1 mm) and are formed when the edema refers to the pulmonary alveoli (interstitial-alveolar syndrome). These lines correspond to the image of so-called ground-glass areas in computed tomography (CT). In turn, overlapping B-lines produce an ultrasound image of a so-called white lung.[12]

It was demonstrated that population size and distribution of B-line artifacts is closely correlated with changes in extravascular lung water (EVLW).[12,22,23] Both the development and regression of B-line artifacts occurs in real time simultaneously with changes in EVLW. Agricola et al. observed a positive linear correlation between the result of line-B artifacts and EVLW, wedge pressure and pulmonary systolic pressure and the result of B-line artifacts and changes in radiography. In this study the sensitivity and specificity of medical ultrasound in the detection of the content of EVLW associated with PED (EVLW > 500 mL) were 90% and 86%, respectively. In turn, the sensitivity and specificity of identification of the EVLW before the occurrence of alveolar PED were 87% and 89%, respectively. This study confirms that images of line-B artifacts occur during interstitial PED, or when no evidence of deviation in a clinical examination or in radiography is found.[12] Regression of B-line artifacts also occurs in real time. In patients subjected to hemodialysis it is consistent with the amount of the removed fluid.[13] In heart failure the number of artifacts correlates with the degree of left ventricular dysfunction or the level of natriuretic peptides (BNP or NT-proBNP).[14,10,15] According to the study of Frassi et al., the strongest predictive factor of their occurrence is the degree of left ventricular diastolic dysfunction. In

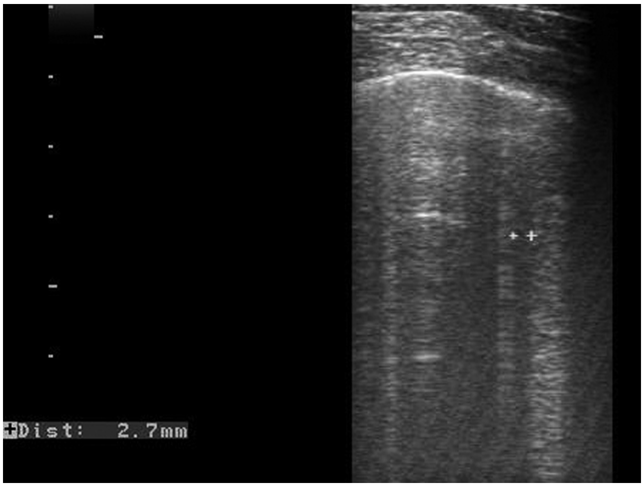

Fig. 2. Cardiogenic PED.

another study it was demonstrated that the presence of bilateral B-line artifacts is associated with significantly higher level of BNP. Specificity and sensitivity in the group of patients with elevated BNP level amounted to 91.7% and 33.3%, respectively.[10]

Medical ultrasound is also useful in differential diagnosis of PED. According to the study of Copetti et al., visualization of images of heterogeneous B+ patterns, separated by areas of normal lung structure, changes in the pleural line associated with the decrease or removal of lung sliding sign and pulmonary consolidation is highly predictive for the early, non-cardiogenic PED. In contrast, images of homogenously distributed B+ patterns are typical for cardiogenic PED[16] (Fig. 2).

5.2. Ultrasound diagnosis of ARDS

From a pathophysiological point of view PED in ARDS consists of three, often overlapping phases[8]: (1) exudative – edema of the interstitial space and almost simultaneous edema of alveolar space, which results in the formation of hyaline membranes; (2) proliferative – proliferation of fibroblasts; (3) fibrinous – formation of intrapulmonary and subpleural alveoli.

This type of PED is characterized by the presence of diffuse inflammation, and edema of interstitial and alveolar space, which results in huge loss of aeration in the dependent lung regions.[17] The diagnosis is based on clinical examination, radiography and CT.

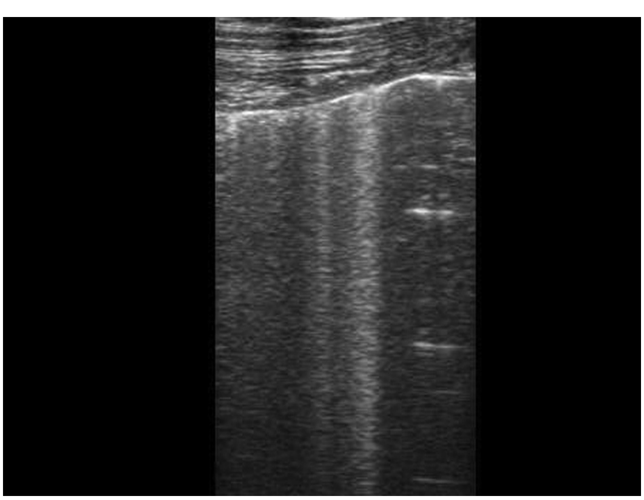

Fig. 3. ARDS.

Medical ultrasound may be useful in the diagnosis of ARDS, and in the evaluation of alveolar recruitment. Ultrasound, similarly to CT reveals a heterogeneous image of the affected lungs. Heterogeneously distributed B-line artifacts, between which spread areas of healthy lungs are visible, irregular outline and thickening of pleural line with the reduction or disappearance of lung sliding sign are typical (Fig. 3). Visualization of these changes in critically ill patients is strongly predictive for early ARDS.[16] Furthermore, the detection of pleural effusions, pulmonary consolidation and lung pulse artifact in the ultrasound scan can support the diagnosis.

Consolidations occur in pulmonary regions, depending on the force of gravity. In patients in the lying position they are most often present at the back wall of the chest, especially at the base of the lungs.[18]

It was demonstrated that in patients with ARDS, medical ultrasound is more accurate than auscultation and radiography in the detection of pleural effusion, pulmonary consolidation and interstitial syndromes.[19]

The use of medical ultrasound for assessment of lung recruitment is the subject of many studies. In one of them airless areas of the dependent lung regions during lung recruitment induced by a positive end-expiratory pressure (PEEP) were subjected to analysis. In the course of increasing PEEP, a regression of the study lung area with a significant increase of partial pressure of oxygen (PaO_2) in the arterial blood was imaged.[20,21]

6. Conclusions

TUS is a simple, cheap, reproducible and free of side effects method of assessing the respiratory system. Use of TUS in the diagnosis of PED is well documented and has been confirmed by a group of experts and can be performed at the bedside. Research by BLUE protocol allows for the diagnosis of PED as one of the causes of acute respiratory failure. Analysis of the changes depicted in the TUS distinguishes non-cardiogenic and cardiogenic PED. TUS seems to be one of the most promising imaging techniques for the diagnosis of lung diseases and monitoring of respiratory functions.

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