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REVIEW

Lung ultrasound in the critically ill

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Abstract - The lung is classically investigated using physical examination and radiographs and computer tomography (CT) scans complement this approach. These traditional tools do, however, have drawbacks. The present article shows the potential of an immediate and accurate method of investigating this vital organ: lung ultrasound. Ten signs allow the precise location of the lung (bat sign), the definition of a normal lung surface (lung sliding, A-lines), pleural effusion (quad sign, sinusoid sign), lung consolidation (tissue-like sign, shred sign), interstitial syndrome (lung rockets) and pneumothorax (stratosphere sign, lung point). A simple grey-scale unit and a particular probe – microconvex, ideal for the lung, but also for the whole body in the critically ill - are required. Using these standardized signs, lung ultrasound allows main acute disorders to be diagnosed with an accuracy close to that of CT. With regards to the interstitial syndrome, although traditionally not used by the intensivist (using ultrasound or any other method), this application provides a standardized approach in two basic settings: acute respiratory failure (BLUE-protocol) and acute circulatory failure (FALLS-protocol). The ten signs assessed in the adult can also be applied in the neonate, since no differences are found. In most other settings (Acute Respiratory Distress Syndrome, trauma, pulmonology, cardiology), the same ten signs are the basis. Interventional ultrasound is of major help in the critically ill. Although neglected since the birth of ultrasound, the lung is fully accessible by this method. The main outcomes of this visual approach are an immediate bedside diagnosis and the possibility of decreasing procedures involving radiation exposure.

Keywords - **Lung ultrasound, chest ultrasonography, acute respiratory failure, acute circulatory failure, pulmonary oedema, pulmonary embolism, pneumonia, pneumothorax, interstitial syndrome, fluid therapy, haemodynamic assessment, intensive care unit, critical care, emergency medicine**

Introduction

Lung ultrasound in the critically ill is a small part of critical ultrasound examination and is apparently a recent field. It is in fact the outcome of a slow process that was initiated in 1946 [1]. Since 1989 we have had the privilege of extending the 1982 ADR-4000 technology of François Jardin's medical Intensive Care Unit, devoted to cardiac assessment [2], to the whole body, basically defining the field of critical ultrasound [3]. The ADR-4000 was perfectly suitable for this bedside use. In the development of this concept, the lung was our first priority, although it had traditionally been considered unsuitable for study with ultrasound [4]. However, a simple deciphering of the lung code has shown that this dogma was wrong.

Acute respiratory failure and acute circulatory failure are two major concerns in critical care. This review will illustrate the role that lung ultrasound can play in these conditions.

Seven principles of lung ultrasound, standard technique, normal patterns

The first principle to be considered is that the BLUE-protocol is performed with a simple unit. Since 1992, we have used a machine which is still manufactured and suitable. Seven criteria are required. A smart machine has a dimension for accessing patients in any situation (*our reference: 29 cm width, regardless height*). It has an optimal image resolution (*our reference: enclosed figures*) and a fast start-up time (*our reference: 7 seconds*). A smart probe is able to document superficial and deep lung, anterior and subposterior thorax, lower extremity deep veins, caval veins, heart, without changing settings. Vascular, cardiac, and abdominal probes can do part of the work, but none is perfect for the lung, and we aim not to lose time changing and cleaning the probe (*our reference: an 8-cm long, 5-MHz microconvex probe with a 1-17 cm range of exploration able to assess the whole body in a critical setting*).

A compact design is required and the machine should be easy to disinfect (*our reference: a flat keyboard*). An intelligent cart of suitable size for the unit is needed without lateral extensions which increase the overall width. Small portable units allowing bed-to-bed use were available long before the era of laptop technology (*our reference: a smart 1992 cart of overall width 33 cm*). A simple technology, without Doppler or complex modes (harmonics etc.), allows immediate use and low cost (*our reference: the cost of a modest car)*. Some doctors, including the author, work in aircrafts, where hand-held units are mandatory. We use a compact (14 x 14 x 16 cm), light (1.8 kg) unit.

Second principle: in the thorax, air and fluids have opposite gravitational directions, but can also be intimately mingled. The artifacts result from this mingling.

Third principle: the lung is a very voluminous organ. Standardized areas can be defined [5]. The probe is applied directly to the intercostal space, avoiding traditional subcostal routes. Of four defined stages of investigation, only Stage 1

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(anterior analysis) and Stage 3 (subposterior analysis) are used in the BLUE-protocol (Figure 1).

The fourth principle observes that all signs arise from the pleural line (Figure 2).

The fifth principle highlights the static signs, i.e., mainly the air artifacts. Usually considered undesirable, they were classified in our 2005 textbook [6]. The normal artifact is the A-line, a horizontal repetition artifact (Figure 2).

The sixth principle indicates that the lung is a vital organ, which should permanently move, generating lung sliding (Figure 2).

The seventh principle specifies that nearly all acute disorders abut the pleural line: pneumothorax, pleural effusions, interstitial oedema, and most acute lung consolidations.

The ten signs of lung ultrasound in the critically ill

Each disorder has a specific air-fluid ratio (second principle outlined in the previous section). Pleural effusion is pure fluid. Alveolar consolidation is mainly fluid. Interstitial syndrome is mainly air, pneumothorax exclusively air. Our first studies were performed using Computer Tomography as the gold standard [see refs. 11-12,16,25,33,35,40,47]. At the thoracic area, the BLUE-protocol uses no more than ten signs.

1) The pleural line

This is described in Figure 2. The bat sign, visible only in longitudinal scans, should be recognized in any lung examination, a mandatory first sign to record. It is a permanent landmark of the lung surface.

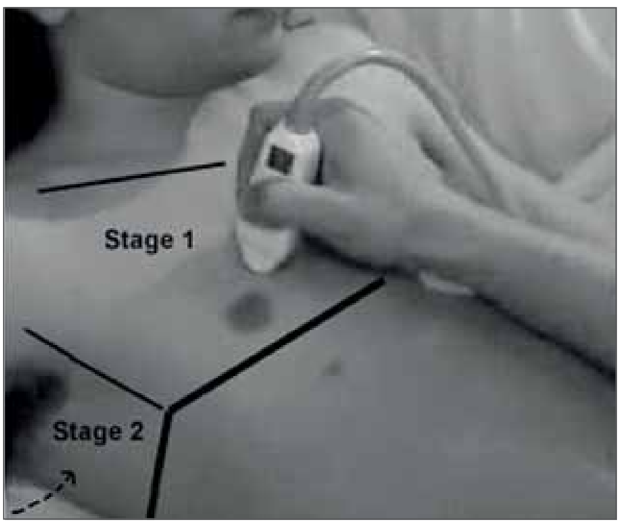
2) The A-line (normal lung surface)

Many artifacts can be described, so we classified them using an alphabetic nomenclature [7]. The A-line is the manifestation of air (here physiologic in a healthy lung). This is a repetition of the pleural line, located deeper, at the same distance as the skin-pleural line distance (Figure 2).

3) Lung sliding (normal lung)

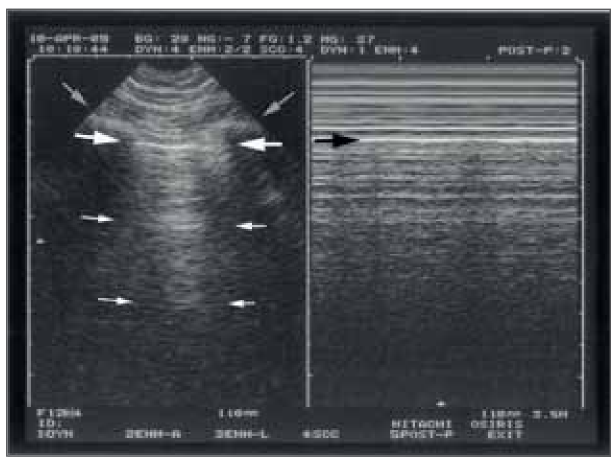
Lung sliding is a movement visible at the pleural line, synchronized with respiration, since the lung descends toward the abdomen on inspiration. Lung sliding is a relative movement, localized at the pleural line and below, contrasting with the motionless superficial tissues. The M-mode clearly identifies this relative motion, yielding the seashore sign (Figure 2). We bypass all filters (persistence filters, harmonics and any sophisticated facilities) because they make lung ultrasound more difficult.

Figure 1. Stages of investigation



The anterior and posterior axillary lines delineate anterior, lateral, and posterior areas. When both hands are laid over the chest wall, the lower finger determines the limit of the lung. Stage 1 is defined by the exploration of the anterior zone (1) in a supine patient at ground level (in terms of gravity). Stage 1' defines a semi-recumbent patient. Stage 2 includes the lateral zone (2). In Stage 3, our short probe is inserted as far as possible, pointing toward the sky, on the posterior wall (arrow) and the patient minimally turned to the opposite side. Stage 4 is a comprehensive analysis adding the supraclavicular and posterior areas, with the patient positioned laterally or seated. The dotted arrows indicate the point allowing detection of all cases of free fluid and most cases of alveolar consolidation at a glance. Note the short microconvex probe - a basic requirement for reaching posterior areas.

Figure 2. Normal lung surface



Left: Longitudinal scan of an intercostal space. Only artifacts (rib shadows and air) are visible. Ribs cast frank acoustic shadows. The pleural line, a roughly horizontal hyperechoic line, is located (upper horizontal arrows) between two ribs (gray arrows), 0.5 cm lower in the adult. The upper rib, pleural line, and lower rib outline the bat sign. The horizontal lines (lower horizontal arrows) that arise from the pleural line and are displayed at regular intervals, called the A-lines, have clinical applications. Right: Seashore sign (M-mode). The seashore sign demonstrates lung sliding. It corresponds to the displacement of the lung along the craniocaudal axis, synchronized with respiration. The motionless superficial layers generate horizontal lines (wave pattern). The motion created by lung sliding generates a sandy pattern, arising from the pleural line itself (arrow).In the newborn, the same bat pattern is visible in proportion to the size of the infant.

4) The quad sign (pleural effusion)

The ultrasound diagnosis of pleural effusion has been known to physicians since at least 1946 [1,8]. This application is now routine in many critical care centres, but has the drawback of being viewed by many as the only role of thoracic ultrasound [9]. We found that the traditional abdominal approach was imperfect. Our direct intercostal approach, permitted by our universal microconvex probe, generates different signs with the advantage that it can be standardized. In addition, this direct approach prevents ghost images generated by the trans-diaphragmatic approach.

Pleural effusions are traditionally defined as anechoic collections. This is not reliable in the most severe cases (empyema, haemothorax). We prefer to use two signs which independently allow the diagnosis. Using an intercostal, longitudinal approach, the fluid effusion appears as limited by four regular borders, forming a quad: the quad sign (Figure 3). The pleural line and the acoustic shadows of ribs make three constantly straight borders. The deep border is also regular, since it is constituted by the lung itself, a regular structure. This ultrasound equivalent of the visceral pleura is called the lung line.

5) The sinusoid sign (pleural effusion)

The quad sign is the main static sign. It is associated with a dynamic sign, the sinusoidal sign, describing the centrifugal inspiratory movement of the lung line toward the pleural line. This displays a sinusoid on the M-mode (Figure 3).

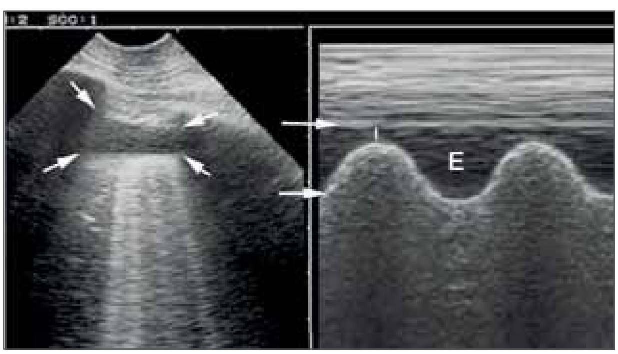
Quad signs and sinusoid signs indicate pleural effusion with a 97% specificity when the gold standard is withdrawal of pleural fluid [10]. The sensitivity and specificity of ultrasound are 93% when compared with CT [11]. Minute volumes of effusion are not detected using CT, and apparently decrease ultrasound specificity. Above all, the feasibility of ultrasound is nearly 100%. The described standardized signs are applicable in all patients equally, including challenging ones.

Free effusions are located above the diaphragm, at least posteriorly [10]. This provides an opportunity to define a standardized point of search, called the PLAPS-point, for Postero-Lateral Alveolar and/or Pleural Syndrome [5].

6) The tissue-like sign (lung consolidation)

Nearly all cases of acute lung consolidation abut the wall and are solidly pleural-based [12]. Therefore, the ultrasound beam, not stopped by air, can traverse the consolidated lung through this acoustic window. As opposed to the other main syndromes (pleural effusion, interstitial syndrome, pneumothorax), lung consolidations can locate in small or unusual sites and can thus be missed. Most cases (90%) locate at the PLAPS-point, however [12]. A short microconvex probe can therefore facilitate their search. Lung consolidation was described long ago [1,13,14], but once again little practical use was made of it in the critically ill. Here also, we provide technical adaptation. The tissue-like sign indicates an image which looks like a tissue, i.e., is echogenic like a liver, and which behaves like a tissue, i.e., does not generate any sinusoidal sign (Figure 4).

Figure 3. Pleural effusion



Pleural effusion, intercostal approach. The left figure (real time) shows the quad sign, i.e., the four regular borders of the fluid effusion, especially the deep one, limited by the two lower arrows. This effusion is 16-mm thick on expiration and 4-mm thick on inspiration. Note that the lung at this area (Stage 3) is not consolidated, as shown by the visible air artifacts. Right: the M-mode image highlights the sinusoidal sign, a basic dynamic sign specific to fluid pleural effusion, also indicating low viscosity. As the lung expands its volume toward a core-surface axis, the pattern is sinusoidal and is synchronous to the respiratory cycle. I: inspiration. E: expiration. Upper arrow: pleural line. Lower arrows: lung line.

Figure 4. Lung consolidation

Lung consolidation of the lower lobe at the PLAPS-point. Behind the pleural line (upper white arrow), and behind the lung line (lower white arrow), a tissue-like mass can be described, and above all, the shred sign is highlighted by the black vertical arrows, arising from different parts, making a shredded line not parallel to the pleural line. Below the shred line, air artifacts from aerated lung or pleural effusion are visible. Note the associated pleural effusion, between the white arrows.

7) The shred sign (lung consolidation)

The lung line of the quad sign is regular. Conversely, the deep border of a lung consolidation, in contact with aerated lung, is irregular, shredded, and may be the main sign. Only in the case of massive, translobar consolidation is there no shred sign, but the dimensions of the consolidation, 9-11 cm in the adult, are not compatible with pleural effusions (which never reach more than 6 cm in our observations). Using the tissue-like and shred signs to define lung consolidation, ultrasound had 98% specificity and 90% sensitivity [12]. This sensitivity depends on the location of the consolidation and its extension to the chest wall. Small consolidations at unusual locations can be missed.

8) The B-line (interstitial syndrome)

Interstitial syndrome is central to the BLUE-protocol. Although this diagnosis is not required in the culture of the intensivist (and the methods of diagnosis in a critically ill person are limited anyway e.g., auscultation, radiography), the BLUE-protocol yields immediate therapeutic plans on the basis on this information. Interstitial syndrome seen by the intensivist is quite equivalent to the diagnosis of pulmonary oedema.

We use a sign described through technology from 1982, published in 1994 [15] and further developed in 1997 [16], with clinical applications (the B-line) published in 1998 [17]. This artifact is defined according to seven features: these are comet-tail artifacts, strictly arising from the pleural line, hyperechoic, well-defined laser-like, spreading to the edge of the screen without fading, obliterating normal A-lines and moving in concert with lung sliding (Figure 5). These features distinguish the B-lines from many other comet-tail artifacts that can be found, such as the Z-lines, which are ill-defined, short, do not erase A-lines, do not follow lung sliding, are seen in more than 80% of cases in normal subjects and have no significance. E-lines are air artifacts generated by subcutaneous emphysema, and therefore arise superficially.

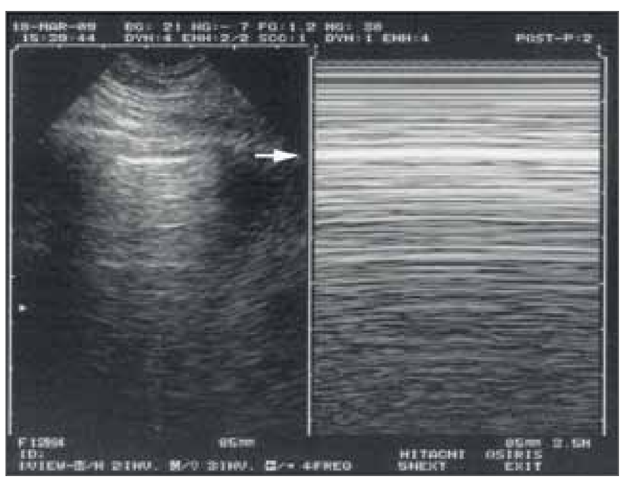
B-lines are generated by elements with a high acoustic impedance gradient from the surrounding structures, like water surrounded by air: water is an ultrasound conductor whereas air is a hindrance. The structures generating B-lines are too small for *direct* visualization. They are present at and all over the lung surface and are separated from each other by 6/7 mm or less. They are present in pulmonary oedema and resolve with therapy [18]. All these features are characteristic of thickened interlobular septa (6/7 mm apart), and ground-glass areas (3 mm apart). Ultrasound B-lines are an equivalent of Kerley lines [19]. What is detected using ultrasound at the lung surface, i.e., the thickened superficial septa, reflects septal behaviour deep within the lung [16].

Numerous B-lines (lung rockets) disseminated to the whole anterolateral chest wall define diffuse ultrasound interstitial syndrome. Diffuse anterolateral lung rockets correlate with radiographic alveolar-interstitial syndrome with 93% sensitivity and 93% specificity [16]. When the correlations were made using CT, not radiography, sensitivity and specificity were 100% [16]. During 19 years of observation, we have been unable to see diffuse lung rockets in healthy subjects. A patient with subpleural thickened interlobular septa or ground-glass areas always exhibits ultrasound lung rockets. Our first observations have been increasingly confirmed [20-23].

Figure 5. Interstitial syndrome

Three or more B-lines between two ribs in a single view define lung rockets (see description in the text). The number of B-lines here is roughly five or six, a pattern correlated with ground-glass areas. This patient had acute haemodynamic pulmonary oedema.

Figure 6. Pneumothorax and the stratosphere sign



Abolition of lung sliding, visible in real time, demonstrated using M-mode. Exclusive horizontal lines are displayed, indicating complete absence of dynamics at and below the pleural line: the stratosphere sign. The arrow designates the location of the pleural line. There is no static difference between this left image and that of Figure 2. Both indicate air (normal for Figure 2, free air here).

A-lines and B-lines cannot be visible in the same area. There is no intermediary stage between them, allowing a dichotomous analysis of injured lungs.

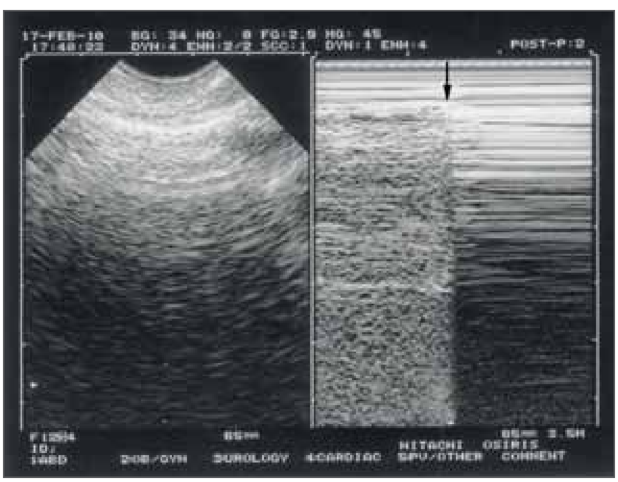
Acute interstitial syndrome, especially of haemodynamic origin, is generally extensive, explaining why the diagnosis can be made easily using standardized points (see BLUE-protocol). Searching for localized interstitial syndrome (of little relevance in the BLUE-protocol) requires comprehensive examination.

Ultrasound analysis of interstitial syndrome is relevant for diagnosing haemodynamic pulmonary oedema (when diffuse) with 100% sensitivity and 92% specificity [17], chronic obstructive pulmonary disease or asthma (when absent) [17], pulmonary embolism (when absent, and when venous thrombosis is present), with 92% sensitivity [24], pneumothorax (when absent, with absent lung sliding) with 100% sensitivity [25], pneumonia (when motionless or asymmetric [26], and even as endpoint for fluid therapy during shock [27]. This suggests that efforts should be made to incorporate this method into standard teaching.

9) Abolished lung sliding and the stratosphere sign (pneumothorax)

Air was traditionally considered a hindrance to the practice of ultrasound. If intensivists accept sequential thinking, this diagnosis becomes accessible. One, two or three signs are required to rule in or out most cases of this life-threatening disorder, within one minute. Bedside radiography underestimates the real volume, up to missing a large percentage of cases, even under tension [28-32]. In supine patients, 98% of significant cases are at least anterior [33]. The upper and lower BLUE-points are immediately informative.

Figure 7. Pneumothorax and the lung point



The lung point is observed in real time but can be recorded using the M-mode. This image shows a sudden (arrow) replacement of a seashore sign by a stratosphere sign, at the very location where the lung is in transient contact with the wall on inspiration and no longer on expiration (right of the right image).

The absence of lung sliding is a basic, first step for the diagnosis of pneumothorax, which was described long ago in horses [34]. Lung sliding allows pneumothorax to be confidently rejected since its negative predictive value is 100% [35]. Instead of the familiar lung sliding, a striking absence of motion arising from the pleural line is always observed. Sensitivity is 95% (100% when cases of subcutaneous emphysema are considered as nonvisible lung sliding). The abolition of lung sliding generates the stratosphere sign on M-mode (Figure 6). Doppler is not mandatory. One can use linear probes, but our microconvex probe consistently allows full investigation of this area.

Abolished lung sliding is frequent in critically ill patients. Acute respiratory distress syndrome, massive atelectasis (including one-lung intubation), pleural symphysis (inflammatory adherences), severe fibrosis, phrenic nerve palsy, jet or high frequency ventilation, cardiopulmonary arrest, simple apnoea, oesphageal intubation, inappropriate filters, inappropriate probes can abolish lung sliding. The positive predictive value is only 87% in the general population [35], falls to 56% in the critically ill [40], and to 27% when only patients with acute respiratory failure are considered [26]. Ironically, lung sliding is most often absent in patients at maximal risk for pneumothorax and who will not tolerate it. We reiterate that the absence of lung sliding is *not* specific to pneumothorax. Other signs point to the diagnosis.

The A-line sign is the second main sign. We described that A-lines indicate air (normal air, or here, pneumothorax). In pneumothorax, the A-line is associated with abolished lung sliding. From the pleural line arise only A-lines (Figure 6): the A-line sign. The A-line sign is 100% sensitive for the diagnosis of complete pneumothorax. Specificity is only 60% [25], but what matters is that the slightest B-line (even motionless) allows pneumothorax to be ruled out [25]. This information is basic in the numerous cases where lung sliding is absent in the absence of pneumothorax. Linear probes are too superficial for showing the basic difference between B and Z-lines: B-lines are long, Z-lines are short.

10) The lung point (pneumothorax)

When abolished lung sliding and the A-line sign are detected, ultrasound confirmation is possible using the lung point, a 100% specific sign, observed in no other condition [40]. The term ‘lung point’ assumes that absent lung sliding and the A-line sign were identified in Stage 1. The probe, gradually moved laterally, will suddenly detect an area where, with the probe now held still, visualization of either lung sliding or B-lines during inspiration can be recorded. This is a binary rule, whether or not the lung is in contact with the chest wall (Figure 7). The lung point indicates that lung sliding abolition is not linked to technical flaws.

The overall 66% sensitivity of the lung point is a function of size. In major retractions, the lung does not touch the wall and cannot yield any lung point. Interestingly, sensitivity for occult pneumothorax is high: 79% of cases missed on bedside radiography are diagnosed using ultrasound [41]. Said differently, the lung point indicates pneumothorax volume: moderate, generally radio-occult if anterior; massive if posterior or even absent. Lateral lung points were correlated with a 90% need for drainage, versus 8% with anterior lung points [41].

The role of ultrasound for diagnosing pneumothorax and assessing its volume has been confirmed recently [36-39].

Clinical applications of lung ultrasound in the critically ill

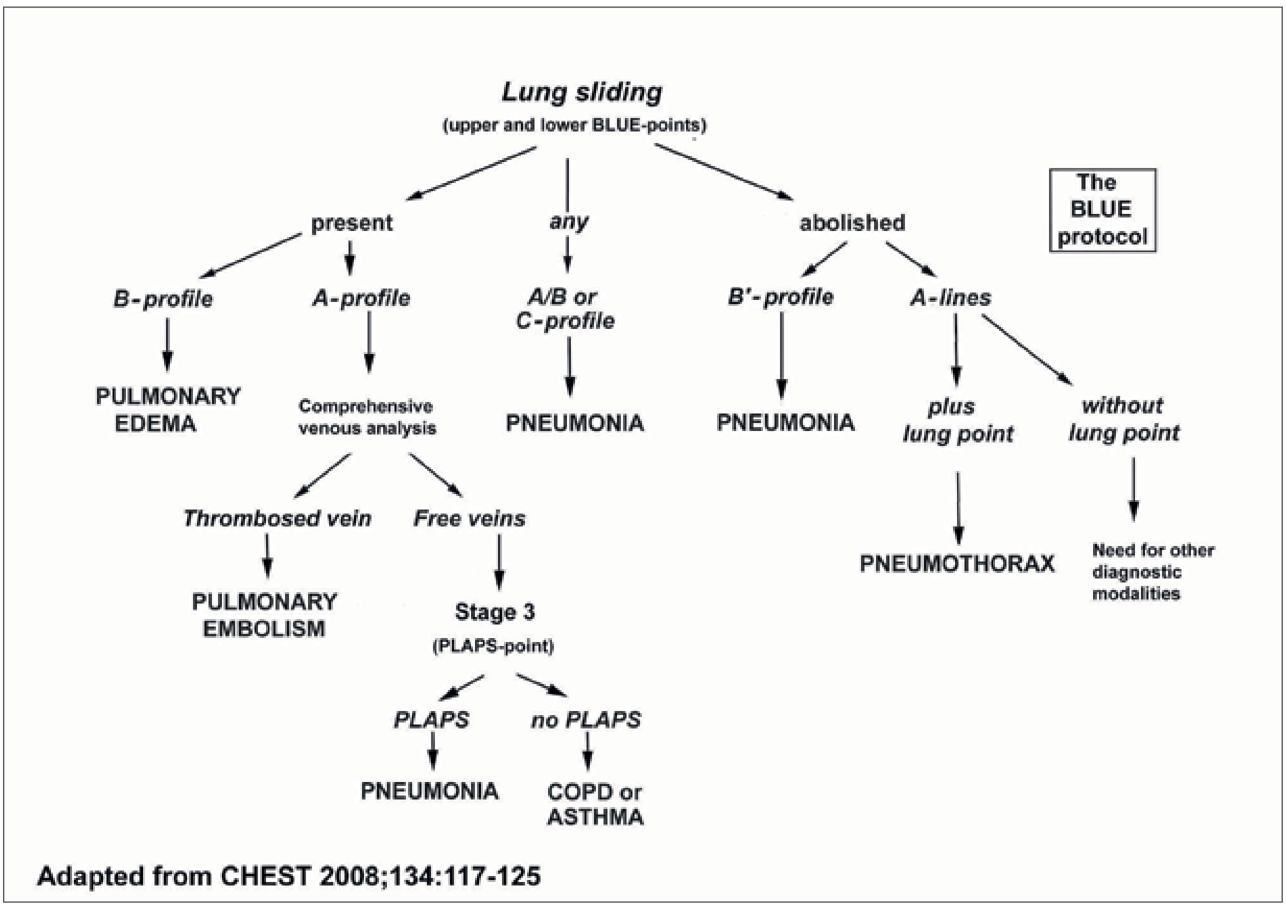
The BLUE-PROTOCOL - an integrated approach for the diagnosis of acute respiratory failure

Acute respiratory failure is one of the most distressing situations for the patient. In this difficult setting, initial mistakes are frequent [42]. This prolongs the distress of the patient, and has deleterious outcomes. The BLUE-protocol is an exclusive ultrasound approach to be used with such patients, based on physiopathology, and resulting in a 90.5% diagnostic accuracy alone, but intended to be combined with simple clinical data [26]. It proposes a step-by-step analysis, achievable in three minutes, using a suitable machine, a universal probe, and standardized points.

Three situations are considered, combining signs with locations: 1) anterior lung sliding present or absent; 2) anterior lung rockets present or absent; 3) posterolateral alveolar and/or pleural syndrome (PLAPS) present or absent. With the notion of PLAPS there is no requirement to distinguish consolidation from effusion, since the results are the same. Seven profiles are generated. Each cause of respiratory failure yields a particular ultrasound profile. Here, B-lines play a central role. The normal anterior lung surface (A-profile) requires a venous analysis (Figure 8).

Pulmonary oedema. Diffuse bilateral anterior lung-rockets indicate pulmonary oedema [16]. Their association with lung sliding generates the B-profile, which is recognized in less than half a minute. The B-profile indicates haemodynamic pulmonary oedema with 97% sensitivity. The lung-rockets are looked for at standardized points: the upper and lower BLUE-points. Note that lateral locations provide redundant information in the BLUE-protocol, and posterior interstitial syndrome can be generated by simple gravity. Briefly, in pulmonary oedema, all interlobular septa are thickened by oedema and the transudate does not impair lung

Figure 8. The BLUE-protocol decision tree



This decision tree, slightly modified from the original article (With the permission Chest 2008;134:117-125), indicates the way we proceed for immediate diagnosis of the main causes of acute respiratory failure, using a lung and venous ultrasound approach.

sliding. The 95% specificity is explainable since some infectious diseases and chronic interstitial diseases yield the B-profile.

COPD and asthma. Absent lung-rockets associated with lung sliding, i.e., normal lung surface, indicates asthma or COPD.

Pulmonary embolism. The anterior lung surface is normal (A-profile) in 95% of cases. In our series, 80% of patients with pulmonary embolism had visible venous thrombosis. Of patients without the A-profile, 99% had no pulmonary embolism, and 2% of patients with the A-profile without venous thrombosis had pulmonary embolism. Simple scintigraphy, which is less irradiating [43], may be proposed sometimes instead of CT for confirming the diagnosis of pulmonary embolism.

Pneumothorax. Absent lung sliding plus absent B-lines (A'-profile) are logical findings.

Pneumonia. Since numerous causes are possible, pneumonia generates several profiles, mainly asymmetry (from left to right, explaining the A/B profile, from posterior to anterior, explaining the A-profile plus PLAPS), anterior consolidations (C-profile), and the generation of exudate, which may stick the lung to the parietal pleura, impairing lung sliding (B'- profile). The presence and distribution of the B-lines helps distinguish between haemodynamic and permeability-induced pulmonary oedema [26].

Rare causes of acute respiratory failure (frequency < 2%) were excluded, resulting in a simple decision tree. Rare diagnoses do not mean difficult diagnoses. In massive pleural effusion for instance, simple traditional tools (history, radiography, and also... ultrasound) encounter little diagnostic difficulty. Causes of dyspnoea not requiring admission to the ICU (hyperventilation syndrome etc.) were not included.

The heart does not feature in the BLUE-protocol, again favouring simplicity. Simple emergency cardiac sonography (without Doppler) is always performed following the BLUE-protocol, although the absence of the B-profile, even if associated with left heart anomalies, makes the diagnosis of pulmonary oedema unlikely.

The aim of the BLUE-protocol is to afford immediate relief to dyspnoeic patients by pointing to appropriate therapy, and to decrease the need for irradiating, time-consuming or painful tests, such as CT, echocardiography and arterial puncture. Video sequences are available at www.ceurf.net.

The limited investigation (including FALLS-protocol) - a different approach considering haemodynamic therapy

The limited investigation assesses shock patients. It combines a simple cardiac sonography, the FALLS-protocol (FALLS for fluid administration limited by lung sonography, a minute part of lung ultrasound), and venous ultrasound (caval veins) if lung ultrasound does not contribute. Traditional tools for haemodynamic monitoring are familiar but a gold standard for assessing clinical volumes has still to be defined. Lung ultrasound in the critically ill makes advantage of three features:

1) Interstitial syndrome is a silent step which precedes alveolar oedema, i.e., the step that no intensivist wants to create during fluid therapy.
2) Lung ultrasound is able to detect interstitial syndrome using a tool which is fully accurate, immediate (a few seconds), and easy to learn (a few hours, with high interobserver agreement [11].
3) Interstitial syndrome may be considered as a direct parameter of clinical volumes, because it shows fluid in a normally fluid-free organ.

A correlation between lung ultrasound and pulmonary artery occlusion pressure was published in 2002 [44], and was subsequently used in a cardiology setting [21] and in the critically ill [27]. The limited investigation (considering haemodynamic therapy) proposes a straightforward approach: simple cardiac sonography to rule out tamponade or pulmonary embolism, then lung ultrasound to definitely rule out obstructive shock (by ruling out tension pneumothorax) then cardiogenic shock (where the B-profile should be exhibited). When there is an A-profile, the FALLS-protocol really begins: an A-profile indicates that this patient can receive fluid therapy. When an A-profile remains unchanged during fluid therapy that leads to clinical improvement, this defines hypovolemic shock. If fluid therapy generates lung-rockets with no improvement of the signs of shock, such patients have, schematically, septic shock, the only remaining cause (rarities apart: anaphylactic shock, spinal shock etc.). This is logically the time to interrupt fluid therapy and to initiate vasopressive support. Note that this septic shock has benefitted from early and massive fluid therapy, in accordance with current standards [45].

If the physician considers that such patients initiate the flat slope of cardiac function, some fluid can be withdrawn, using several blood tests – blood cultures etc., or simply the extended FALLS-protocol, which uses passive leg raising for reversible fluid volume mobilization.

Other uses of lung ultrasound in the critically ill

Radiography or CT in ARDS, or neither?

CT provides a nice overview, but its drawbacks should be known. The costs of CT make it unavailable for many patients. Delay, transportation, iodine injection, irradiation and supine position raise problems with its use in the critically ill. The radiograph is easy to record, but is not designed to be a reference since it misses to a varying degree the disorders assessed here [46]. Ultrasound is quite similar to CT in most aspects [10,12,16,35,41], and better than CT in assessing lung sliding, phrenic function, intra-parenchymal necrosis [47], dynamic air bronchogram [48] and others, since its resolution is superior and this is a real-time method. Lung ultrasound should be accepted in the years to come as a reasonable bedside gold standard.

Other advantages

Countless uses of ultrasound can be considered. Many signs allow pneumonia and atelectasis to be distinguished. In airway management, ultrasound can be life-saving. Thoracentesis is of major help [10]. Lung ultrasound is highly feasible: this voluminous organ is accessible wherever the probe is applied on the thorax. The concordance rate is high after limited training in suitable centres.

The ten basic signs of lung ultrasound are found, with no differences, in the critically ill neonate (PICU), making the development of paediatric lung ultrasound an absolute priority. Apart from the areas of intensive care, anaesthesiology and emergency medicine, lung ultrasound can be adopted in cardiology, pulmonology, thoracic surgery, and, not to be forgotten extra-mural medicine, a simple idea implemented long ago [49]. Lung ultrasound has few limitations: parietal emphysema, dressings.

Although beyond the scope of the present article, it is also possible to recoup the cost of the ultrasound unit within a few weeks, to resolve medico-legal issues, and to use our substitute to traditional gel.

Conclusion

In a field where everything must be fast and accurate, lung ultrasound plays a first-line role in the diagnosis of acute respiratory failure (BLUE-protocol) or acute circulatory failure (FALLS-protocol). Simplicity is favoured (a simple unit, one simple probe, no Doppler, a dichotomous decision tree), which is key in developing this kind of visual medicine [50].

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