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REVIEW ARTICLE

Usefulness of lung ultrasound in the bedside distinction between pulmonary edema and exacerbation of COPD

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Abstract This review discusses the usefulness of bedside lung ultrasound in the diagnostic distinction between different causes of acute dyspnea in the emergency setting, particularly focusing on differential diagnosis of pulmonary edema and exacerbation of chronic obstructive pulmonary disease (COPD). This is possible using a simple unit and easy-to-acquire technique performed by radiologists and clinicians. Major advantages include bedside availability, absence of radiation, high feasibility and reproducibility, and cost efficiency. The technique is based on analysis of sonographic artifacts instead of direct visualization of pulmonary structures. Artifacts are because of interactions between water-rich structures and air and are called "comet tails" or B lines. When such artifacts are widely detected on anterolateral transthoracic lung scans, we diagnose diffuse alveolar-interstitial syndrome, which is often a sign of acute pulmonary edema. This condition rules out exacerbation of COPD as the main cause of an acute dyspnea.

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Introduction

Sophisticated technologies developed during the last few years revolutionized health care in thoracic diseases because of the ability of improving image resolution together with the possibility to obtain electronic data to be stored and shared with other consultants. B-mode sonography is not a new technology, since it was firstly proposed for medical purposes more than 50 years ago. Its application in the diagnostic procedures of thoracic diseases has always been considered of limited importance, as the lung is considered poorly accessible by ultrasound. This is because of pulmonary air content and solid structures of the thoracic cage, which prevent the progression of the ultrasound beam and causes production of artifacts. This consideration, together with the widespread use of traditional radiology and the development of new thoracic imaging technologies, has prevented for many years development of lung ultrasound procedures. During the last few years, the concept of using ultrasound as a real-time bedside clinical tool for the clinician in the emergency setting is obtaining a growing consensus, which has led to a number of new applications of sonography. Between them, lung examination is the most innovative one. Rather than from technologic progress, the latest development of lung ultrasound is based on new applications and discovery of the significance of sonographic artifacts. Analysis of the correlations of some artifacts patterns with clinical and radiologic diagnosis in intensive care unit (ICU) patients has led to the important intuition of Lichtenstein et al. who were the first to describe the sonographic diagnosis of the alveolar-interstitial syndrome [1]. Despite that it happened about 10 years ago, this is an area of bedside diagnosis that will be new to many sonographers and practicing clinicians. The growing interest on its practical applications heralds lung ultrasound as an essential tool for the intensivist and the pulmonologist. The current article will review the clinical application of lung ultrasound in the diagnosis of the alveolar-interstitial syndrome, specially focusing on its usefulness in the bedside distinction between pulmonary edema and exacerbation of chronic obstructive pulmonary disease (COPD) as the cause of acute dyspnea. The first part will review why differentiating different causes of acute dyspnea (i.e., pulmonary edema from respiratory causes) may be difficult and will analyze the potential benefits of lung ultrasound over other techniques. The second part will describe the ultrasound technique for the diagnosis of the alveolar-interstitial syndrome, providing an update on the latest available information.

Diagnosing acute dyspnea

Diagnosing and managing adult patients with acute dyspnea challenge physicians. The most important issue is differentiating patients with a cardiogenic cause of respiratory failure from those with acute airflow limitation because of pulmonary diseases. Sometimes, this problem is not easy to solve, particularly in the emergency setting and in elderly patients. We know from literature that diagnosing airflow limitation or elevated cardiac filling pressure traditionally relies on a combination of several findings. They are physical signs, history recording, and traditional tests such as chest X-ray, electrocardiogram, and laboratory data [2, 3]. When considered alone, clinical evaluation and history recording are not specific [4–6]. Radiographic signs, such as redistribution and cardiomegaly, are good predictors but rely on high-quality films and radiologist skill [3, 7]. Moreover, recent researches suggest that chest radiography is often misleading in the evaluation of patients with decompensated heart failure in the emergency setting, resulting in misdiagnosis and inappropriate treatment [8]. Recently, the assay of serum BNP or NTpro-BNP has been described as a powerful diagnostic test for heart failure, yet the exact role in the emergency setting of these hormones is under debate [9–12]. Electrocardiogram is not accurate enough to make the appropriate diagnosis [13]. Echocardiography rules out left ventricular dysfunction or right cardiac overload but may not be helpful in delineating diastolic dysfunction. Particularly in elderly patients, differentiating causes of acute dyspnea is difficult, because very often, cardiac and respiratory diseases coexist, and atypical clinical presentation is confusing [14, 15].

The value of lung ultrasound follows from the inadequacy of physical findings, chest radiography, hormone level, electrocardiogram, and echocardiography in delineating the origin of the acute dyspnea in the emergency setting. Sonography of the lung has some certain advantages over other diagnostic tools, inasmuch as it is free from radiation and can be easily performed by clinicians and radiologists at bedside [16].

Technical equipment

Visualization of the chest wall, pleura, and pulmonary pathologies requires a simple B-mode ultrasound unit without the need of color Doppler. This technology has been available for many years [16]. Information about pulmonary pathologies could be obtained using linear, abdominal, or microconvex probes, but to analyze the interstitial artifacts, we should use low frequency to extend the ultrasound beam to deep structures. In our review of the literature, we found different studies performed with any probe [17–20], but the first published experience on the ultrasound diagnosis of the alveolar-interstitial syndrome was performed with a 5-MHz microconvex probe [1]. The most authoritative opinion on this topic comes from the group of Dr. Lichtenstein. They consider the microconvex as the best probe for bedside lung ultrasound [16]. This probe has the advantage of working deeply enough to analyze vertical artifacts and being small enough to thread between thoracic bones. Moreover, it can be considered all around and used as the unique probe for general application in the emergency setting. We have experienced using the abdominal probe at 3–5 MHz, which, in our opinion, has the advantage of coupling a wider visualization of the pleural layers together with detection of deep structures [19].

The ultrasound sign

The lung is characterized from an intimate mixture of air and water, and the change in their balance is a basic principle of pulmonary diseases. This change cannot pass unnoticed to the ultrasound probe, because air and water have opposite acoustic impedance. From the interactions between air and water arise lung artifacts. Lung ultrasound is largely based on the analysis of these artifacts rather than direct visualization of structures. The alveolar-interstitial syndrome of the lung is characterized from slight water increase while air content is reduced. It is mostly because of thickening of interlobular septa, ground-glass areas and increase in extravascular lung water. The major causes are cardiogenic and lesional pulmonary edema, infectious interstitial processes, and chronic diffuse parenchymal lung diseases. The characteristic sonographic sign is a vertical artifact called "comet tail" or B line [1, 21, 22]. It is

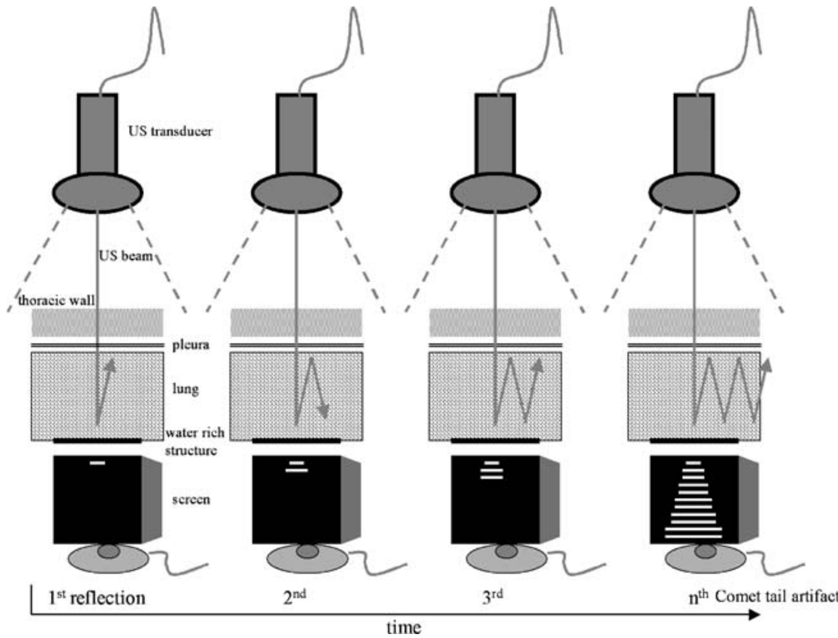

Fig. 1 Schematic explanation of the phenomenon of resonance, which generates the formation of the comet tail artifact on the screen. The beam is "trapped" between two elements with a great difference in acoustic impedance (air and water). In case of an aerated lung, they are present in a water-rich structure (thickened interlobular septa and/or alveolar fluid content) and its surrounding areas (alveolar air)

generated by multiple reflections of the beam trapped between air- and water-rich structures, like the edematous interlobular septa, creating a phenomenon of resonance (Fig. 1). B line appears on the screen as a laser-like vertical beam, which arises from the pleural line and spreads up without fading to the edge of the screen (Fig. 2). Moreover, it is synchronous with lung respiratory movements. Computed tomography (CT) correlation suggested that B lines correspond to thickened interlobular septa with a width of no more than 700 μm, a size which is under the resolution of ultrasound but allows generation of the artifacts [1]. Several B lines visible in a single scan are called "lung rockets" or B+ lines (Fig. 3). This pattern disseminated in more scans on each lung defines diffuse alveolar-interstitial syndrome (Fig. 4) [1, 19].

The definition of diagnostic criteria of the ultrasound test for alveolar-interstitial syndrome is nowadays a matter of some debate. We know from literature how to define the B line, which has the features already described and must be critically distinguished from E and Z lines. These latter lines are two very similar artifacts. E lines are a sign of subcutaneous emphysema (E for emphysema) and are long but do not arise from the pleural line. Z lines are devoid of clinical meaning and differ from B lines because they quickly vanish without reaching the edge of the screen and are independent from lung respiratory movements [22]. How many B lines in a lung scan can be considered to be pathologic? There are some controversy in the literature about this point. Isolated B lines could be found in any thoracic scan of a normal lung. The pathologic pattern is detection of multiple B lines in a single scan (B+ pattern). In their original study performed by intensivists, Lichtenstein et al. observed that the mean distance between two adjacent interlobular septa at lung surface is never more than 7 mm, and this should be the widest distance between B lines to be significative. They concluded that using the microconvex

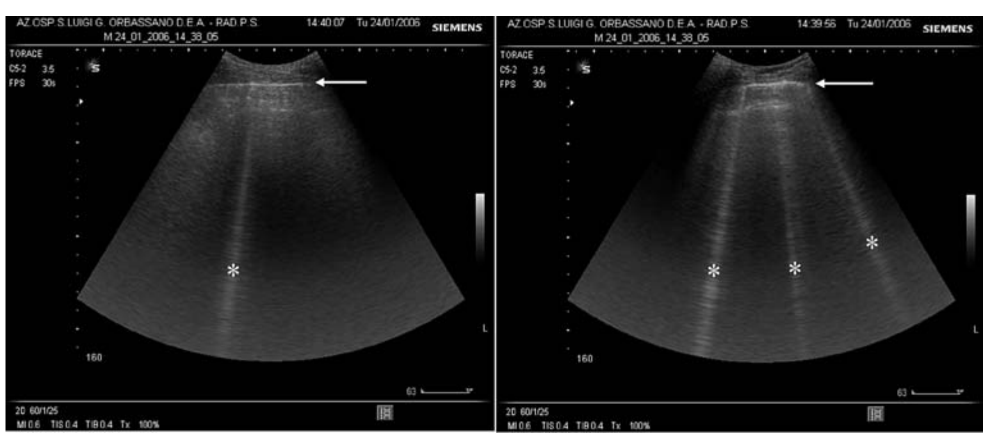

Fig. 2 *Left panel* oblique lung scan showing a single vertical artifact called comet tail or B line. This is a normal finding. *Right panel* a similar scan showing multiple comet tails <7 mm apart. This is still considered a normal finding. *Arrow* pleural line, *asterisks* comet tails

Fig. 3 Oblique lung scan showing multiple comet tails or B lines with a distance between them of less than 7 mm. This is the B+ pattern. *Arrow* pleural line, *asterisks* comet tails

probe three B lines should be enough to make diagnosis of a positive lung scan [1]. Reissig and Kroegel in their study performed with the linear probe in the hands of radiologists, adopted the criteria of more than six artifacts per scan [17]. The difference is because of diverse extension of the visualized pleural line using linear and microconvex probes. Our criterion to define a B+ pattern using the abdominal probe is to count at least three artifacts with a distance between adjacent lines of no more than 7 mm [19]. Visualization of isolated comet tails, called also B lines, or visualization of multiple artifacts of more than 7 mm apart in a single scan, is considered a normal finding (Fig. 2).

The technique

The ultrasound examination consists of bilateral scanning of the anterior and lateral chest walls performed on patients in supine or near-to-supine position, which is often mandatory in the emergency setting. This standardized position has the advantage of being applicable in any condition. We normally use the abdominal 3.5-MHz probe, with preset screen focus at the height of the visualized pleural line. The chest wall is divided into eight areas (two anterior and two lateral areas per side), for each of which one scan is obtained (Fig. 5). The anterior chest wall is delineated from the sternum to the anterior axillary line and is subdivided into upper and lower halves (approximately from clavicle to the second-third intercostal spaces and from the third space to diaphragm). The lateral zone is delineated from the anterior to the posterior axillary line and is subdivided into upper and basal halves. Each of the eight chest areas has two to three intercostal spaces with a number of possible positions of the probe. We normally proceed by firstly analyzing all the spaces by longitudinal scans, moving the probe over the thorax wall in a sliding movement. Once the sonographic image of pleural line is detected through location of the ribs and visualization of the "bat sign" (see Fig. 6 and legend for explanation) [22], we turn the probe to obtain the intercostal scan with the maximum extension of the visible pleura (oblique scan). Between the two and three intercostal scans recordable at each thoracic areas, we consider the most positive one (i.e., the scan with the higher number of B lines). The time needed to perform the examination varies from a few seconds to 1–2 min [19, 23].

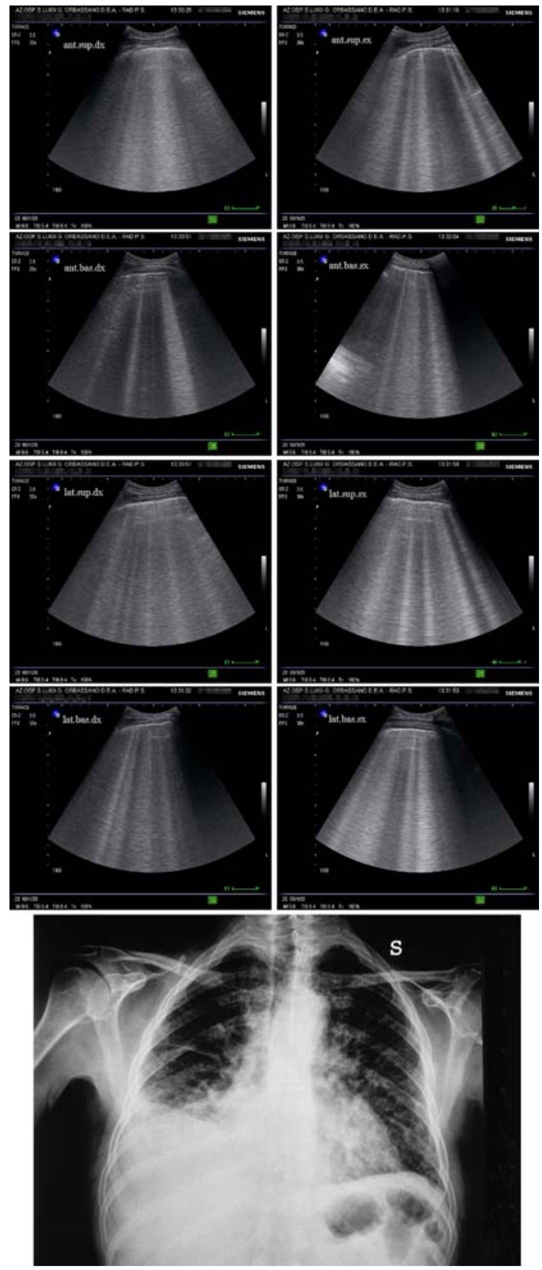

Fig. 4 A pattern of sonographic diffuse alveolar-interstitial syndrome in a case of cardiogenic pulmonary edema. *Upper panel* bilateral and multiple B+ patterns. *Lower panel* corresponding chest radiography showing signs of pulmonary congestion and pleural effusion

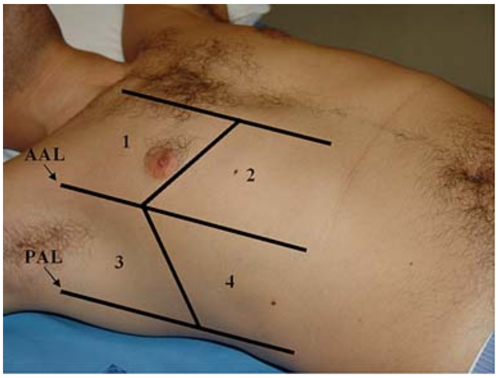

Fig. 5 The areas of thoracic ultrasonography. Areas *1* and *2* upper anterior and lower anterior. Areas *3* and *4* upper lateral and basal lateral. Each area was the same on right and left sides. *AAL* Anterior axillary line, *PAL* posterior axillary line

The definition of a positive ultrasound lung examination needs some careful considerations. On his first original paper, Lichtenstein did not provide a definition, shortly saying that bilateral detection of B+ patterns at the anterior chest areas allows diagnosis of the alveolar-interstitial syndrome [16]. Probably, this is enough in the critically ill patients admitted to an ICU and submitted to invasive ventilation. Agricola et al. defined a positive test result as bilateral multiple comet tail images either disseminated all over the anterolateral lung surface or limited to the lateral lung surface, which is a little more outlined [24]. In our opinion, especially in the daily practice of an emergency department (ED), we would need a better definition of what should be considered positive (or pathologic), because diseases are more various and less severe than in the ICU setting. Moreover, data from literature show that multiple B lines could be detected also in laterobasal scans of patients with normal lungs. This was shown by some authors, with a percentage ranging from 14% to 28% [1, 17, 25]. In our experience on ED patients admitted with any diagnosis, B+ lines can be seen in any transthoracic ultrasound scan even in patients with normal lung but isolated and mainly confined to the laterobasal areas (see Table 1 for percentages) [23]. Another point is that B+ lines could be detected even in areas surrounding isolated radiographic alveolar consolidations [1, 19, 23]. This features could be confounding when bedside lung ultrasound is performed to rule out the sonographic alveolar-interstitial syndrome, because B+ scan detection at some thoracic areas are not necessarily linked to diffuse interstitial lung involvement. This is the reason why a criteria of detection of B+ pattern on at least two scans on each side should be adopted to make the diagnosis of diffuse alveolar-interstitial syndrome when sonography is performed by four transthoracic scans per side [19, 23].

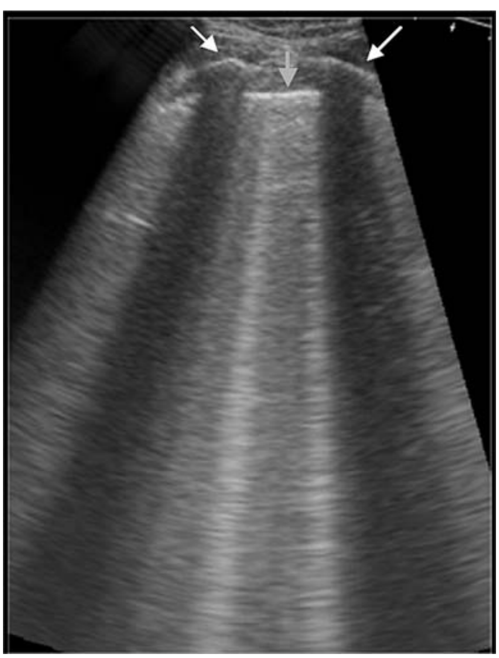

Fig. 6 A longitudinal sonographic lung scan showing the bat sign. This sign allows detection of the pleural line between two adjacent ribs. The ribs would be the wings while the pleural line, between and under them, would correspond to the body of the bat. This sign is useful to detect the pleura. *Grey arrows* ribs, *white arrow* pleura

The clinical utility of ultrasound

Diagnosing sonographic alveolar-interstitial syndrome at bedside and real time may have immediate effects on the management of critically ill patients. A problematic differential diagnosis between respiratory and cardiogenic cause of acute dyspnea could flow into dangerous delay in the beginning of proper treatment or administration of useless therapy. The interpretation of radiologic signs of pulmonary congestion, such as redistribution and interstitial edema, are often questionable and subjective, especially in case of bad quality films. Moreover, good reading requires a radiologist and is not immediate. If a simple ultrasound unit is available, clinicians could diagnose or exclude the

Table 1 Distribution of 85 positive scans (B+ lines) recorded in the 8 individualized areas of transthoracic lung ultrasound in a group of 145 patients with normal lungs at chest radiography and clinical final diagnosis (Volpicelli et al. [23])

Areas of thoracic ultrasound	Positive scans	Percent
Upper anterior right	4	2.8
Lower anterior right	4	2.8
Upper lateral right	7	4.8
Laterobasal right	27	18.6
Upper anterior left	3	2.1
Lower anterior left	4	2.8
Upper lateral left	3	2.1
Laterobasal left	33	22.8

alveolar-interstitial syndrome in real time. There are two published studies which analyzed the accuracy of the lung ultrasound B+ pattern in the recognition of the alveolar-interstitial syndrome when compared to chest radiography and final diagnosis. The first one was performed in the ICU setting on critically ill patients mostly submitted to mechanical ventilation and showed a sensitivity of 93.4% and a specificity of 93.0%, together with a feasibility of 99% [1]. The other one was performed in the ED and showed similar results (sensitivity 85.7%, specificity 97.7%, feasibility 98.3%, interobserver variability 4.9%) [19]. In a series of patients seen by the intensivists in emergency situations, the recognition of any diffuse interstitial lung involvement ruled out in a few minutes (not to say seconds) some pulmonary pathologies but especially a respiratory cause of acute dyspnea like exacerbation of COPD [26]. Diagnosis of diffuse sonographic alveolar-interstitial syndrome allows detection of pulmonary edema with a sensitivity of 100% and specificity of 92% [26]. In a preliminary study, detection of interstitial involvement by lung ultrasound has shown to drive clinical decision with high accuracy [27]. The ultrasound examination is digitally recordable, and this is another advantage over auscultation. Moreover, permanent digital records of lung ultrasound scans allow monitoring of B+ pattern clearing during treatment of pulmonary congestion in acute decompensated heart failure and high-altitude pulmonary edema [28, 29]. Different studies showed that chest sonography targeted to assessment of B lines can be easily performed by intensivists [1], radiologists [17], ER physicians [19], and cardiologists [18]. Finally, it should be mentioned that the thickening of the interlobular septae in both chest ultrasonography and CT scans is a nonspecific sign, which does not allow distinction between cardiogenic pulmonary edema, ARDS, and interstitial pneumonia. The integration of sonography with other bedside tests and patient's history or even the serial lung ultrasound evaluation during diuretic treatment could be of value in discriminating between different causes of diffuse alveolar-interstitial syndrome (study in progress).

Conclusions

Ultrasound is an old technique, but its application on the lung in the emergency setting is a relatively new approach. The bedside recognition of diffuse sonographic alveolar-interstitial syndrome relies on examination of vertical artifacts comet tail or B line. They represent very easy-to-acquire ultrasound signs, which allow bedside distinction of pulmonary edema from exacerbation of COPD as the cause of acute dyspnea in the emergency setting. Lung ultrasound has the advantage of being nonionizing, immediately implemented, highly feasible, and time saving. We think it will spread very soon as a new visual stethoscope in the daily practice of radiologists, emergency physicians, intensivists, cardiologists, and pulmonologists.

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