Lung Ultrasound as A Diagnostic Tool for the Acutely Ill Patient

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Conflict of interest: None declared
Funding: No funding sources

Abstract
As for other imaging techniques, lung ultrasound signs are not specific for a diagnosis However, clinically driven lung ultrasound protocols with focused assessment allow, settings and clinical conditions, to rule in or out quickly and accurately several diagnoses. As a monitoring tool, semi-quantitative assessment of lung aeration has greatly developed in the last few years. A better bedside aeration assessment awaits improvement of the current scoring system with different definitions of moderate and severe loss of aeration and finer quantification of the nonaerated tissue within consolidations. One additional potential improvement is the detection of overinflation, which is reasonably suggested by reduced sliding; however, lung sliding has never been objectively quantified and relies on "eyeball assessment" by expert examiners.

Keywords: Lung Ultrasound, Acutely Ill Patient

Tob Regul Sci. ™ 2023 ;9(1) : 5640-5650
DOI: doi.org/10.18001/TRS.9.1.393

Introduction

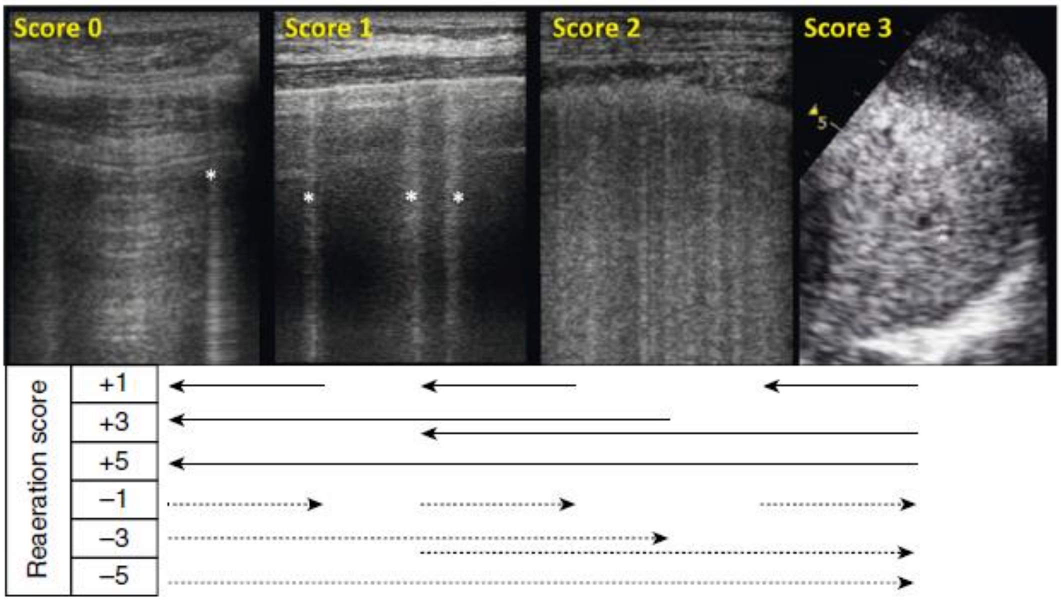
As for other imaging techniques, lung ultrasound signs are not specific for a diagnosis However, clinically driven lung ultrasound protocols with focused assessment allow, in particular settings and clinical conditions, to rule in or out quickly and accurately several diagnoses (1) .

Lung Aeration Assessment and Clinical Applications:

The number and type of ultrasound artifacts visualized in an intercostal space vary in function of the loss of aeration of the underlying lung regions . As shown in vitro and in vivo progressive homogeneous loss of aeration determines the switch from A-lines to a B- pattern, with a progressively increasing number of B-lines that coalesce more and more.

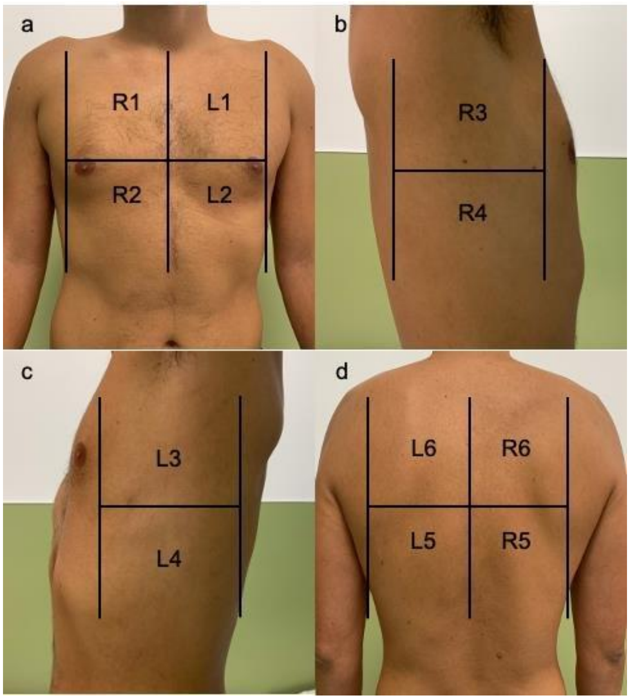
Complete loss of aeration corresponds to a tissue-like pattern. Attempts to semiquantify loss of aeration have led to different lung ultrasound rating systems (2) .

The one most frequently used in the ICU distinguishes four steps of progressive loss of aeration , each corresponding to a score: A-lines or two or fewer B-lines (normal aeration, score 0), three or more well-spaced B-lines (moderate loss of aeration, score 1), coalescent B-lines (severe loss of aeration, score 2), tissue-like pattern (complete loss of aeration, score 3)



(Fig.1) Semiquantification of lung aeration (transversal scans)

This score is computed in six regions per hemithorax: sternum, anterior,and posterior axillary lines identify anterior, lateral, and posterior areas, each divided into superior and inferior fields **(3).**



(Fig. 2) six regions per hemithorax of LUS

The global lung ultrasound score corresponds to the sum of each region's score and ranges from 0 (all regions are well aerated) to 36 (all regions are consolidated) . **(4)** .

In patients with ARDS, the regional lung ultrasound score is strongly correlated with tissue density assessed with quantitative computed tomography (CT), with each step increase of the score from 0 to 3 being associated with a significant gain of density . Moreover, the global lung ultrasound **(4)** .

The aeration score identifies four progressive steps of aeration (score 0: A-lines or two or fewer well spaced B-lines; score 1: three or more well-spaced B-lines; score 2: coalescent B-lines; score 3: tissue-like pattern). It is computed in 12 standard thoracic regions.

Reaeration score may be computed in the same regions to assess lung reaeration in ventilator-associated pneumonia after antibiotic treatment and in acute respiratory distress syndrome after positive end-expiratory pressure titration **(3).**

Blue Protocol

Anterior lung sliding is checked first. Its presence discounts pneumothorax. Anterior B lines are sought. The B profile suggests pulmonary edema. The B', A/B, and C profiles suggest pneumonia. The A profile prompts a search for venous thrombosis. If present, pulmonary embolism is considered. If absent, PLAPS is sought. Its presence (A profile plus PLAPS) suggests pneumonia; its absence (normal profile) suggests COPD/asthma

This algorithm, using ultrasound alone, would have retrospectively given an accurate diagnosis in 90.5% of cases. Its routine integration into the clinical approach would give even better results. This algorithm was called Bedside Lung Ultrasound in Emergency the BLUE protocol. When your patient is blue, promptly perform a BLUE protocol . **(5)**.

The absence of echocardiography in this algorithm stems from the fact that, eve if yielding data of primary importance, it gives indirect arguments, whereas lung ultrasound provides a direct approach to acute respiratory failure. In practice, a cardiac analysis completes our approach **(6**) .

Clinical Implications

Using lung ultrasound saves time and decreases the need for CT, whose drawbacks include delayedcare implementation, irradiation, cost (therefore available only in resource-rich countries), and the required supine position .

Limitations

The operators in this study have several years of experience. They were not blinded to the patient's clinical presentation, yet ultrasound profiles were established based on objective signs. Among the erroneous results (9.5%), some resulted from limitations of this simplified ultrasound approach: problems distinguishing pulmonary edema and interstitial pneumonia, or embolism without thrombosis **(5)**.

Others can be explained by possible flaws in the reference tests: "decompensated COPD" associated with the B profile or PLAPS, or "pulmonary edema" without the B profile.

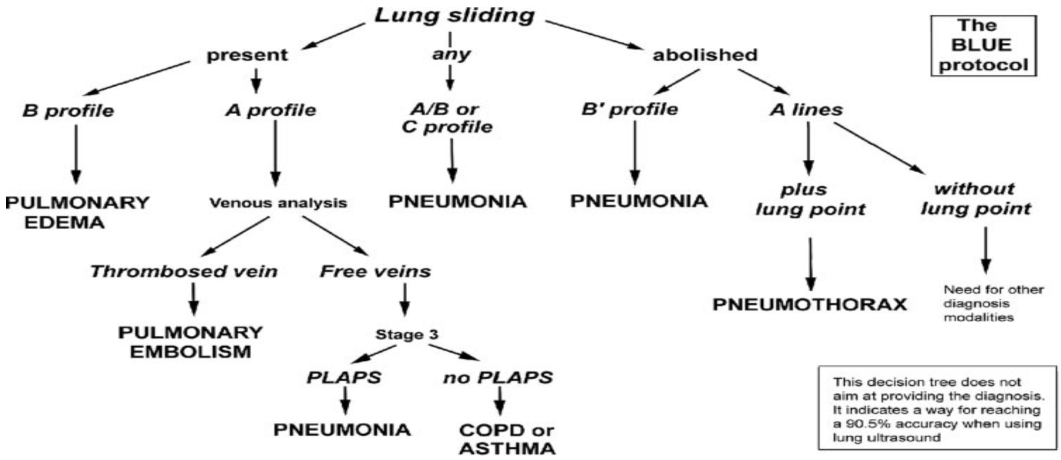


Figure 3. A decision tree utilizing lung ultrasonography to guide diagnosis of severe dyspnea (5).

As regards the excluded patients, among rare causes of dyspnea, massive pleural effusion was not a diagnostic problem. Chronic interstitial diseases produce B lines; the solution deserves a subtle approach that cannot be discussed here in .

Among undefined official diagnosis, note that all patients had one characteristic ultrasound profile. Among patients with several official diagnoses, their inclusion would require an accurate way to determine the respective role of each mechanism involved in respiratory distress.The choice of the material can be decisive. Cumbersome echocardiographic units with cardiac probes usually have insufficient resolution for the lung (5).

Recent ultracompact technologies (not a mandatory requirement in hospital settings), if technologically designed for cardiac investigations, with no consideration for the lung, will not solve this problem. Both systems usually present additional drawbacks: cost, switch-on time, keyboard design that prevents rapid disinfection,and modes that seek to remove artifacts. The choice of the probe is critical. Vascular probes usually prevent deep analysis and artifact recognition (5).

Their micro convex probe, the optimal type of probe for the lungs, is also ideal for emergency whole-body analysis. A/B profile represents anterior-predominant B - lines at one side and predominant A lines at the other. C profile represents anterior alveolar consolidation(s). PLAPS represents posterior and/or lateral alveolar and/or pleural syndrome. All these definitions are based on the patient being supine or semi recumbent (7) .

Assessment of Acute Respiratory Failure

In the BLUE protocol, lung ultrasound signs are associated to build up different profiles to be applied in patients presenting to the emergency department with dyspnea . Anterior diffuse lung sliding with predominant A-lines makes the A-profile.

The A-profile with normal posterior fields corresponds to normal parenchyma and orients to non parenchymal diseases (severe asthma, acute decompensation of chronic obstructive pulmonary disease [COPD]); if associated with ultrasound-detected deep venous thrombosis

(DVT), it strongly suggests pulmonary embolism. In a successive study, a combination of A-lines, DVT, and subpleural consolidations (corresponding to pulmonary infarctions) allowed the diagnosis of pulmonary embolism and in the emergency department **(8) .**

The A-profile with lobar consolidation in dependent lung regions is associated with pneumonia or the acute respiratory distress syndrome (ARDS) . The presence of A-lines without lung sliding, lung pulse, and any B-line strongly suggests pneumothorax.

The B-profile is defined by an anterior, bilateral, symmetrical B-pattern associated with lung sliding. It may help to distinguish cardiogenic pulmonary edema from acute COPD decompensation and other diseases in the emergency department . It is important to emphasize that a single region with a B-pattern does not indicate cardiogenic edema.

B-pattern distribution helps in differential diagnosis : a mono lateral B-pattern orients toward pneumonia; if bilateral (i.e., at least two regions per side) it points to cardiogenic pulmonary edema when homogeneous or to ARDS when nonhomogeneous. Assessment of this bilateral and homogeneous B-pattern is now recommended to evaluate and grade pulmonary edema during heart failure (**9) .**

Additional ultrasound signs help distinguish ARDS and cardiogenic edema: patients with ARDS have nonhomogeneous lung disease combining normal areas with A-lines (spared areas), B-pattern, and sub pleural and translobar consolidations, with reduced or abolished lung sliding and irregular and thickened pleural line **(10) .**

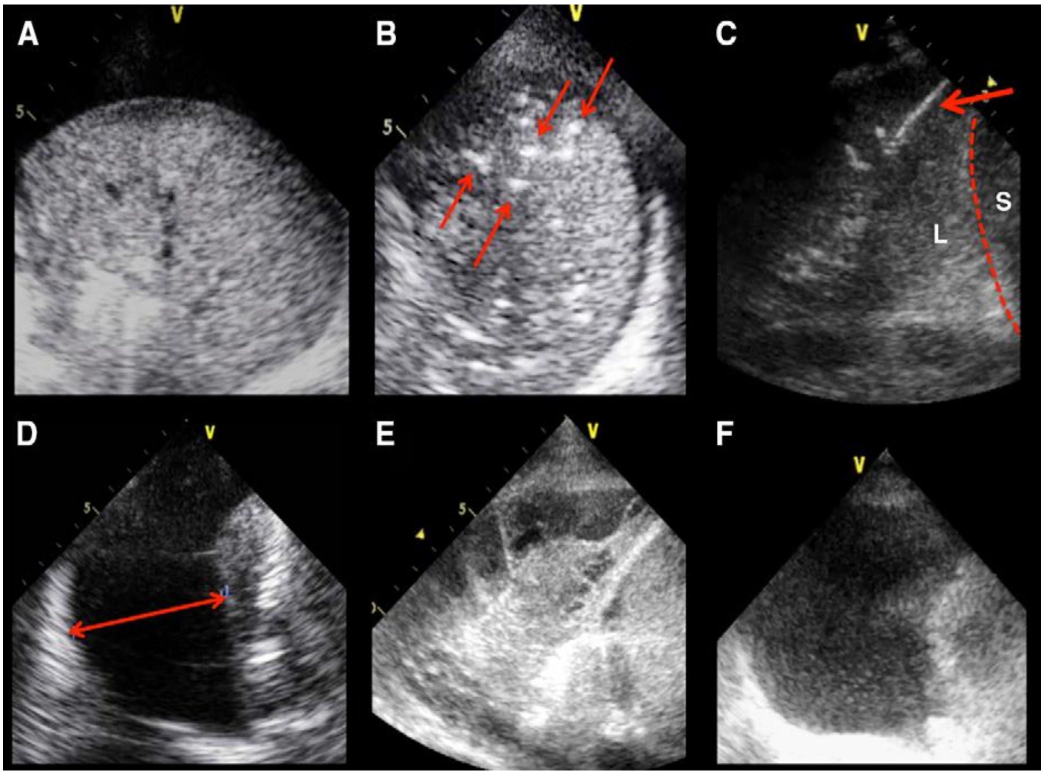
q In a different clinical context, patients with a known diffuse parenchymal lung disease (pulmonary fibrosis, sarcoidosis, lymphangitic carcinomatosis, etc.) also had a lung ultrasound pattern characterized by diffuse B-lines with irregular and thickened pleura when compared with the healthy population **(11) .**

The C-profile corresponds in the BLUE protocol to anterior lung consolidations and correlates with pneumonia or ARDS . An ultrasound-aided definition of ARDS has also been proposed for the diagnosis in resource-limited settings: in the Kigali modification of the

Berlin definition , bilateral infiltrates at chest X-ray are replaced by bilateral B-pattern and/or consolidation at lung ultrasound **(12) .**

An ultrasound-based approach can save time in the assessment of dyspnea, but it needs to be integrated with a standard clinical aroach to optimize diagnostic accuracy .

A comprehensive flowchart for the assessment of acute respiratory failure on the basis of ultrasound findings is proposed.



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(Fig. 4) Lobar consolidations and septa within Pleural effusion

Figure 4. (A–C) Lobar consolidations are visualized as a tissue-like pattern; the air bronchograms are visualized as hyperechoic signs within consolidation and provide additional information on consolidation etiology.

(A) The consolidated lung is visualized in transversal scan. It is homogeneously gray: air bronchogram is absent, which means airway is not clearly patent. Dis obstructive fiber bronchoscopy may be indicated; no final conclusions on consolidation etiology can be drawn.

(B) Multiple white spots (red arrows) are visualized within the consolidated lung in transversal scan and move synchronously with tidal ventilation: dynamic air bronchogram rules out obstructive atelectasis .

(C) A dynamic linear/arborescent air bronchogram is specific for community-acquired and ventilator associated pneumonia . (D–F) Ultrasound features of pleural effusions .

(D) Pleural effusion is here visualized in transversal scan as an anechoic space between the lung (on the right) and the posterior wall of the chest (on the left); transversal scan allows the measurement of the maximal interpleural distance (red arrow) and the quantification of the fluid collection, providing information about adequacy of chest drainage. Its homogeneous anechoic pattern orients to transudate; the lung appears partially consolidated .

(E) Septa and adherences are visualized within the pleural effusion in transversal scan: a phlogistic etiology is suggested, and septa discourage percutaneous chest drainage .

(F) A massive echoic pleural effusion is visualized in transversal scan between a collapsed lung (on the right) and the posterior wall of the chest (on the left); the nonhomogeneous pattern orients to exudate or blood (depending on clinical context); chest drainage is indicated **(13)** .

Assessment of Circulatory Failure and Cardiac Arrest :

As hypothesized by several authors and demonstrated by a prospective observational stud, an early multi organ point-of-care ultrasound evaluation allows reaching almost perfect concordance with a final diagnosis of undifferentiated hypotension in the emergency ward.

A combined ultrasound assessment of the right ventricle, the inferior vena cava, and the lung can rapidly rule out causes of obstructive shock, such as substantial pericardial effusion, acute cor pulmonale,or pneumothorax (5). Left cardiogenic shock can be ruled in or out depending on the presence or absence of a diffuse homogeneous B-pattern (14) .

Among the remaining causes of hemodynamic instability, hypovolemic shock is expected to improve after fluid therapy, whereas distributive shock has a more variable and transient response. As recently demonstrated, the change from A-lines to B-pattern under fluid therapy early identifies lung extravascular leakage in patients with ARDS with septic shock and indicates that fluid therapy should be discontinued .Accordingy, lung ultrasound can integrate and optimize an ultrasound-aided approach to the patient with sepsis (15) .

Echocardiography identifies some of the causes of cardiac arrest and is now recommended The addition of lung, femoral vein, and abdomen ultrasound to rule out pneumothorax, DVT, and free fluid in the abdomen in cardiac arrest has been proposed . To date, a single prospective application was performed, comining the evaluation of lung sliding to focused echocardiography (16) .

Lung Ultrasound–guided Mechanical Ventilation

Lung ultrasound was proposed as an imaging tool to guide and monitor mechanical ventilation . First, it may help airway management: visualizing the oro tracheal tube beside the trachea, it identifies esophageal intubation and, by visualizing bilateral sliding, it confirms tracheal intubation and excludes selective bronchial positioning (4) .

Ultrasound can be used to guide the setting of mechanical ventilation as Well. Reaeration during a recruitment maneuver can be directly and real-time visualized .In general, patients with diffuse loss of aeration at ultrasound examination (i.e., also affecting anterior fields) may be PEEP responders, whereas those with focal loss of aeration (i.e., posterior consolidation with normal anterior fields) are more prone to over distension of the normal parenchyma , as previously indicated by CT studies (17) .

Changes in lung ultrasound score correlated with PEEP induced increases of end-expiratory lung volume and were therefore proposed for bedside assessment of lung recruitment. However, this volume increase does not correspond to the reinflation of previously collapsed lung tissue (i.e.,lung recruitment), as most of the gas enters already inflated lung regions (18) .

Accordingly, lung ultrasound score parallels lung tissue density and aeration in patients with ARDS, but changes of lung ultrasound score are not related to the amount of recruitable lung tissue . Whether PEEP induced changes in size of tissue-like areas could be used to assess lung recruitment at the bedside, although reasonable, remains to be demonstrated . Patients classified as PEEP non responders may successfully respond to prone positioning . In patients with focal loss of aeration and a normal anterior lung ultrasound pattern, consolidated posterior regions did, in fact, show greater re aeration with prone positioning than in patients with more diffuse disease (19).

Moreover, the amount of re aeration of posterior lung regions assessed by ultrasound after 3 hours of prone position was associated with a positive clinical response, defined as a partial pressure of arterial oxygen to fraction of inspired oxygen higher than 300 mm Hg after 7 days of treatment .

As already stated, the lung ultrasound score can help distinguish patients at high and low risk of postextubation distress .A score 2 pattern seems to best identify the failing patients . The lung ultrasound score predicts extubation failure probably because decreased pulmonary aeration is a final common pathway of patients failing extubation for different reasons (20) .

The combination of lung ultrasound and other ultrasound techniques in the assessment of the patients to be weaned has been suggested not only to identify the frailest patients early but also to understand the underlying mechanism, being the main causes of weaning failure detectable with ultrasound (i.e., unsolved lung disease, diaphragm dysfunction, and cardiac failure) (21) .

Detection and Management of Respiratory Complications in Mechanically Ventilated Patients

Lung ultrasound, thanks to its ready availability at the bedside, could become a key tool for the early diagnosis of the most common complications of mechanical ventilation, such as pleural effusion, alveolar consolidation related to atelectasis or VAP, and pneumothorax. Pleural effusion appears as a dependent, usually echo-free, zone acting as an acoustic window (22) .

Inside the pleural effusion, the lung can be seen as a bright lung line if it remains aerated or as a floating consolidation if not. Pleural effusion can be easily distinguished from peri splenic or peri hepatic fluid collections by the visualization of the diaphragm in longitudinal scan . Lung ultrasound also allows accurate and clinically useful estimates of the volume of effusion : in supine position, in transversal scan, an inter pleural distance of 5 cm or more at the lung base is highly predictive of pleural effusion of 500 ml or more (23) .

A linear relationship has also been identified, each centimeter of inter pleural distance corresponding to 200 ml of fluid . Transudates are always anechoic and homogeneous, whereas exudates may appear echoic, heterogeneous, and loculated .Lung ultrasound is also a valid tool to guide effusion drainage and monitor its effectiveness . The interposition of gas between the visceral and parietal pleura is marked by the absence of lung sliding, B-lines, and lung pulse . Diagnosis of pneumothorax is confirmed by the visualization of a lung point in a more lateral part of the chest wall. This corresponds to the limit of the pneumothorax and can be used to measure its extension : a lung point beneath the mid axillary line in a presumed free collection indicates a collapse of at least 30% of the parenchyma. However, in a completely collapsed lung, no lung point can be visualized Lung ultrasound performs better than chest X-ray for diagnosing pneumothorax, particularly in trauma patients .In the emergency room, lung ultrasound is a valid alternative for early diagnosis of pneumonia in adults (23) .

Consolidations are predictors for the diagnosis of community-acquired pneumonia . In ICU patients, intricate causes of loss of aeration may give rise to B-pattern and consolidations.

Consequently, in these patients a tissue-like pattern is not sufficient for the diagnosis ; instead, the presence of a dynamic linear/arborescent air bronchogram within a consolidation seems to be a specific sign of VAP. A clinical ultrasound score can be easily computed at the bedside for early VAP diagnosis. Typically, reabsorption atelectasis appears as consolidated parenchyma with a reduced lung volume; the air bronchogram is either static (initial phase) or completely absent (complete reabsorption of air in small airways; If the air bronchogram is dynamic, obstructive atelectasis is ruled out (24) .

No or static air bronchogram suggests non-patent airway and may be an indication for disobstructive fiber bronchoscopy; a dynamic air bronchogram corresponds to patent airways, and fiber bronchoscopy may also be indicated to obtain a distal microbiological sample .

The vascularization of a lung consolidation can be visualized by color Doppler. A well-perfused lung region with complete loss of aeration corresponds to intrapulmonary shunt, thus suggesting a significant contribution of the consolidation to hypoxemia. However, color Doppler assessment of lung perfusion is only qualitative; a quantitative assessment may be useful in the future to quantify the intrapulmonary shunt and monitor the response to treatments (25) .

Limitations of Lung Ultrasound

Like other ultrasound techniques, lung ultrasound is operator-dependent and requires training for image acquisition and interpretation. Concerning image acquisition for lung aeration assessment, inter observer agreement was almost perfect ; in image interpretation, inter operator agreement was strong or almost perfect, depending on the scoring system adopted (26) .

Simple findings can be easily acquired with a short training: anesthesia residents were able to rule out pneumothorax after 5 minutes of on line training , and pleural effusions were easily detected by ICU residents after a few hours of theoretical and handson work

Lung ultrasound depends on transmission of ultrasound beams through the chest wall to the lung surface. This propagation from skin to lung can be prevented by subcutaneous emphysema or large thoracic dressings. Once the ultrasound beams are transmitted and the lung is aerated, the examination only allows analysis of the lung surface (27)

This means that only fields immediately beneath the probe are explored, thus underlying the need for as comprehensive and systematic an examination as possible. Moreover, caution is recommended in the interpretation of lung ultrasound findings in diseases that may have no or minimal extension to peripheral fields (i.e., deep peribronchial mass/abscess, histiocytosis, tuberculosis, aspergillosis, bronchiectasis).Finally, no specific lung ultrasound sign has been found for the detection of lung overinflation (28) .

Future Perspectives for Lung Ultrasound

As a monitoring tool, semi-quantitative assessment of lung aeration has greatly developed in the last few years. A better bedside aeration assessment awaits improvement of the current scoring system with different definitions of moderate and severe loss of aeration and finer quantification of the nonaerated tissue within consolidations (29) .

One additional potential improvement is the detection of overinflation, which is reasonably suggested by reduced sliding; however, lung sliding has never been objectively quantified and relies on "eyeball assessment" by expert examiners **(30)**

No Conflict of interest.

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