Lung Ultrasound Imaging: A Primer for Echocardiographers

Eugene Yuriditsky, MD, James M. Horowitz, MD, Nova L. Panebianco, MD, Harald Sauthoff, MD, and Muhamed Saric, MD, PhD, *New York, New York; and Philadelphia, Pennsylvania*

Lung ultrasound (LUS) has gained considerable acceptance in emergency and critical care medicine but is yet to be fully implemented in cardiology. Standard imaging protocols for LUS in acute care settings have allowed the rapid and accurate diagnosis of dyspnea, respiratory failure, and shock. LUS is greatly additive to echocardiography and is superior to auscultation and chest radiography, particularly when the diagnosis of acute decompensated heart failure is in question. In this review, the authors describe LUS techniques, interpretation, and clinical applications, with the goal of informing cardiologists on the imaging modality. Additionally, the authors review LUS findings associated with various disease states most relevant to cardiac care. Although there is extensive literature on LUS in the acute care setting, there is a dearth of reviews directly focused for practicing cardiologists. Current evidence demonstrates that this modality is an important adjunct to echocardiography, providing valuable clinical information at the bedside. (J Am Soc Echocardiogr 2021;34:1231-41.)

Keywords: Lung ultrasound, Heart failure, Point-of-care ultrasound

Historically, aerated lungs and the bony thorax have been viewed as barriers to sonographic evaluation. However, altered pleural and parenchymal tissue characteristics produce specific artifacts that can be used to aid in diagnosis of lung pathologies.[1-3] Normal, aerated lung is characterized by very different acoustic impedance compared with the chest wall, resulting in near complete reflection of the ultrasound signal at the lung surface. In contrast, when air is replaced by tissue of similar acoustic impedance to soft tissue, such as in cases of pneumonia, ultrasound is transmitted, allowing distinct image formation.[4]

Lung ultrasound (LUS) was pioneered by Dr. Daniel Lichtenstein in 1989 at the University Hospital Ambroise Paré.[5] This modality has gained significant acceptance across fields such as critical care and emergency medicine, as it allows rapid bedside assessment of patients with respiratory failure without the drawbacks of conventional radiography and chest computed tomography (CT).[6,7] Furthermore, LUS is additive to echocardiography and is part of multiple point-of-care ultrasound (POCUS) protocols in the evaluation of hypotension, shock, and cardiac arrest.[3,5,6] This ultrasound imaging modality has been proved to be superior to portable chest radiography, is more rapid and less resource intensive than chest CT, and is considered the standard of care for critically ill patients.[3,8-10] Additionally, unlike radiography and CT, LUS involves no ionizing radiation and can be repeated without additional risk to the patient.

Although some published literature on LUS exists in cardiology journals, cardiologists are yet to fully apply this imaging modality in daily practice.[4,8,11] LUS is thought to be a fairly simple skill with quick examination time (<5 min) and high intra- and interobserver reproducibility.[12,13] With increased availability of portable and pocket-sized POCUS devices, understanding of LUS can be additive to clinical data in the evaluation and management of acute decompensated heart failure (ADHF) or shock.[3,14] As providers are frequently called to perform emergent bedside echocardiography, a basic understanding of extracardiac findings would be additive in answering the clinical question and further elucidating the patient's noninvasive hemodynamic profile. In the face of the coronavirus disease 2019 (COVID-19) pandemic, with cardiologists often deployed to COVID-19 units to assess patients with complex cardiac and pulmonary derangements, this skill is particularly important.

Although LUS may be considered a novel application of ultrasound in cardiology practice outside of acute care, echocardiography societal awareness and application of this imaging modality has traction. The National Board of Echocardiography Examination of Special Competence in Critical Care Echocardiography content outline includes lung and pleural ultrasound as topics under the section of "integrated ultrasound imaging."[15] In this article, we review LUS techniques, applications, and findings associated with different pathologies as they would be relevant to cardiologists. In the hands of trained providers, this safe, portable, and repeatable diagnostic imaging modality

From the Division of Cardiology, Department of Medicine, New York University School of Medicine, New York, New York (E.Y., J.M.H., M.S.); the Department of Emergency Medicine, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania (N.L.P.); and the Division of Pulmonary, Critical Care, and Sleep Medicine, Department of Medicine, New York University School of Medicine, New York, New York (H.S.).

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Reprint requests: Eugene Yuriditsky, MD, Division of Cardiology, Department of Medicine, New York University School of Medicine, 530 First Avenue, Skirball 9R, New York, NY 10016 (E-mail: *eugene.yuriditsky@nyumc.org*).

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Abbreviations

ADHF = Acute decompensated heart failure

BLUE = Bedside lung ultrasound in emergency

COPD = Chronic obstructive pulmonary disease

COVID-19 = Coronavirus disease 2019

CT = Computed tomography

FALLS = Fluid administration limited by lung sonography

HF = Heart failure

LUS = Lung ultrasound

PE = Pulmonary embolism

PLAPS = Posterolateral alveolar and/or pleural syndrome

POCUS = Point-of-care ultrasound

can reduce patient cumulative radiation exposure, prevent unnecessary tests, and enhance clinical care at the bedside.

IMAGING PRINCIPLES

The principles of LUS are founded in direct visualization of anatomic structures and uniquely to the interpretation of artifacts that would normally limit imaging.[2,4,10] In normal aerated lungs, the pleura is the only visible structure, as air beneath the pleura dissipates the ultrasound beam. In contrast, pleural and parenchymal disease alters tissue characteristics and generates signature artifacts. Although LUS is commonly used to evaluate for parenchymal pathology, it may also be used to assess for disease of the parietal pleura and abnormal fluid collections around the lung.

Equipment and Settings

Portable POCUS machines, including handheld devices, are suitable for the performance of LUS. The technology is simple, as there is no requirement for filters, harmonic imaging, or Doppler.[5,11,16] The probe, preset, and scanning technique varies on the basis of the clinical question. When performing an examination to assess for interstitial lung water (B-lines), images are optimized by selecting the phased-array or curvilinear transducer, using the lung preset, the focal zone set to the level of the pleura, tissue harmonics off, gain increased in the far field, and a scanning depth of roughly 15 cm on the basis of the habitus of the patient.[17] When assessing more superficial pleural-based structures, the image is optimized by using the high-frequency linear transducer, with gain set so that the rib shadow is black and the pleural line is white, focal zone at the pleural line, and the depth varying on the basis of the patient's habitus.

Imaging Transducers

Although standard echocardiography is performed using a phased-array transducer, LUS can be performed with a variety of transducers. Linear, phased-array, or curvilinear transducers can be used in LUS with specific advantages and disadvantages to each selection according to the clinical question[6,18,19]:

- High-frequency linear probes in the range of 7 to 13 MHz provide the best imaging of the pleura and are most suited to evaluate for lung sliding to assess for pneumothorax or parietal pleural-based pathology. In larger patients, beam penetration may be insufficient, as depth is usually limited to 6 cm.
- Curvilinear probes in the range of 1 to 5 MHz have improved penetration for deeper structures such as pleural effusions or consolidated lung. Initial screening for deep and superficial structures can be performed with this transducer. The large footprint of the transducer can make scanning between ribs more challenging, though it allows information to be obtained from across multiple rib spaces at once.
- Phased-array probes in the range of 2 to 5 MHz offer a smaller footprint compared with curvilinear probes, are most accessible to the cardiologist, and allow both LUS and cardiac ultrasound. These transducers are great multipurpose devices for pleural, parenchymal, and cardiac imaging.

Scanning Technique

Traditionally, the transducer is placed perpendicular to the ribs with the indicator facing cephalad. Alternatively, it can be positioned parallel to the intercostal space to visualize a larger segment of the pleura.[11] LUS can be performed with the patient in any position. There are multiple imaging protocols described in the literature, each tailored to a specific clinical scenario ranging from simple four-region scans to >28-region scans.[3,5,6,20,21] There are two scanning protocols we believe are most relevant to cardiologists in the rapid evaluation of respiratory failure at the bedside: the bedside lung ultrasound in emergency (BLUE) protocol and scanning at the third intercostal space.

The BLUE Protocol

The BLUE protocol is designed for rapid diagnosis of respiratory failure in a supine patient, with scanning limited to three zones per hemithorax (Figure 1).[5,16,22,23] Zones are defined as follows:

- The upper BLUE point is located at the anterior chest at the midclavicular line and second to third intercostal space.
- The lower BLUE point is located at the lateral chest at the anterior axillary line and just above the nipple.
- The posterolateral alveolar and/or pleural syndrome (PLAPS) point is located at the posterior axillary line at the most inferior point above the diaphragm. The PLAPS point allows the diagnosis of consolidation and pleural effusions.

Scanning at the Third Intercostal Space

It has been demonstrated that in a semisupine patient, signs consistent with pulmonary edema ("wet spots"), described subsequently, are most prominent at the third intercostal space along the midaxillary and anterior axillary lines.[24] As the diagnosis of heart failure (HF), semiquantitative analysis of pulmonary edema, and differentiation from alternative causes of dyspnea are of most interest to cardiologists, this simple four-point scan may offer an optimal balance between accuracy and simplicity.

SIGNS AND FINDINGS ON LUS

There are a number of common signs described on LUS to aid in the differentiation of various pathologies (Table 1).[5,11,14,18] Much of the nomenclature assigned to these findings originates from Dr. Lichtenstein's original description of pulmonary findings with ultrasound and have persisted as the field of work has expanded. A limitation of LUS is that the pathology must extend to the pleura to be amenable to sonographic evaluation, as intraparenchymal and mediastinal pathology may not be well visualized. Establishing the

HIGHLIGHTS

- LUS has gained wide acceptance, is simple, and is additive to echocardiography.
- LUS can rapidly assist in the evaluation of acute dyspnea.
- B-lines, a finding in pulmonary edema, are diagnostic and prognostic in HF.

diagnosis of pulmonary edema and differentiation from alternative causes of dyspnea and/or pain are of most interest to cardiologists. LUS findings must be integrated with clinical data and pretest probability.

The Normal Pattern

With the ultrasound transducer placed perpendicular to a rib space, the hyperechoic pleural line, also termed the visceral-parietal pleural interface, is visualized deep to the ribs (Figure 2A). The "bat sign" describes the view obtained with the ribs appearing as wings. Lung sliding represents the normal horizontal side-to-side motion of the visceral pleura over the parietal pleura during spontaneous and mechanical respiration.[5,19,25] Flickering or shimmering visualized at the pleural line during respiration occurs when the visceral and parietal pleural are normally opposed (Video 1).[3,25]

M-mode helps define lung movement relative to the motion of superficial structures.[5,6,11] The M-mode corollary to lung sliding is termed the "seashore sign." The stationary chest wall and subcutaneous tissue appear as parallel lines above the pleura, analogous to water on the shore. Lung motion with respiration (motion of the alveolar septae below the pleural line) creates a speckled or grainy appearance analogous to sand appearing below the pleura (Figure 2B).

A-lines are reverberation artifacts appearing as repetitive, horizontal, equidistant reflections of the hyperechoic pleural line and are indicative of gas beneath the pleura. As the ultrasound beam encounters the boundary between visceral pleura and air beneath, >99% of the beam is reflected back, with the pleural line appearing as a white band (Figure 3, Video 2).[5,8,26] The "A-profile," defined by the presence of lung sliding together with A-line artifacts, is consistent with a normal pattern.[5,6,26] However, such a pattern may also be present in the setting of disease processes sparing the parenchyma (i.e., asthma, pulmonary embolism [PE]).

Alveolar and Interstitial Pathology Including Pulmonary Edema

Reverberation artifacts generated from impedance mismatch between air and fluid-filled or thickened intralobular septae are termed B-lines.[5,11,23,26-28] The presence of three or more B-lines at a single intercostal space, termed the "B-profile," is indicative of an alveolar or interstitial process such as pulmonary edema, acute respiratory distress syndrome, or pulmonary fibrosis (Figure 4, Videos 3 and 4).[23,26,28]

Features almost constant of B-lines are as follows:

- they arise from the pleural line,
- they move in concert with lung sliding,
- they are well defined and laserlike,
- they are long and spread vertically to the edge of the screen (≥13 cm in depth),
- they often obliterate A-lines, and
- they are hyperechoic.

Vertical artifacts other than B-lines can be identified on LUS but do not meet the above criteria. For instance, Z-lines are short, do not abolish A-lines, and have no pathologic significance, while E-lines arise above the pleural line in subcutaneous emphysema.[3,5] As B-lines are commonly reflective of interstitial or pulmonary edema, this finding is of most interest to cardiologists. In a large meta-analysis of 1,301 patients, the sensitivity and specificity of B-lines for pulmonary edema were 97% and 98%, respectively (Table 2).[29,30] Distinguishing the various alveolar or interstitial processes requires additional clinical and sonographic information, as subsequently described. In pulmonary congestion, B-lines are dynamic; just like pulmonary edema, they can resolve rapidly with treatment.[4,31-34] By guidelines, three or more B-lines should be noted in at least two zones bilaterally.[6,23,35] As gravity alone can lead to posterior interstitial changes, only anterior B-lines are considered in the BLUE protocol.

Pneumothorax

Pneumothorax results in air in the potential space between the visceral and parietal pleura and abolishes ultrasonographic lung sliding (Video 5).[5,6,11,18] In a positive pneumothorax scan, the

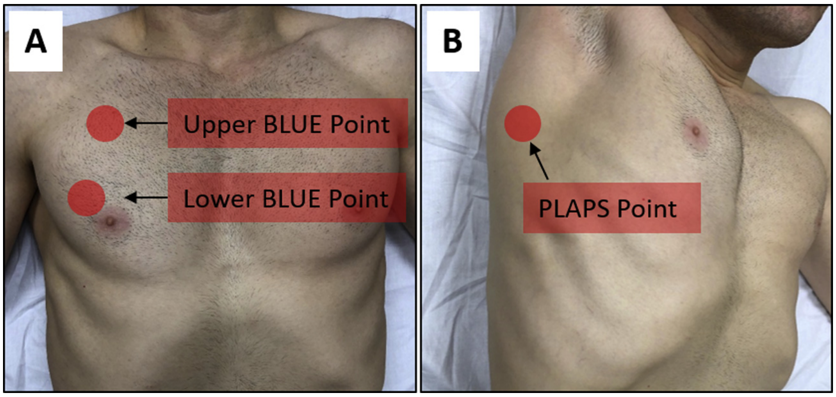

Figure 1 Chest landmarks. **(A)** The upper and lower BLUE points identified on the anterior chest. **(B)** PLAPS point as the intersection between the lower BLUE point and the posterior axillary line.

Table 1 Signs and definitions on LUS

Sign	Sonographic description	Clinical significance
Bat sign	Pleural line visualized between two ribs	Normal architecture visualized with the transducer placed at an intercostal space perpendicular to the ribs
Lung sliding	Flickering or shimmering at the pleural line with respiration	Normal opposition of the visceral and parietal pleural with motion during respiration
Seashore sign	M-mode corollary to lung sliding; motionless chest wall creates horizontal "waves," while sliding creates "sandy" echotexture beneath the pleura	Ancillary sign in the confirmation of lung sliding
Abolished lung sliding	Lack of opposition between the pleural surfaces or adherence of the visceral and parietal pleural layers	Pneumothorax, pleural adhesions, massive atelectasis, pulmonary fibrosis
Stratosphere/ barcode sign	M-mode corollary to abolished lung sliding; parallel horizontal lines visualized above and below the pleura	Ancillary sign to 2D ultrasound in the confirmation of abolished lung sliding
Lung point	Intermittent lung sliding in contact with the chest wall during inspiration	Specific for the diagnosis pneumothorax and size estimation
A-lines	Horizontal reverberation artifacts of the pleural line	Gas beneath the parietal pleura indicates absence of alveolar/interstitial disease; seen in normal lungs, pneumothorax, asthma or COPD
A-profile	A-lines in conjunction with lung sliding	Normal parenchymal appearance with respiration
B-lines	Vertical, hyperechoic, laserlike reverberation artifacts extending ≥13 cm	Alveolar/interstitial process such as pulmonary edema, ARDS, pulmonary fibrosis, pneumonia
B-profile	B-lines in conjunction with lung sliding	Alveolar/interstitial process such as pulmonary edema without adherent pleural layers
Tissuelike sign	Lung has the appearance of liver	Translobar consolidation
Shred/fractal sign	Irregular, fractal-like appearance at the border of consolidated and aerated lung	Nontranslobar consolidation
Quad sign	Fluid demarcated by rib shadows, visceral pleura, and parietal pleura	Pleural effusion
Z-lines	Static vertical artifacts, do not move with lung sliding, fade with depth	No pathologic significance

2D, Two-dimensional; *ARDS*, acute respiratory distress syndrome.

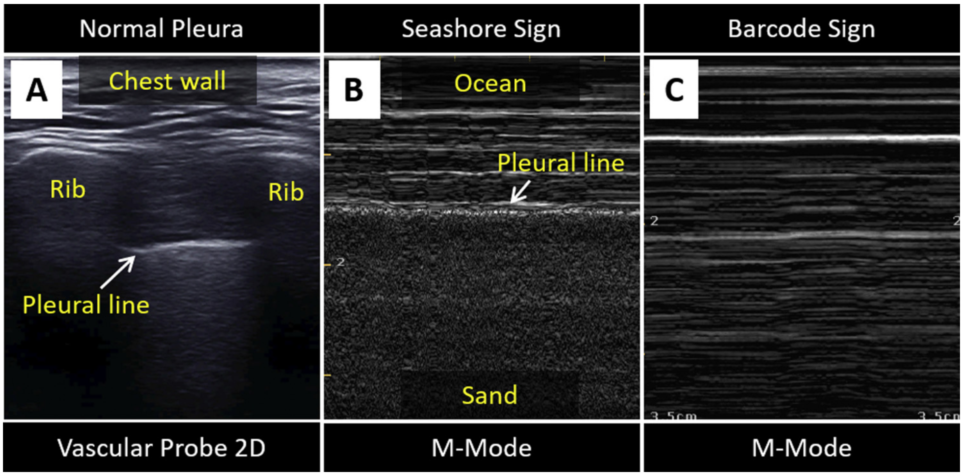

Figure 2 Pleural lines. **(A)** Normal hyperechoic pleural line visualized between two ribs with the transducer in a perpendicular orientation. **(B)** M-mode of lung sliding with horizontal lines above the pleura representing the chest wall and grainy echotexture below the pleural line indicative of lung sliding. This signature is termed "seashore sign." **(C)** M-mode of abolished lung sliding appearing as multiple horizontal lines termed the "barcode" or "stratosphere" sign.

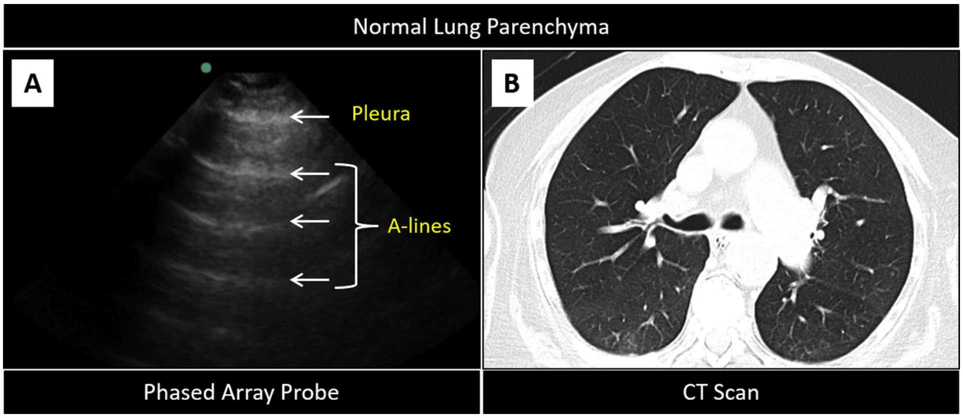

Figure 3 A-lines. **(A)** Two-dimensional image of A-lines, reverberation artifact from the pleural line, obtained with a phased-array transducer. **(B)** Chest CT of normal lung parenchyma for reference.

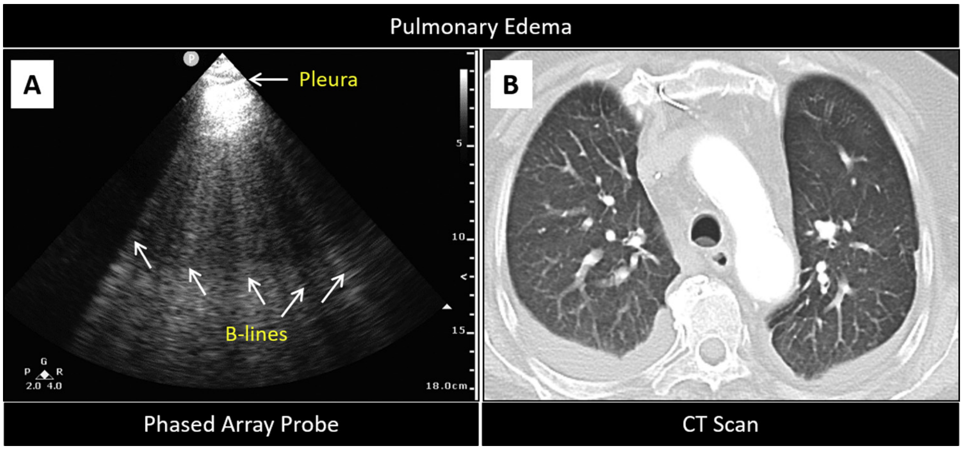

Figure 4 B-lines. **(A)** Two-dimensional image of multiple B-lines in a patient with pulmonary edema obtained with a phased-array transducer. **(B)** Pulmonary edema on chest CT.

Table 2 Selected meta-analyses evaluating sensitivity and specificity of LUS in various clinical scenarios

Diagnosis	Ultrasound findings	Number of patients	Sensitivity (%)	Specificity (%)	Reference
Pulmonary edema	B-lines	1,075	94	92	27
	B-lines	1,301	97	98	26
Pneumothorax	Abolished lung sliding, absent B-lines	1,048	90	98	34
	Abolished lung sliding, absent B-lines, lung point	7,569 (hemithoraces)	88	99	33
Pneumonia	Focal B-lines, consolidation with air bronchograms	742	95	90	36
	Focal B-lines, subpleural consolidation	5,108	92	93	37
PE	Wedge-shaped subpleural lesions	1,356	85	83	39
	Wedge-shaped subpleural lesions	887	87	82	40
Pleural effusion	Anechoic or hypoechoic space	1,554	94	98	35
COPD/asthma exacerbation	A-profile without PLAPS	527	78	94	42

pleural line appears as a static structure without shimmering over the respiratory cycle. If B-mode imaging is equivocal, M-mode scanning serves as a confirmatory tool. The M-mode corollary to absent lung sliding is termed the "barcode sign" or the "stratosphere sign." In contrast to the sandy appearance below the pleural line with normal lung sliding, repetitive horizontal lines are visualized both above and below the pleural line (Figure 2C).[5,6,25] B-line artifacts are absent in pneumothorax, as these arise from the visceral pleura

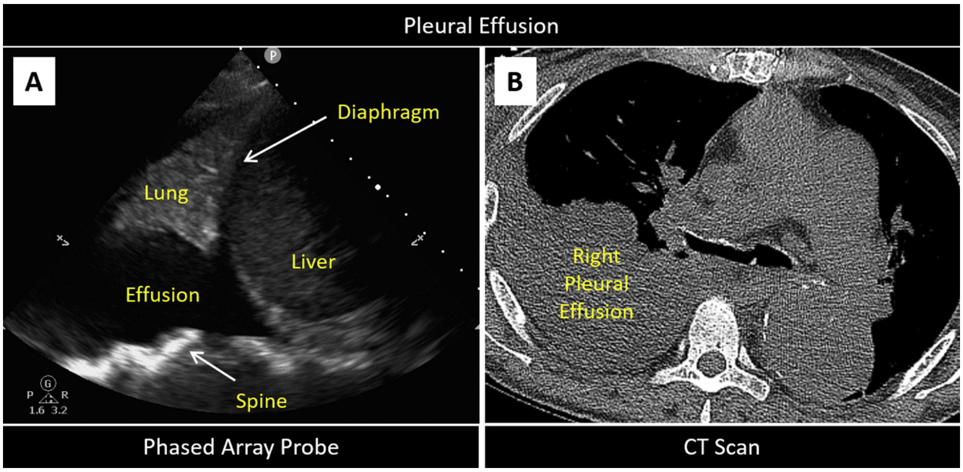

Figure 5 Pleural effusion. **(A)** Two-dimensional image obtained with a phased-array transducer demonstrating an anechoic pleural effusion with atelectatic lung. The liver is visualized to the right of the image, and the spine is apparent beneath the effusion. **(B)** Chest CT demonstrating a pleural effusion for reference.

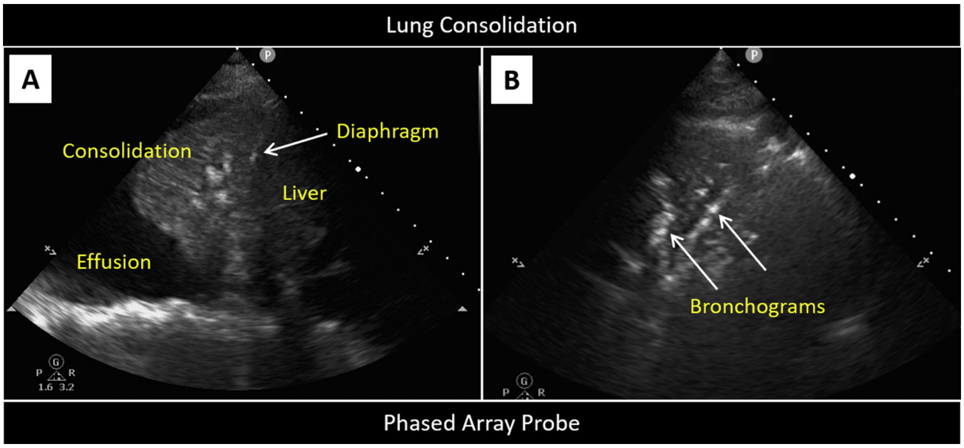

Figure 6 Lung consolidation. **(A)** Two-dimensional image of consolidated lung obtained with a phased-array transducer. The consolidated lung appears similar in echotexture to the liver *(right)* and is contained within a pleural effusion. **(B)** Additional example of pneumonia with air bronchograms visible within the consolidation.

and cannot be visualized when there is air inhibiting contact with the parietal pleura.

The absence of lung sliding suggests the presence of a pneumothorax. However, a "lung point," which is the transition zone exhibited by lung sliding of the noncollapsed lung that contacts the visceral pleura and the collapsed lung that does not connect, is most specific sign for this pathology (Video 6). Although chest radiography and LUS are both very specific for pneumothorax, LUS is significantly more sensitive (52% vs 88%, respectively).[36,37] Although the presence of a lung point rules in pneumothorax, this finding may be absent in cases of a small or posterior pneumothorax. Similarly, lung sliding may be absent in the setting of prior pleurodesis, pneumonia, pulmonary blebs, and contusion and therefore cannot be taken outside of the context of the patient.

Pleural Effusion

In cardiology, we are accustomed to visualizing pleural effusions in standard echocardiographic windows. Placing the transducer at the PLAPS point on either side, just slightly above the diaphragm at the posterior axillary line, provides an alternative window.[5,6] The indicator is directed cephalad with the diaphragm and liver or spleen located at the right side of the image. Effusions appear anechoic or hypoechoic in contrast to consolidated lung, which appears as a tissue density commonly referred to as "hepatization" (Figure 5, Video 7).[6,19,38] This view eliminates the need to distinguish pleural effusions from pericardial effusions, which, with poor echocardiographic windows, may be challenging. Air-filled lungs obscure visualization of the spine above the diaphragm. In the setting of pleural effusion, ultrasound waves are transmitted through the fluid, allowing visualization of the spine as an additional clue to the presence of an effusion. Similarly, the presence of a mirror artifact above the diaphragm suggests a lack of pleural effusion. Several studies have evaluated echogenic findings of pleural fluid to determine if effusions are exudative or transudative.[39,40] For instance, presence of complex fluid with septations is consistent with an exudative effusion.

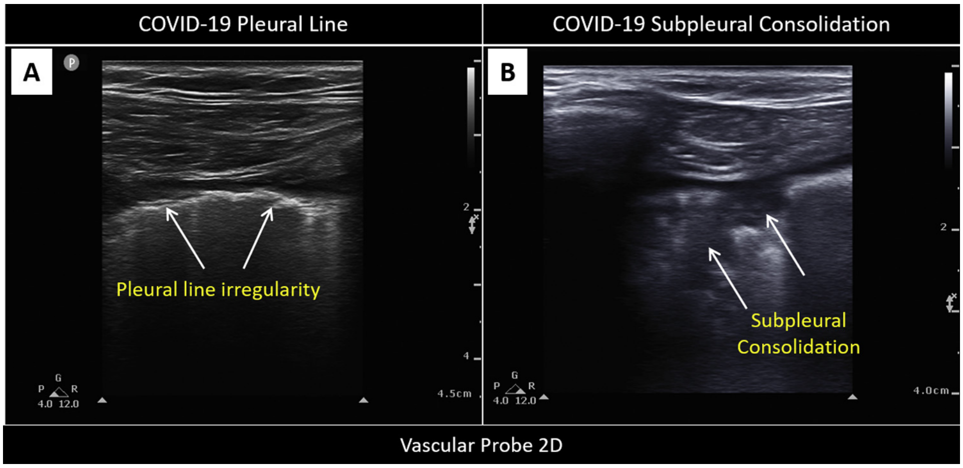

Figure 7 COVID-19 LUS findings. **(A)** Two-dimensional image of an irregular, fragmented pleural line obtained using a high-frequency transducer. **(B)** Subpleural consolidation visualized as a hypoechoic structure with irregular margins.

Consolidation and Atelectasis

Lung consolidations are commonly located at the PLAPS point. The distinction between atelectasis and consolidation is often challenging. A large, translobar consolidation has the echotexture of liver termed the "tissuelike" or "hepatization" sign.[6,19,41,42] Other findings may include an irregular, fractal-like line between consolidated and aerated lung, termed the "shred sign." Air bronchograms, white tubular structures within a consolidation, may be observed in cases of pneumonia (Figure 6, Video 8).[5,6,43] With findings of focal B-lines and air bronchograms, LUS has been shown to be up to 95% sensitive and 93% specific for the diagnosis of pneumonia in large meta-analyses (Table 2).[41,42]

Pulmonary Embolism

The sensitivity and specificity of LUS for PE are upward of 83% and 85%, respectively, with the predominant finding being pleural-based consolidations consistent with infarction.[44,45] Alternatively, the finding of A-lines with lung sliding in the setting of acute dyspnea or respiratory failure, in conjunction with deep venous thrombosis, is highly specific for PE.[5,26] Multiorgan sonography, including the combination of LUS, lower extremity venous sonography, and echocardiography, in the assessment of the right ventricle has been described as a reasonably sensitive and specific approach for the diagnosis of PE.[46]

LUS with echocardiography cannot be used alone for the diagnosis of acute PE, because sonographic findings are most commonly associated with intermediate- and high-risk PE, and therefore low-risk clots may be missed. However, it can function as an adjunct or valuable alternative in the emergency setting or when CT is not immediately available or the patient is too unstable to move or to evaluate for right heart strain when assessing the significance of the injury. Similarly, in a patient with hemodynamic instability and no findings of PE on ultrasound, the root cause of instability is unlikely secondary to acute PE.

Chronic Obstructive Pulmonary Disease and Asthma

Chronic obstructive pulmonary disease (COPD) and asthma are bronchial diseases sparing the pleural surface and parenchyma. The finding of bilateral lung sliding with A-lines without PLAPS is the sonographic finding consistent with COPD or asthma and is 94% specific for this condition.[26,47] Although this pattern makes pleural and parenchymal processes unlikely, it can also be a normal finding or observed in the setting of PE.

COVID-19

LUS is of particular interest during the COVID-19 pandemic. Early in the US pandemic, diagnostic testing was limited, personal protective equipment shortages inhibited traditional diagnostic practice, and although chest CT was specific for the disease, this imaging modality was generally limited to stable patients. Sonographic findings of COVID-19 pneumonia are those typical of acute respiratory distress syndrome.[48,49] B-lines are frequently seen but may be nonhomogenous and patchy in contrast to cardiogenic pulmonary edema. The pleural line may appear irregular with areas of discontinuity (Figure 7A). Subpleural consolidations appear as hypoechoic structures with irregular (shredded) borders (Figure 7B, Video 9). Handheld POCUS devices with wireless tablets can be placed in separate plastic covers to minimize contamination risk. Additionally, the teleguidance feature on some handheld devices can limit the need for imaging experts to have direct patient contact.[50,51] In this disease, LUS findings may be predictive of clinical outcomes such as intensive care unit admission and mortality.[52,53] A scoring system incorporating the extent of B-lines and the presence of consolidation, in conjunction with limited echocardiographic findings evaluating ventricular function, may be valuable in identifying those at risk for certain clinical end points.[53]

CLINICAL APPLICATIONS OF LUS

The main LUS protocols are targeted toward emergency and critical care providers and tailored to provide a prompt diagnosis of respiratory failure and circulatory shock integrating cardiac ultrasound in a holistic approach.[5,6,20,54] For cardiologists, LUS can be a key diagnostic tool to be incorporated into the care of patients in the cardiac intensive care unit. Additionally, this modality has gained traction in the assessment of pulmonary congestion before hospital discharge and in the outpatient setting.[24,32,55-58]

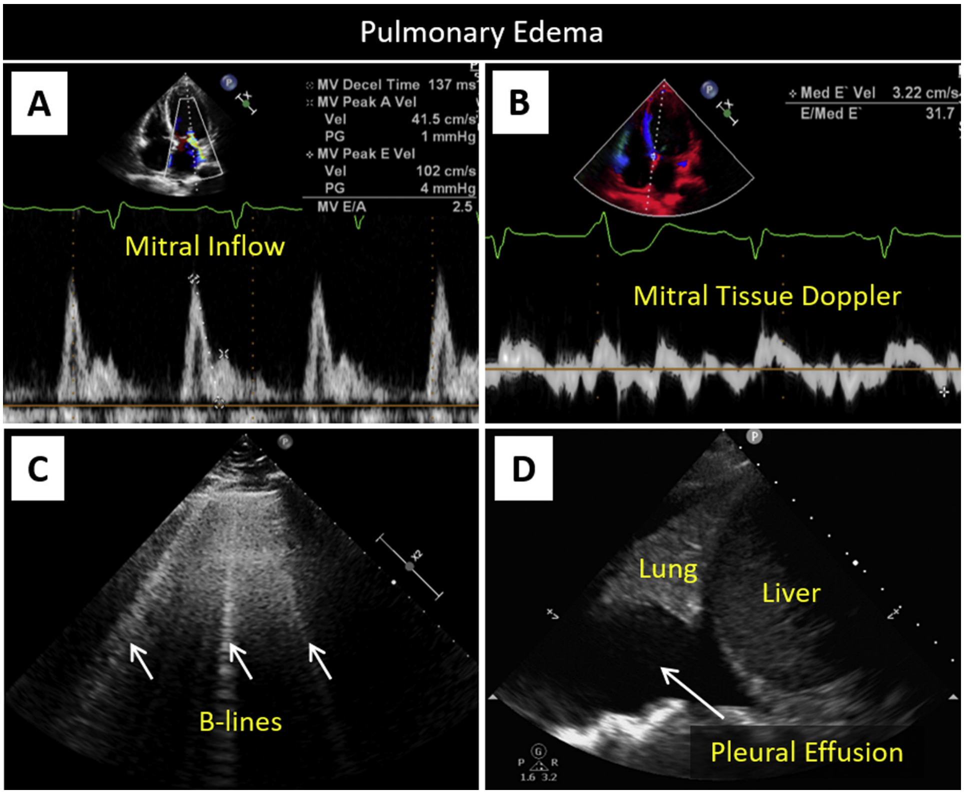

Figure 8 Pulmonary edema. **(A)** Pulsed-wave Doppler at the mitral valve demonstrating rapid E-wave deceleration. **(B)** Tissue Doppler at the medial mitral annulus demonstrating low e′ velocities consistent with elevated left atrial pressure. **(C)** Multiple B-lines obtained using a phased-array transducer. **(D)** Pleural effusion on LUS.

LUS in Decompensated HF in the Nonemergent Setting

ADHF is a diagnostic challenge. Physical examination, chest radiography, and natriuretic peptides have limited accuracy in the detection of pulmonary congestion.[6,26,29,30,34,35] LUS is recommended by the European Society of Cardiology guidelines in the diagnosis and management of decompensated HF.[57] Adding LUS to a standard diagnostic approach of dyspnea and suspected HF in the emergency department, 19% of patients are reclassified in terms of diagnosis.[35] The quantity of B-lines has significant correlation with left-sided filling pressures, radiographic pulmonary edema, and measures of extravascular lung water.[24,33,56,59] Compared with echocardiographic assessment of left atrial pressure, LUS is exceedingly simple.[59] When encountering a patient with suspected ADHF, the major questions to ask are whether there are multiple diffuse B-lines consistent with pulmonary edema and whether an alternative etiology explains the clinical presentation (i.e., pneumonia, COPD).

There is mounting evidence that LUS can be used in the outpatient setting to titrate medications, reduce hospitalizations, and improve patient-reported quality metrics.[7,56] B-lines detected by LUS in the outpatient setting among patients with HF are associated with readmission and mortality even in the absence of auscultatory findings to suggest pulmonary edema.[57,60] Additionally, the number of B-lines present on hospital discharge has been associated with mortality and hospitalization.[61] When compared with standard follow-up outpatient care, a LUS-guided diuretic management approach has been shown to decrease the number of decompensations and improve walking capacity.[62] LUS has been implemented during exercise stress testing; fewer B-lines are associated with event-free survival.[20] As these artifacts are dynamic and resolve with diuresis and dialysis, frequent LUS can be an adjunct to monitoring progress and in the diagnosis of euvolemia in this population.

LUS in Acute Dyspnea

When evaluating acute respiratory failure with LUS, the first questions to ask are (1) Is lung sliding present? and (2) Do I see an A-lines or B-lines?[5,18,19,26] This assessment can be performed using the upper and lower BLUE points, while interrogation of the PLAPS point thereafter can identify consolidation or pleural effusion. Following is a simplified LUS approach to the patient with acute respiratory failure.

- Lung sliding with extensive B-lines (B-profile) defines alveolar-interstitial syndrome and is very sensitive and specific for pulmonary edema, a more common entity than interstitial lung disease. Subsequent workup with cardiac ultrasound can define the mechanism of pulmonary edema (i.e., left ventricular systolic dysfunction, acute valvular regurgitation).
- Lung sliding with A-lines (A-profile) excludes pulmonary edema as a cause of acute respiratory failure and makes the diagnosis of COPD, asthma, or PE more likely. Venous sonography can be added to the workup; deep venous thrombosis with an A-profile in a patient with acute dyspnea is highly specific for PE. Additional evaluation of the PLAPS point can further define pneumonia or pleural effusion when the diagnosis is in question.
- Abolished lung sliding with A-lines (A′-profile) raises concern over pneumothorax, as this pattern suggests that the visceral and parietal pleura are

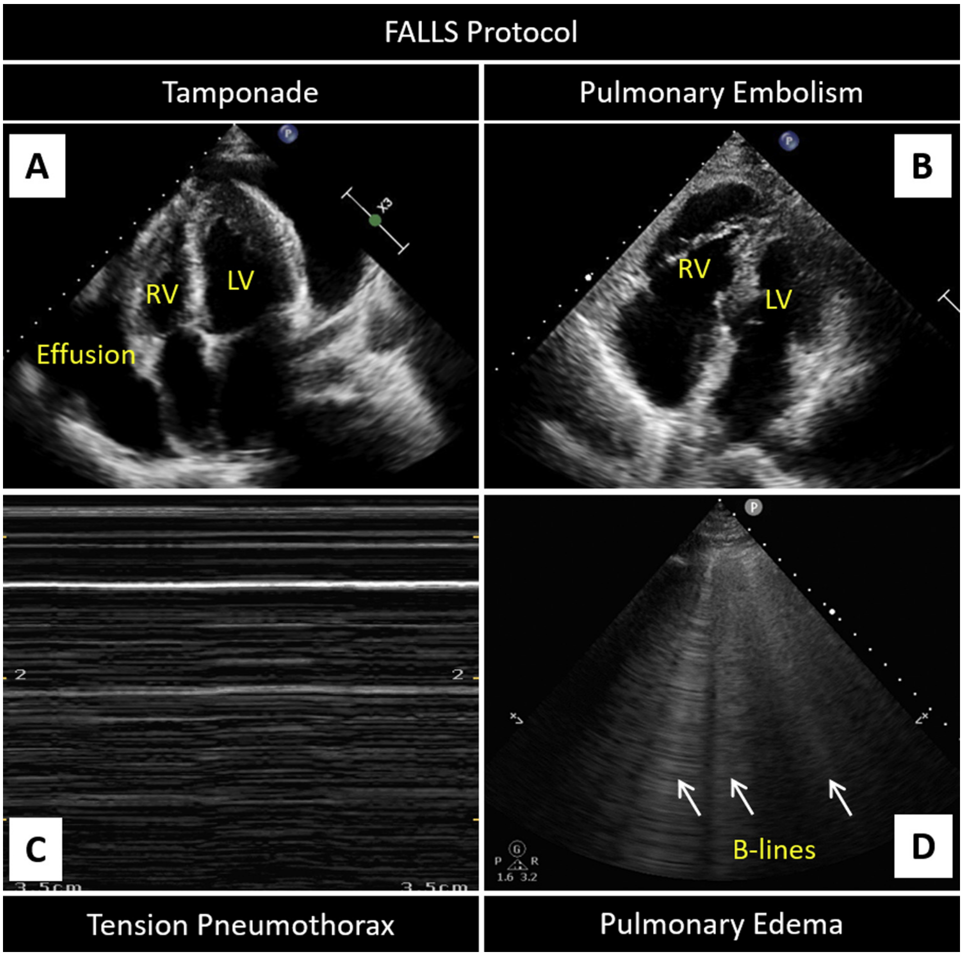

Figure 9 Examples of pathologies detected using the FALLS protocol in shock. **(A)** Echocardiogram demonstrating pericardial effusion in a patient with clinical tamponade. **(B)** Echocardiogram demonstrating right ventricular dilation in a patient with PE and shock. **(C)** LUS M-mode demonstrating pneumothorax. **(D)** LUS demonstrating pulmonary edema in a patient with cardiogenic shock.

unopposed. Identifying a lung point, the transition between present and abolished lung sliding, is highly specific for pneumothorax.

- Abolished lung sliding with B-lines (B′-profile) is most consistent with pneumonia at a particular zone. Unlike the A′-profile, abolished lung sliding in this scenario is consistent with adhesion of the two pleural surfaces. Identification of lung hepatization or air bronchograms defines a pneumonia.

As the diagnosis of ADHF is most relevant to cardiologists when confronting patient with dyspnea, particularly in those who carry the dual diagnosis of COPD and HF, simply evaluating for the B-profile would greatly narrow further investigation. Figure 8 depicts an example of a patient with acute respiratory failure; echocardiographic diastolic parameters are consistent with elevated left atrial pressure, while LUS confirms pulmonary edema and a pleural effusion.

Evaluation of Hypotension and Circulatory Shock

The fluid administration limited by lung sonography (FALLS) protocol is an integrated echocardiographic and LUS assessment of circulatory shock.[3,5,6,54] In a stepwise approach, the FALLS protocol is used to evaluate for obstructive (i.e., extracardiac causes of pump failure such as PE, tension pneumothorax, tamponade), cardiogenic, and distributive shock, with the following questions to improve diagnostic accuracy in patients with undifferentiated symptoms:

1. Is there a substantial pericardial effusion concerning for tamponade?
2. Is there right ventricular dysfunction suggestive of PE?
3. Is there left ventricular dysfunction or severe valvular disease?
4. Is lung sliding absent consistent with tension pneumothorax?
5. Is there a B-profile with left ventricular dysfunction consistent with cardiogenic shock?
6. Is there an A-profile that suggests "dry lungs" and fluid tolerance?

Once obstructive and cardiogenic shock are excluded, fluids can be administered with ongoing monitoring by LUS, with B-lines defining the limit of volume repletion. Figure 9 is an example of echocardiographic and LUS pathology encountered in the FALLS protocol.

CONCLUSION

LUS is a simple and informative imaging modality that is readily available, takes <5 min to perform, is repeatable, and is safe. It is commonly used in the evaluation of undifferentiated dyspnea in emergency and intensive care medicine, though it is yet to be fully adopted by cardiologists. It is sensitive and specific for the diagnosis of ADHF, greatly outperforming clinical, laboratory, and radiographic assessment. Likewise, lack of diffuse B-lines in an patient with acute dyspnea virtually excludes ADHF as a cause and allows the clinician to explore alternative etiologies. Advances in portable and handheld POCUS technology places LUS at arm's reach of our patients. The addition of LUS to bedside echocardiography can be invaluable in making an accurate clinical assessment when faced with respiratory failure or shock. Cardiology trainees, as well as those managing acutely ill cardiac patients, should obtain familiarity with this imaging modality and use it in routine clinical practice.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.echo.2021.08.009.

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