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Should lung ultrasonography be more widely used in the assessment of acute respiratory disease?

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"The lung lends itself perfectly to ultrasound examination, with its advantages of immediate bedside diagnosis and decreased irradiation."

This article explains why lung ultrasound should be more widely used as a complement to, or in place of, radiography or CT when assessing critically ill patients. Ten standardized signs allow the precise localization of the lung surface, the definition of a normal lung surface and of the main disorders (pleural effusion, lung consolidation, interstitial syndrome and pneumothorax). A simple grayscale unit and a microconvex probe, ideal for the lung, but also for the whole body in the critically ill patient, are described. Lung ultrasound allows accurate diagnosis of the main acute disorders. Interstitial syndrome is central in two settings: the bedside lung ultrasound in an emergency (BLUE) protocol, a standardized approach to an acute respiratory failure using lung ultrasound, and the fluid administration limited by lung sonography (FALLS) protocol, which describes hemodynamic management of acute circulatory failure using lung ultrasound. The scope of lung ultrasound can extend to acute respiratory distress syndrome assessment, trauma, pulmonology and neonatal intensive care, among others. The lung lends itself perfectly to ultrasound examination, with its advantages of immediate bedside diagnosis and decreased irradiation.

Ultrasound is an old tool for the physician [1]. To the question "Should it be more widely used in the assessment of acute diseases", using the logistics present in our intensive care unit [2], it was long ago suggested that this was a basic tool for the first-line care of acutely ill patients [3]. While the community little by little realized its wide potential, we tried to answer the question of its feasibility (for use by 'non-experts') by proposing a simple use, fully adapted to the critically ill patient, using a simple technique, a simple machine and one simple universal probe.

But how could the lung, the most vital organ, be included in such a concept, considering that air is reputed to be an insuperable obstacle to ultrasound waves [4]? A simple task of deciphering the code of lung ultrasound, the language of the artifacts (usually considered a hindrance) and patient work of submission allowed us to adapt our vision of simplicity, using a standardized approach to the acutely injured lung. Like a decaphonic scale, or even an alphabet, just ten signs can be used to build infinite kinds of applications (Figure 1).

Ten signs: the alphabet of lung ultrasound

We will not describe here all of the seven principles of lung ultrasound, nor our technique (our standardized points of research – Figure 2), but we will just highlight the seventh principle: all acute disorders touch, or reach, the lung

Keywords: acute circulatory failure • acute respiratory failure • ARDS • intensive care unit • lung ultrasound • pneumonia • pneumothorax • pulmonary edema

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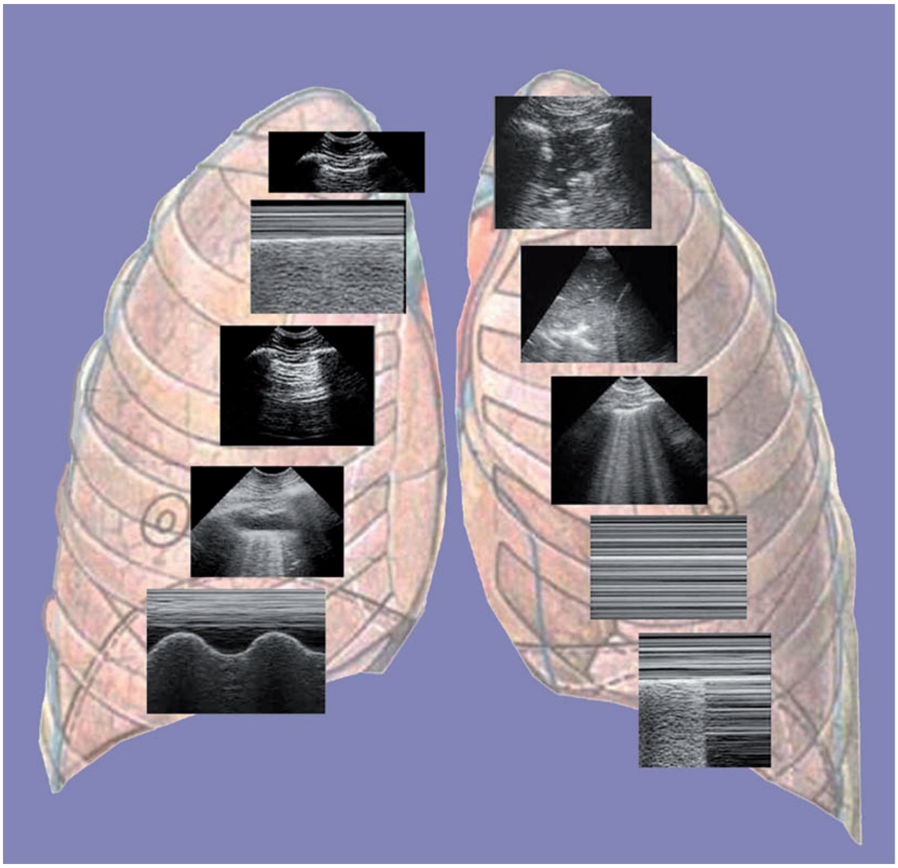

Figure 1. The ten signs of lung ultrasound in the critically ill. This figure shows the alphabet of lung ultrasound in the critically ill. In the right lung on top is the location of the pleural line (bat sign). The bat sign is a sort of G-key, allowing immediate recognition of the lung surface in all circumstances. Just below is the lung sliding (seashore sign in M-mode). Below is an A-line featuring horizontal repetition of the pleural line, a basic sign of air barrier. Below are the quad sign and the sinusoid sign, allowing standardized diagnosis of pleural effusion. In the left lung, on top is the typical shred sign (irregular deep border) indicating lung consolidation. Below is the tissue-like sign, another sign of consolidation. Below is the B-line, a sensitive sign: this is a comet-tail artifact arising from the pleural line, hyperechoic, long, well-defined, erasing A-lines, moving in concert with lung sliding. Several B-lines visible between two ribs are called lung rockets. See their practical relevance in the text. Below is the stratosphere sign, demonstrating abolition of lung sliding. The last image is the lung point, a sign specific to pneumothorax (the lung point corresponds to the cyclic and sudden visualization of lung signs when the collapsed lung touches the chest wall on inspiration).
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surface, generating a perfect window for ultrasound diagnosis. Comprehensive details of this are found in [5].

The normal lung generates lung sliding and A-lines (Figure 1). Pleural effusion has been a familiar diagnosis for decades [6]. It summarized the potential of thoracic ultrasound [4]. This was achieved by radiologists using abdominal probes, abdominal approaches and signs of questionable value (the anechoic tone is missing in the most severe cases: hemothorax and empyema). Our direct intercostal approach, permitted by our microconvex probe, generates specific signs with the advantage of being standardizable (quad sign and sinusoid sign). The specificity of this approach is 97% [7].

The diagnosis of lung consolidation was also approached long ago [8]. Here again, it was possible to standardize the signs. The shred sign and the tissue-like sign alone yield 90% sensitivity and 98.5% specificity, respectively [9].

The diagnosis of pneumothorax (i.e., free air in an organ full of air) seemed like a challenge, but just needed mastery of the artifacts. Some preliminary studies suggested a role for ultrasound [10]. Yet strict standardization is required because the outcome is the insertion, or not, of a tube into the thorax. If ultrasound needs to be confirmed, it is rendered a waste of time. The diagnosis is made if the physician thinks sequentially. The first step is that lung sliding allows pneumothorax to be ruled out [11]. There is an increasing body of work devoted to abolished lung sliding [12–15], but this sign, although interesting, is not sufficient, since it is very common in the critically ill [16]. As the second step, this sign must be associated with the A-line sign. For the third step, for 100% confidence, it should be associated with a specific sign: the lung point [17].

Interstitial syndrome is highlighted by an artifact sometimes called the comet tail artifact [18], yet we think the label 'B-line' is necessary to avoid confusion with other comet tail artifacts. B-lines are usually generated by thickened subpleural interlobular septa. Numerous B-lines, called lung rockets, indicate interstitial syndrome. Ground-glass areas, a higher degree of interstitial syndrome, yield more numerous lung rockets. Interstitial syndrome is ironically one of the most basic applications, perhaps the 'sensitive note' of the decaphonic scale, of prime importance in the BLUE protocol [19,20]. Lung rockets are analyzed in acute respiratory failure [16], mainly for prompt diagnosis of hemodynamic pulmonary edema. They can be discriminant for diagnoses of pneumothorax, embolism, exacerbation of chronic obstructive pulmonary disease or asthma, and some types of pneumonia (see the BLUE protocol section). The first observations are increasingly confirmed [18,21–23].

Why lung ultrasound in the critically ill should be more widely used

If traditional methods (mainly bedside radiography and CT) were devoid of drawbacks, lung ultrasound would be of limited interest. Yet worrying issues are the delay, need for transportation

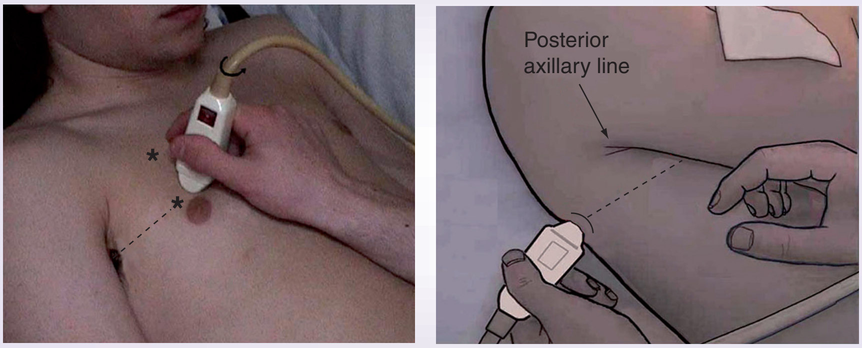

Figure 2. Practical analysis of the lung. The left image first demonstrates one standardized point of analysis: the lower part of the anterior thorax in a supine patient (lower asterisk). Other points include one point at the upper part (upper asterisk), and one semiposterior point above the diaphragm, continuing the lower anterior point. Second, we can see the 5-MHz microconvex probe that makes critical ultrasound easy. This one in particular can analyze from 1 to 17 cm, i.e., the pleural line as well as the deep lung consolidations, and the whole body (venous network, heart, abdomen and optic nerve). This probe is smart: no time is lost changing it (meaning neither disinfecting it or purchasing it). The 8-cm probe length allows posterior analysis of critically ill patients who are in the supine position.
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(in the case of CT), poor accuracy (of radiography) and high irradiation, not forgetting the cost, which is a prime concern for most people.

Value as a function of settings

The BLUE protocol, a diagnostic approach to acute respiratory failure

The BLUE protocol makes exclusive use of lung and venous ultrasound [16]. It is based on profiles, which consider signs combined with topographic distributions. Seven characteristic profiles are located on its decision tree (Table 1).

> "Lung ultrasound usually provides immediate answers to questions where only sophisticated techniques were used hitherto."

Diffuse bilateral anterior lung rockets plus lung sliding are the typical profile of acute hemodynamic pulmonary edema. An absence of anterior B-lines plus venous thrombosis is quite specific to pulmonary embolism (lung rockets are infrequent and suggest other diseases). The A-line sign plus abolished lung sliding makes pneumothorax probable (one B-line invalidates the diagnosis)– the lung point is specific. A normal lung pattern (anteroposterior A-lines plus lung sliding) is the profile of acute asthma and decompensated chronic obstructive pulmonary disease.

Pneumonia yields four characteristic combinations: the B'-profile (anterior lung rockets plus abolished lung sliding), the C-profile (anterior areas of consolidation), the A/B-profile (unilateral anterior lung rockets) and the A-profile plus posterior or lateral alveolar and/or pleural syndrome (abbreviated as PLAPS).

Miscellaneous

Pleural effusion, even if not visible on an x-ray, can benefit from thoracocentesis, even in ventilated patients [7]. Pneumothorax volume can be assessed – and monitored – using the lung point location and evolution [15,17]. Massive pneumonia can be distinguished from complete atelectasis using the dynamic air bronchogram, a sign specific to pneumonia [24]. Ultrasound in airway management can be life saving [25].

Value as a function of specialty

Critical care physicians

The FALLS protocol uses the potential of the B-lines to indicate pulmonary edema at the initial, silent step, allowing hemodynamic management in acute circulatory failure. At the anterior chest wall, when a pulmonary artery occlusion pressure of 18 mmHg is reached during fluid therapy, B-lines replace A-lines, roughly speaking, before clinical change [26]. The FALLS protocol allows us to redefine the field of critical ultrasound by adding the lung, simplifying the cardiac analysis and adding an approach to the veins revisited in light of the BLUE protocol, which is basically opposed to traditional venous scanning [5].

Intensivists

In acute respiratory distress syndrome, lung ultrasound allows a withdrawal of pleural effusion, prompt detection of pneumothorax, and can probably guide alveolar recruitment and help in the decision regarding prone positioning.

Anesthesiologists

Situations when preoperative cardiac function must be assessed call for use of the B-line (principle of the FALLS protocol).

Prehospital physicians

Traumatic hemothorax, pneumothorax and lung contusion are accessible [27] using the concept of point-of-care ultrasound [28].

Pulmonologists

Our concern is mainly the acutely ill, yet our standardized approach can be used for better management of pulmonary diseases, including cancer. Several studies are available [20,29,30].

Pediatricians (neonatal care)

The ten basic signs of lung ultrasound are found, with no difference, in the critically ill neonate, making the development of pediatric lung ultrasound an absolute priority [31].

Physicians in extreme environments or remote areas

Pneumonia in poor countries as well as pneumothorax in spaceships is a major target.

Table 1. Ultrasound profiles used in the bedside lung ultrasound in an emergency protocol.

Ultrasound definitions	Diagnosis	Specificity of ultrasound using the defined profile (%)	Sensitivity of ultrasound using the defined profile (%)
B-profile (Diffuse anterior bilateral lung rockets with lung sliding)	Acute hemodynamic pulmonary edema	95	97
A-profile (Diffuse anterior bilateral A-lines with lung sliding)	Acute asthma or decompensated COPD	97	89
A-profile with deep venous thrombosis	Pulmonary embolism	99	81
A'-profile (Diffuse anterior A-lines with abolished lung sliding)	Pneumothorax	100[†]	88
B'-profile (B-profile with abolished lung sliding) A/B profile (A-profile at one lung, B-profile at the other) C-profile (Anterior lung consolidation) A-profile plus PLAPS	Pneumonia	94	89

[†]When lung point present.
BLUE: Bedside lung ultrasound in an emergency; COPD: Chronic obstructive pulmonary disease; PLAPS: Posterolateral alveolar and/or pleural syndrome.
Data on specificity and sensitivity from [15].

Cardiologists

Cardiologists may consider the lung as a main target for directly assessing cardiac function.

Radiologists

Radiologists will still be called in cases of the rare limitations of ultrasound: extensive subcutaneous emphysema, extensive dressings and deep lesions (almost never an emergency concern).

Other disciplines

Thoracic surgeons, emergency physicians, family physicians and each discipline where the lung is more or less in focus will benefit from some of these applications.

How lung ultrasound will evolve in the years ahead

We can foresee several outcomes. The community will realize that lung ultrasound is one of the most feasible disciplines – probably the easiest in a field reputed to be operator-dependent: such a voluminous organ cannot be missed. Unlike the heart (an expert field), the abdomen (more than 20 organs to analyze) or even more complex situations such as the fetus, the normal lung pattern is the same, wherever the probe is applied. Lung ultrasound is a dichotomous approach: the signal can generate only A-lines or B-lines, broadly speaking. The concordance rate is high after limited training. We think the inclusion of this field in medical studies is unavoidable. Our center [101] provides the keys for standardized training. Lung ultrasound should be accepted in the years to come as a reasonable bedside gold standard for all cases where traditional tools have drawbacks or are of limited availability.

The physician will use the right tool for the appropriate use. Thinking that we need up-to-date, sophisticated machines is a misconception. This issue is a logical outcome: since no manufacturer appears to be focusing on the lung, the ability of a given machine to visualize it is dictated by pure chance. Since 1992, we have had the pleasure of using a tool (still manufactured) that makes lung and critical ultrasound easy. We invite the manufacturers of the laptop market to be inspired by our message of simplification. Our 29-cm wide unit (33-cm wide using a smart trolley) is easily wheeled from bed to bed, from the intensive care unit to the emergency room, using four wheels (an old but major advance). We consider that the width (and not the height) is the important dimension. Only special settings (mainly prehospital medicine) would require miniaturization. Our image quality is analogical. Our grayscale system is simple, devoid of Doppler and so-called facilities, and preserves the air artifacts (not the current trend in modern machines). Lung ultrasound uses natural, unfiltered images. Each filter makes it more difficult. Our start-up time is short (7 s). Our keyboard is flat, which is a must for efficient cleaning. The probe is a sensitive point in our philosophy. We have access to a 5-MHz microconvex probe with universal potential (excluding neonates). We advise against cardiac probes, and do not use the linear probe advocated by some, for several reasons, including uncertain recognition of deep artifacts. Our probe is ideal for the lung, but also, in critical care, for the whole body, especially for studying the whole venous network or the optic nerve [5]. Lastly, our unit is unbeatable in terms of cost.

Medicolegal rules will have to adapt to this new gold standard. Lung ultrasound is an elegant answer to the problem of increasing radiation [32]. In numerous cases where the physician would currently ask for a CT, we envision that he or she will request (or, better, perform) an ultrasound examination for a fast and reliable answer.

Conclusion

In fields where everything must be fast and accurate, lung ultrasound should definitely be more widely used to diagnose an acute respiratory (BLUE protocol) or circulatory (FALLS protocol) failure. Lung ultrasound usually provides immediate answers to questions where only sophisticated techniques were used hitherto. We favor simplicity (a simple technology, one simple probe and a dichotomous decision tree), a key factor for developing this kind of visual medicine [33]. Lung ultrasound shows sonography as it actually is: a genuine stethoscope (from *scopein*, to observe, and *stethos,* the chest wall).

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The author has no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

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