



Advances in lung ultrasound in critically ill patients

Luigi Vetrugno¹, Tiziana Bove¹, Giovanni Maria Guadagnin¹, Daniele Orso¹, Alessandro Brussa¹, Giovanni Volpicelli²

¹Anesthesiology and Intensive Care Clinic, Department of Medicine, University of Udine, Udine, Italy; ²Department of Emergency Medicine, Ospedale San Luigi Gonzaga, Orbassano, Torino, Italy

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Correspondence to: Luigi Vetrugno, MD. Anesthesiology and Intensive Care Clinic, Department of Medicine, University of Udine, P.le S. Maria della Misericordia n.15, 33100 Udine, Italy. Email: luigi.vetrugno@asuiud.sanita.fvg.it.

Abstract: Since its introduction 20 years ago, transthoracic lung ultrasound in critically ill patients has been shown to be an invaluable bedside diagnostic tool to influence patient management and to guide therapeutic decisions. Furthermore, to optimise mechanical ventilation, a systematic evaluation of the lung region can be carried out. We can predict that in the future transthoracic lung ultrasound may play an important role in the definition of adult respiratory distress syndrome (ARDS) grading. In the diagnosis of pneumothorax, the use of transthoracic lung ultrasound has progressively spread, leading it to become the first-line tool in ruling out tension pneumothorax in haemodynamic unstable patients, even in pre-hospital emergency settings. In septic patients, fluid administration is still a matter of concern. Transthoracic lung ultrasound can detect fluid refractory, i.e., lung fluid “intolerance”, which is a useful guide in the haemodynamic management of these patients. Lung ultrasound also allows pleural effusion quantification and whether or not it is appropriate to drain the patient, of course, in a clinical context. However, urgent standardisation in the methodology of pleural effusion quantification is required. As a result, transthoracic lung ultrasound seems to be a powerful tool in the hands of a trained intensivist, and, at present, to avoid using it seems unjustified.

Keywords: Acute respiratory failure; fluid management; lung ultrasound (LUS); pleural drainage; pneumothorax

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Introduction

In the last 15 years, transthoracic lung ultrasound (LUS) has proven to be one of the most revolutionary diagnostic tools in the intensive care environment (1) where acute respiratory failure is the most frequent cause of hospitalisation with a mortality rate of 33–37% among those requiring invasive mechanical ventilation (2). Its great success is due to it being minimally invasive, easily repeated and simple to carry out. Furthermore, transthoracic LUS only requires a rapid learning curve; 25 supervised tests are sufficient to achieve a basic knowledge (3). Moreover, the impact of transthoracic LUS can lead to important clinical decisions being made in about 50% of intervention cases:

bronchoscopy, chest tube placement, positive end-expiratory pressure (PEEP) titration, recruitment manoeuvre, fluid management, diuretics, antibiotic initiation/change, physiotherapy (4). Additionally, the early use of scoring such as the “LUS score” is helpful in predicting the outcome of patients admitted to the intensive care unit (ICU) (5). With its image artefacts (A-lines, B-lines) or direct images (lung consolidations, pleural effusions), LUS provides significant information that can be integrated with the clinical signs and symptoms of the critically ill patient. In the following paper, we will focus on four of the major aspects that have revolutionised our clinical practice in recent years, each one making a huge impact on patient care (*Figure 1*). This review is aimed at those doctors who are already using

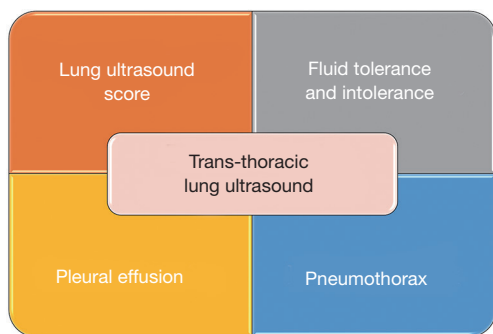


Figure 1 Four major aspects of lung ultrasound that can make a huge impact on patient care.

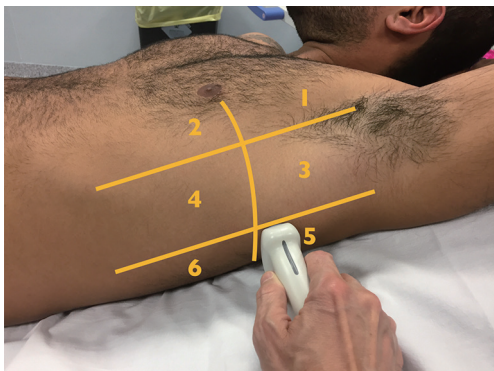


Figure 2 Three different areas of the thorax, anterior, lateral and posterior regions, divided by anterior and posterior axillary lines as anatomical landmarks. Each area is further divided into superior and inferior, thus defining six specific sections per hemithorax.

transthoracic LUS in daily clinical practice, assisting them in focusing on certain precise aspects, specifically diagnosis, prognosis and future haemodynamic applications.

LUS score

LUS examination is primarily based on the evaluation of artefacts, since ultrasound is not transmitted through aerated interfaces. LUS may appear simple but needs to be performed with rigorous methods to produce as much reliable information as possible (6,7). Different features of LUS patterns have been described and most relate to the aeration level of the parenchyma (8). Typical findings of LUS examinations are the so-called “A-lines”, a reverberation artefact of a pleural line spreading through aerated lung parenchyma, and the visualisation of pleural sliding, the relative mutual movement of visceral and

parietal pleura during the inspiration (9). Pathological findings relate to diminished aerated parenchyma. “B-lines” represent the decrease in air content of the lung parenchyma and—in the appropriate clinical picture—reflect the presence of extravascular lung water (EVLW) which alters the gas-tissue interface and produces comet-tail artefacts moving from the pleural line to deep parenchyma (7,10). The presence of B-lines implies a moderate reduction of lung aeration, which is typical of interstitial syndrome (11). Lung consolidation consists of a major loss of aerated parenchyma (i.e., lobar pneumonia, pulmonary contusion or atelectasis), which appears as a tissue-like texture. The shred sign, suggestive of an indented pleural line around the lung consolidation, and the dynamic air bronchogram, caused by air penetration in the bronchial tree but not in the alveolar space, better defines the aerated parenchyma mass loss (12,13).

Lung aeration is therefore an important aspect to consider in optimising the ventilatory parameters and in monitoring a successful weaning process in order not to lose aerated parenchymal mass. In this context, LUS examination is a structured, standardized and comprehensive evaluation of pulmonary parenchyma that aims to help clinicians monitor lung aeration (14). Indeed, LUS patterns provide a satisfying picture of the aerated parenchyma and any variation can be effectively translated into a score. Therefore, LUS evaluation starts with the identification of three different areas of the thorax, anterior, lateral and posterior regions, divided by anterior and posterior axillary lines as anatomical landmarks. Each area is further divided into superior and inferior, thus defining six specific sections per hemithorax (Figure 2). Four different aeration patterns are assigned to each region: (I) presence of A-line artefacts (A), typical of normal aeration; (II) prevalence of B-line patterns (B1), suggesting a limited decrease in lung aeration (i.e., interstitial syndrome); (III) confluent B-lines (B2), suggesting a more severe loss of aerated lung due to liquid imbibition of the alveolar space (i.e., pulmonary oedema); (IV) complete lung consolidation (C), with hepatisation of lung parenchyma and dynamic air bronchogram, suggesting major loss of aerated lung mass. The LUS is then calculated on the basis of the worst ultrasound pattern detected in each region, whereby A =0 points, B1 =1 point, B2 =2 points, C =3 points. The total LUS score comes from the sum of each region’s points, ranging from 0 to 36 (15,16).

The LUS score helps clinicians to obtain a detailed screenshot of aerated parenchymal mass and it also provides detailed information of clinical relevance (9). Where the

Table 1 Comparison between lung ultrasound (LUS) score and computed tomography findings in ARDS patients

Findings	LUS evaluation	Chest CT
Static findings	Evidence of bilateral interstitial syndrome (B1–B2 pattern)	Bilateral ground-glass opacification
	Static air bronchogram	Bronchial dilatation within consolidated areas
	“Spared areas” with spotted distribution of B-lines and consolidation	Dependent region consolidation with antero-posterior density gradient
	Indented and thickened pleural line	–
Dynamic findings	Dynamic air bronchogram	–
	Reduced or abolished “lung sliding”	–
	Lung pulse	–

ARDS, adult respiratory distress syndrome; CT, computed tomography.

role of LUS in diagnosing pneumothorax is a recognised practice, more recent and fascinating roles are its ability to optimise ventilatory settings in adult respiratory distress syndrome (ARDS) patients, estimate the recruitable, poorly aerated pulmonary mass, monitor lung aeration during the weaning process, and give a reliable prognostic factor.

In ARDS patients the aeration loss typically strikes focal regions of parenchyma, focusing mainly on the lower lobes, while upper regions may remain normally aerated (17). LUS patterns in ARDS consist of both B-lines and consolidation (18). Since lung recruitment involves particularly poorly aerated areas rather than consolidated regions (5), an LUS score allows clinicians to quantify the relative share between these two patterns, helping to set appropriate mechanical ventilation parameters, balance alveolar recruitment and reduce the risk of lung overinflation.

On the other hand, other clinical features, such as pulmonary oedema, are characterized by multiple and confluent B-lines throughout all examined areas, due to an increase of intravascular hydrostatic pressure (18,19). This condition benefits from positive-pressure ventilation, which rebalances hydrostatic pressure between the intravascular and interstitial spaces. In this context, the LUS score best defines recruitment areas (20) and may guide incremental PEEP trials in order to restore a normal pulmonary pattern (15).

Moreover, the LUS score acts as a useful tool to monitor lung aeration during the weaning process. Failed extubation complicates 3–30% of successful spontaneous breathing trials (21), causes a longer stay in ICU (22), increases the risk of ventilator-associated pneumonia (23), and has higher morbidity and mortality rates (24). The LUS score shows

how switching from positive to negative pressure produces better aeration of the lower posterior regions, while in the upper anterior and lateral areas it may decrease. The reduced aeration rate during a spontaneous breathing trial may reveal its outcome (16).

Finally, the LUS score is acquiring greater prominence for its prognostic implications. LUS scores are claimed to correlate with the severity of a disease and mortality rates of ARDS patients. In particular, the number of B-lines at ultrasound evaluation seems to directly correlate to mortality (25), while the LUS score relates to EVLW, measured by the transpulmonary thermodilution technique (5). This means LUS is a non-invasive, real-time, radiation-free, bedside method for the early diagnosis and correct prognosis of ARDS patients, suggesting its use as an alternative to radiology in the diagnostic process (*Table 1*).

Fluid management with LUS

The administration of fluids in ICU is the cornerstone in the treatment of critical ill patients (26). Over time this clinical practice has become common sense, associated with a positive feeling of doing something good for the patient. However, recent scientific evidence points out that excessive fluid balance is associated with a worse outcome for the patient (27–29), and, for example, in the septic patient, a positive fluid balance and a high central venous pressure (CVP) have been associated with an increase in mortality (30). Meanwhile, other studies have shown that administering fewer fluids is better (31–34). The FENICE trial brought attention to a “safety problem” due to the fact that only 59% of patients showed fluid responsiveness while the other 41% were exposed to the problem of

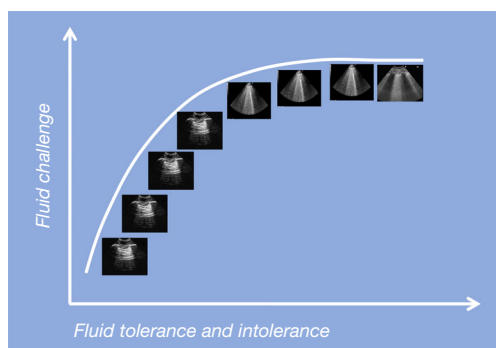


Figure 3 An example of “visual thinking” about an acute condition of systolic or diastolic cardiogenic shock with elevated pulmonary pressures and the development of B-lines.

“overhydration” (35). The last fifteen years have also been characterised by a decline in the invasive haemodynamic monitoring of cardiac output (CO) (36) and a reduced use of semi-invasive or non-invasive techniques due to their intrinsic limitations (37-39). Conversely, there has been an explosion in the use of point-of-care ultrasonography in terms of critical care echocardiography (CCE) and transthoracic LUS (40). So far, things have shifted from numbers, i.e., CO, CVP, wedge pressure, to “visual thinking”, i.e., ejection fraction “eyes ball” assessment for the heart and “A-line profile” and “B-line profile” and so forth for the lungs (40,41). In other words, we have learned that “diffuse” bilateral B-lines instead of “focal” multiple B-lines (i.e., pneumonia) in acute clinical conditions are very often associated with increased EVLW due to a possible systolic or diastolic cardiogenic shock with elevated pulmonary pressures (Figure 3), or to damaged pulmonary vessels (glycocalyx), secondary to the ARDS (42-44). In both cases the lung is “wet” (B-profile) and not “dry” (A profile). It has also been proven that after a fluid bolus, B-lines increase by 8%, with a heterogeneous distribution in the lung and aeration loss, even if haemodynamic variables return to the previous values as a result of fluid redistribution from the vascular compartment (20,45). In other words, the haemodynamic benefits of fluid loading may be associated with worsened lung aeration, and B-lines seem to be directly related to EVLW and higher mortality (20,45,46). In published articles, the recommendations for fluid loading are clear: to be liberal at the initial phase of septic shock, possibly in the first 2 hours (47), because fluid restriction can worsen the function of the organs (33). LUS could today play an interesting role in fluid

management due to the fact that static variables, i.e., CVP, pulmonary arterial occlusion pressure (PAOP), intrathoracic blood volume (ITBV), and so forth, and dynamic indices of preload, i.e., systolic arterial pressure (SAP), pulse pressure variation (PPV), and inferior vena cava (IVC) variation, have shown many limitations (41-42). Combining LUS with CCE can provide highly relevant information (Figure 4) in terms of fluid “tolerance” or fluid “intolerance”. In the first case, a diffuse bilateral “A-profile” (dry lung) means that the patient shows fluid tolerance (43). However, this is not a guarantee that the patient needs fluid, and this is the same limitation shown by dynamic preload indices (44). In the second case, when a diffuse “B-profile” from the base to the apex is shown (wet lung), it is important to stop fluids and think about norepinephrine in those patients who remain hypotensive [mean arterial pressure (MAP) <65 mmHg] after having a proper ultrasound heart examination (20,45). Usually, CO can be estimated with a non-invasive transthoracic echocardiography, as the product of heart rate (HR) and stroke volume (SV), where SV is equal to the product of the velocity time integral (VTI) and the aortic cross section area (CSA). CSA is equal to $\pi (dLVOT_{cm}/2)^2$. To obtain $CSA = \pi (dLVOT_{cm}/2)^2$, the diameter of the left ventricular outflow tract (LVOT) from the parasternal window needs to be acquired, where even the smallest error becomes squared and can generate discrepancies in CO evaluation. To overcome this limitation, the VTI is considered a repeatable measurement that can be obtained in the apical five chamber view using pulsed waves. Normal values for VTI are between 18 and 22 cm. The combination of transthoracic LUS and CCE in this context may allow clinicians to obtain additional information regarding the effect of fluid loading on patients haemodynamic (Figure 4).

The Surviving Sepsis Campaign continues to recommend an empiric fluid bolus of 30 mL/kg for all patients presenting with hypotension or an elevated lactate level, independent of the lung “intolerance” (47). However, there is no clear evidence that substantial fluid resuscitation reliably improves end-organ perfusion in septic patients. A recent study discovered that in adult patients presenting with septic shock, early fluid boluses caused harm (27-30,46). Among intensive care physicians transthoracic LUS is becoming a useful and non-invasive tool to observe the lung’s fluid refractory or fluid “intolerance”. Some data has also suggested that a restricted fluid approach would be prudent in patients with sepsis to reduce morbidity and

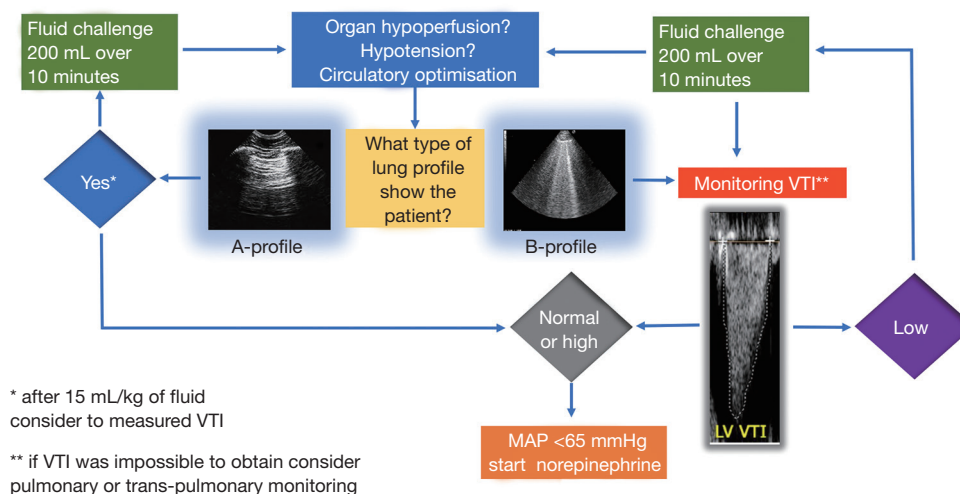


Figure 4 The combination of transthoracic lung ultrasound and critical care echocardiography (CCE) in this context may allow clinicians to obtain additional information regarding the effect of fluid loading on patients haemodynamic. LV VTI, left ventricular velocity time integral; MAP, mean arterial pressure.

improve the outcome (46).

Pleural effusion

Pleural effusion is a common pathological condition among critical care patients. At the time of admission into ICU, 41% of patients are diagnosed with pleural effusion, while 21% will develop it during hospitalisation (48). Because pleural effusion can worsen gas exchange, respiratory mechanics and hemodynamic stability (48,49), an early diagnosis of the presence and quality of the pleural effusion is necessary to adopt adequate therapeutic, invasive or non-invasive strategies. The gold standard for the diagnosis of pleural effusion remains the computed tomography (CT), which requires the patient to be moved out of intensive care, not always an easy task (50). Transthoracic LUS allows a bedside approach for pleural effusion diagnosis with a sensitivity of 92%, a specificity of 93% and a diagnostic accuracy of 93% (51), without ionising radiation. Transthoracic LUS accuracy has proven to be higher than anteroposterior or lateral chest X-rays (52,53), capable of identifying the presence of effusions smaller than 15 mm (53). Therefore, the International Consensus Conference on Lung Ultrasound states, “For the detection of effusion, transthoracic LUS is more accurate than supine radiography and is as accurate as CT (strong: level A)” (7). Transthoracic LUS can also help clinicians to distinguish between the different types of effusion (transudate,

exudate, empyema and haemothorax) by analysing the pleural effusion’s internal echogenicity and changes in lung parenchyma and pleural thickness (>3 mm) (54). Transudates and exudates can both appear as homogeneous anechoic pleural effusions: clinical contexts and visualisation of internal echoes (mobile particles and/or septation) suggest exudates; changes in the appearance of the lung parenchyma (e.g., consolidation) and an increase in pleural thickness can also lead clinicians to identify an exudate pleural effusion (54,55). Empyema and haemothorax can both appear as homogeneous echogenic effusions (54). Transthoracic LUS also enables fluid quantification of pleural effusions and decisions can be made about a therapeutic approach; alterations in gas exchange and fluid volume are the most important considerations when deciding whether or not to drain the pleural effusion. Benefits of pleural drains should be considered against the risk of complications (pneumothorax, haemothorax, visceral injury). Despite reliable estimations of the effusion, its volume remains challenging for various reasons, including a non-established best method, size and position of the thoracic cavity, position of the patient, diaphragm dysfunction, very large pleural effusions, concomitant collapsed lung and lung consolidation (56-60) (Table 2). Of course, a greater thickness of effusion ensures a greater safety margin during both invasive diagnostic (pleural aspiration) and therapeutic (pleural drain insertion) procedures (63). Regarding this safety margin, The British

Table 2 Different studies with different methodology and mean prediction bias

Authors	Patients' setting	Position	Probe position	How to	Mean prediction error/mean bias
Vignon <i>et al.</i> (56)	Spontaneous breathing or mechanically ventilated	Supine	Probe perpendicular to the body axis at the rearest line on the chest, exploring all intercostal space from apex to base	In end expiration measure the maximal perpendicular interpleural distance (D) at lung base Pleural effusion >800 mL when the D is: right ^a >45 mm; left ^b >50 mm	28±146 mL
Balik <i>et al.</i> (58)	Mechanically ventilated	Supine with mild torso elevation at 15°	Probe perpendicular to the body axis at the posterior axillary line, moving cranially	In end-expiration measure the maximal distance between parietal and visceral pleura (Sep) at lung base $V \text{ (mL)} = 20 \times \text{Sep (mm)}$	158.4±160.6 mL
Remérand <i>et al.</i> (61)	Critically ill	Supine	Probe perpendicular to the body axis at the rearest line on the chest, exploring all paravertebral intercostal space from apex to base	In end-expiration measure: (I) the cross-sectional area at half the distance between lung base and apex (A_{US}); (II) the pleural effusion depth (L_{US}) at this point $V \text{ (mL)} = A_{US} \times L_{US}$	-33 mL
Usta <i>et al.</i> (62)	Spontaneous breathing after cardiac surgery	Sitting	Probe parallel to the body axis along mid-scapular line, moving cranially	In end-expiration measure the maximal distance (D) between mid-height of the diaphragm and visceral pleura $V \text{ (mL)} = 16 \times D \text{ (mm)}$	-21.1±97.78 mL

^a, sensitivity 94%, specificity 76%; ^b, sensitivity 100%, specificity 67%. V, pleural effusion fluid volume.

Thoracic Society Pleural Disease Guideline 2010 states, “When using ultrasound to select a site for aspiration of a pleural effusion, the site chosen should have (I) sufficient depth of pleural fluid (at least 10 mm), (II) no intervening lung at maximal inspiration and (III) minimal risk of puncture of other structures such as the heart, liver and spleen” (63). Small effusions (<10 mm thickness) can usually be resolved with non-invasive therapeutic strategies alone (diuretics, antibiotics) (63). Transthoracic LUS will identify the best puncture site for invasive manoeuvres (thoracentesis and pleural drain insertion) to increase periprocedural efficacy and safety and decrease life-threatening complications (64,65). The best puncture site is where the physician can safely identify each anatomical structure (diaphragm, organs, intercostal artery), or the maximum distance between the visceral and parietal pleura (safety margin) (63,66). Despite non-ultrasound guides, pleural drain insertions must be performed into the safety triangle,

the physician being guided by the ultrasound (66). It was once thought that ultrasound could not be employed for intercostal artery visualisation (63). However, several trials have provided evidence about how thoracic Doppler ultrasound can be used to identify intercostal vessels (67-69) for the prevention of bleeding, even in patients with altered coagulation parameters (70). The superiority of ultrasound to detect the best puncture site and reduce potential complications has been confirmed by several studies (64,65), therefore, The British Thoracic Society Pleural Disease Guideline 2010 states, “Site selection for all pleural aspiration should be ultrasound guided” (63). Ultrasound guidance in pleural procedures is performed using both “site marking” and “direct needle guidance”. In the former the physician defines the optimal site with a mark on the skin before puncture, which avoids repositioning the patient as this will cause fluid to move. Direct needle guidance is more technically challenging, however, it permits a

needle's tip real-time visualisation and also guidewire and drainage final position during small-bore pleural drain insertion (66). Transthoracic LUS allows the detection of possible complications after invasive procedures (e.g., pneumothorax, bleeding, see pneumothorax section). Transthoracic LUS also permits the identification of residual pleural effusions despite a poorly supplied pleural drain. The pleural drain should be removed when it drains less than 200 mL per day, the pneumothorax is resolved, or when the drain is no longer functioning (63). Therefore, due to its high accuracy in diagnosing pneumothorax and pleural effusions, transthoracic LUS also provides useful indications about when to remove drains. Moreover, transthoracic LUS identifies co-existing lung diseases, with a higher specificity and sensitivity than chest radiography (pneumothorax, interstitial syndrome, consolidation and atelectasis) (51). As critically ill intensive care patients may have limited mobility, and more recumbent positions can lead to haemodynamic side effects, we suggest a supine position with a mild torso elevation of 15°. In this position all free fluids are collected by gravity at the PLAPS point (posterolateral alveolar and/or pleural syndrome) and so a scan of this PLAPS point can detect and quantify the fluid in the pleural effusion, even small ones (71), using Balik's formula (58). More recumbent patient positions can also lead to overestimating the volume of a pleural effusion (58,60). Due to its bedside approach, thoracic LUS, in the case of pleural effusions, could be essential, from the initial diagnosis, throughout the clinical course, to the final therapeutic treatment (6). We suggest that a thoracic LUS evaluation is performed upon admission of the patient to ICU and re-evaluated daily, or after clinical changes/invasive procedures are performed.

Pneumothorax

The accumulation of air in the pleural cavity causes a condition known as pneumothorax. The amount and rate at which air enters the pleural space (usually virtual) can cause haemodynamic effects as the compression of the large venous vessels inside the mediastinum (as well as the stretching of the parenchymatous structures) determines a life-threatening condition called tension pneumothorax. In critical care medicine, in ICU as well as in the emergency department or a pre-hospital environment, excluding pneumothorax as a cause of a respiratory distress and/or a haemodynamic shock is essential to enable life-saving procedures (emergency chest decompression and thoracic

drainage) (71-74). The gold standard test for the diagnosis of pneumothorax is CT. However, because of the need for a quicker diagnosis, often at the bedside (also because of the non-optimal diagnostic accuracy of the chest radiograph), the use of transthoracic LUS as a diagnostic test for pneumothorax has progressively spread. The sensitivity and specificity of transthoracic LUS in the diagnosis of pneumothorax have been analysed extensively in published articles: sensitivity is around 80–90% and specificity is around 98% (75-79). The sensitivity of the chest radiograph, on the contrary, is about 40–50%. In fact, there is a wide limitation in the diagnostic accuracy of this method linked to the position of the patient and the masking due to bone structures. Since air tends to accumulate in the highest points of the thorax (i.e., in the anti-gravity positions), in the supine patient (as the critically ill patient is most frequently placed), the pneumothorax, even in small cases, is more easily identifiable in the parasternal areas of the thorax, and anteriorly and superiorly in the chest. Visualising at least two ribs longitudinally and the pleural line between the two, allows clinicians to quickly obtain a reference point of the echogenicity and the movement of the pleural line. The probe is then rotated 90° to gain a better visualisation of the pleural line, before eventually zooming in on it. Once the pneumothorax has been identified, it is advised to gradually move the probe towards the axillary line to establish, at least roughly, the dimensions of the pneumothorax (see further on the meaning of the lung point) (71). There is no data in published articles to suggest that the linear probe is better than the convex probe (80). Several sonographic signs have been tested in recent years, including the absence of lung sliding, B-lines or comet-tail artefacts, A-lines, and the lung point sign (81). Lung sliding is an ultrasound sign quite easily identifiable in the healthy chest. However, when air separates the two pleural sheets, the visceral pleura becomes invisible to the ultrasound beam. Sonographically we can detect the presence of the pleural line, which in this case is immobile, signifying that there is no lung sliding. This artefact is detectable in both B-mode and M-mode. The absence of lung sliding does not have a high specificity since other conditions, such as atelectasis, pulmonary contusion or a main stem intubation, can determine the same sonographic sign (81). The presence of even one B-line is virtually able to exclude the pneumothorax. In fact, the genesis of this artefact is linked to the phenomena of multiple refraction of the ultrasound beam inside the parenchyma due to the strong difference in impedance between two surfaces. The B-lines originate from the

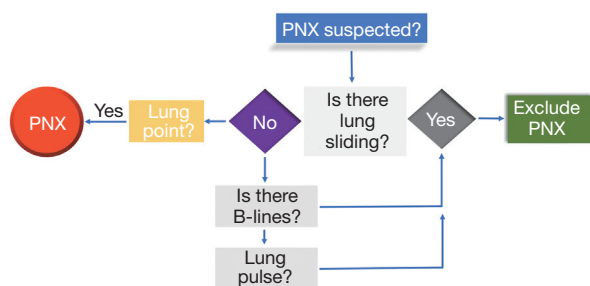


Figure 5 The flow-chart of the role of sonographic signs in the diagnosis of pneumothorax (PNX).

pleural line and have a vertical course within the ultrasound field. They move synchronised with respiratory movements. Because of their nature, the B-lines are not visible if a high-impedance surface, such as air, is interposed between the two pleural sheets. Therefore, the visualisation of one or more B-lines indicates the adherence of the two pleurae and totally excludes the presence of pneumothorax. However, the absence of B-lines does not prove the presence of pneumothorax, this being the normal condition of the healthy lung, besides several pathological conditions (81). In the lung zones next to the heart it is possible to identify an alternative movement to pleural sliding, which consists of a wobbling motion of the pleural line synchronised with the cardiac rhythm. This sign is called the lung pulse. The lung pulse is virtually absent in pneumothorax, unlike other pathological conditions (such as atelectasis), because the amount of air between the pleural sheets prevents the transmission of mechanical oscillation. This sign rules out the presence of pneumothorax, fulfilling the same role of the B-lines. Compared to the signs discussed so far, the lung point, the point where the two pleural sheets come back to each other and therefore lung sliding reappears, if present, confirms the diagnosis of pneumothorax (81). Intuitively, the greater the distance from the hilum (and therefore from the anterior axillary line) to the lung point, the more extensive the pneumothorax. Finding a lung point beyond the medium axillary line predicts (with a sensitivity and specificity of about 80%) a collapse of more than 15% of the lung (82). However, the overall sensitivity in diagnosing pneumothorax by the lung point is very low. In fact, in the case of a complete collapse of the lung, the lung point is absent, since there are no points where the pleura come back to each other. Moreover, in the case of pleural blebs or pleural adhesions that determine the formation of a saccade,

the presence of a lung point may not indicate an extension of the pneumothorax (83–85). Sometimes this condition is associated with the so-called “double lung point” (86). Summarising the role of sonographic signs in the diagnosis of pneumothorax, we can state the following: the first sign to be sought is lung sliding (87). If lung sliding is absent, it is useful to look for the presence of at least one B-line. If there is no B-line, pneumothorax cannot be ruled out. If, at this step, we identify the lung point we can diagnose pneumothorax (71) (Figure 5). Ultrasound is, at present, an extremely useful tool for ruling in or out the diagnosis of pneumothorax in critically ill patients and therefore it is able to rapidly contribute to potentially life-saving therapeutic decisions.

Limitations of LUS

In the intensive care setting, over the years, no monitoring system has been shown to change patients’ outcomes. This is also true of transthoracic LUS. However, with brief training, this tool can be used to detect the severity of lung disease after ICU admission and to monitor the progress of the disease without invasive procedures. Furthermore, the detection of different lung profiles—wet or dry—can facilitate patient diagnosis in the clinical context. If it is true that lung fluid tolerance is a futile finding in the stable patient, because it is no guarantee that the patient needs fluid, lung refractory or fluid intolerance is a very important step in haemodynamic monitoring, albeit requiring competence in CCE. Furthermore, we need to acknowledge the fact that aortic stenosis can preclude this step due to the overestimation of VTI. In this case a haemodynamic invasive monitoring such as the pulmonary or transpulmonary thermodilution technique could be required.

Unfortunately, at present, there is no validated method for establishing the size of a pneumothorax using transthoracic LUS alone. This is very important considering that the current guidelines of the main international scientific societies establish different therapeutic approaches on the basis (besides the traumatic origin of the pneumothorax) of the dimensions of the pneumothorax (the different guidelines agree with each other for no more than 40%) (88) (Table 3). In addition to the limits already described, in the case of emphysematous bubbles that can simulate a pneumothorax (the difference of which, however, may be the presence of a second lung point beyond the first,

Table 3 Guidelines' definition of "large" pneumothorax by upright posterior-anterior chest radiography reading and corresponding recommended treatment

Guideline	Definition of large pneumothorax	Treatment
ACCP (American College of Chest Physicians)	>3 cm apical interpleural distance	Intercostal catheter drainage
BTS (British Thoracic Society)	≥2 cm between lung and chest wall	Aspiration
BSP (Belgian Society of Pneumologists)	Pleural gap along the entire length of the lateral chest wall	Aspiration or small-bore catheter thoracostomy drainage

i.e., double lung point), the biggest limitation in the use of ultrasound in the diagnosis of pneumothorax is the presence of subcutaneous emphysema. In this case, ultrasound can detect vertical linear artefacts, called "E-lines", that could be confused with B-lines, but instead start from the subcutaneous tissue. To correctly distinguish between these two artefacts, it is important to identify the space between two ribs in order to visualise the pleural line. All in all, and with this limitation in mind, we need to remember that transthoracic LUS is a powerful instrument but that diagnosis and subsequent therapeutic decisions must be made on the basis of the clinical context, the patient's history and, ultimately, the entire clinical picture.

Future perspectives for LUS

- (I) We hope that in the future LUS scores would gain greater attention in the ARDS definition and classification, specifically in light of its powerful role to correlate the severity of the disease with the outcome;
- (II) According to several studies (56,58,61,62), the use of transthoracic LUS to estimate pleural fluid requires urgent standardisation, and we hope that given the clinical importance of estimating pleural effusion this point will be discussed in the new version of the International Consensus Conference on Lung Ultrasound Guidelines;
- (III) Although haemodynamic management represents the second most important step after antibiotic prescription in septic patients, transthoracic LUS fluid refractory (intolerance) needs to be recognised as an important step in the management of a patient's fluid, and that the haemodynamic monitoring of the circulatory system is just a piece of the puzzle. To use a metaphor, it seems that we have to search the "key beneath a lamp" (haemodynamic) because "that

is where I can see" (89);

- (IV) Transthoracic LUS has tremendous potential in the evaluation and immediate management of critically ill patients at the bedside. Just as, for many years now, stethoscope has become an indispensable tool (i.e., in emergency medicine, cardiology), thoracic LUS could also become an indispensable tool for the intensivist to make fundamental decisions in the management of critically ill patients.

Conclusions

Advances in transthoracic LUS in critical care incorporate physical examinations and visual thinking strategies in a way that offers many opportunities for both the patient and the physician in terms of early goal-directed monitoring and therapy. The application of transthoracic LUS as a score of lung gravity or recovery in ARDS patients, for the assessment and drainage of pleural effusions, for the discovery of a suspected pneumothorax, or for the evaluation of lung fluid intolerance is now well established. As a consequence, transthoracic LUS appears to be a powerful tool in the hands of a trained intensivist, and, at present, to avoid using it seems unjustified.

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None.

Footnote

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