

REVIEW ARTICLE

Lung ultrasound in acute respiratory failure an introduction to the BLUE-protocol

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ABSTRACT

Critical ultrasound, apparently a recent field, is in fact the outcome of a slow process, initiated since 1946. The lung was traditionally not considered as part of ultrasound, yet we considered its inclusion as a priority in our definition of critical ultrasound. Acute respiratory failure is one of the most distressing situations for the patient. An ultrasound approach of this disorder - the BLUE-protocol — allows rapid diagnosis. Its main features will be described. Each kind of respiratory failure provides a particular ultrasound profile. In this difficult setting, initial mistakes are frequent. The BLUE-protocol proposes a step-by-step approach for making accurate diagnosis. By combining three signs with binary answer (anterior lung sliding, anterior lung-rockets), with venous analysis when required, seven profiles are generated, yielding a 90.5% accuracy. This rate is highly enhanced when simple clinical and laboratory data are considered. The BLUE-protocol can be achieved in three minutes, because the use of an intelligent machine, a universal probe, and standardized points allow major time-saving. Lung ultrasound in the critically ill was long available. In a domain where everything must be fast and accurate, the BLUE-protocol can play a major role in the diagnosis of an acute respiratory failure, usually answering immediately to questions where only sophisticated techniques were hitherto used.

Key words: Lung - Ultrasound - Pneumothorax - Pleural effusion - Barotrauma.

Critical ultrasound, apparently a recent field, is in fact the outcome of a slow process, initiated since 1946.¹ Since 1989 we have had the privilege to use the logistics of François Jardin's medical Intensive Care Unit, devoted to cardiac assessment.² We have extended it to the whole-body assessment, defining the field of critical ultrasound.³ The ultrasound unit an ADR-4 000, with a 1982 technology was perfectly suitable for bedside use. The lung was traditionally not considered for the ultrasound, yet its inclusion was to be a priority in the definition of critical ultrasound.⁴ A simple work of deciphering the lung code, and a patient work of submission (now far from finished) was a necessary step.

Acute respiratory failure is one of the most distressing situations for the patient. An ultrasound

approach of this disorder the BLUE-protocol allows a rapid diagnosis. Its main features will be here described.

Standard technique, normal patterns

First of all, it is maybe useful to recall the seven principles of lung ultrasound.

First principle

THE SIMPLE UNIT

The BLUE-protocol is based on rapidity. Therefore, since 1992 a smart and fast device has been used. The device must respect seven criteria: it should be small in dimensions for accessing patients in any situation (29 cm); it should have an

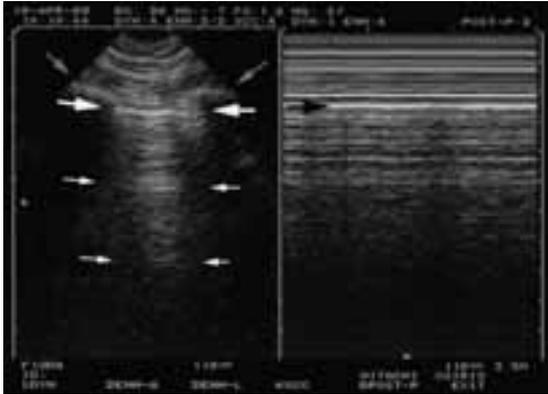


Figure 1.—The signs from the pleural line 1.

optimal image resolution (see enclosed figures); it should have an immediate start-up time (7 seconds); it should be able to provide with a smart probe, to document superficial as well as deep lung, anterior and subposterior thorax, deep veins including inferior vena cava, heart, without any change of setting, meaning major time savings. Vascular, cardiac and abdominal probes can be of some help, but none is perfect for the lung; as we do not have to lose time changing and cleaning the probe (a 8-cm long, 5-MHz microconvex probe with a 1-17 cm range of exploration able to assess the whole-body in critical setting); it should be compact to be easily disinfected (a flat keyboard); it should have an intelligent cart fitting to the unit, without lateral expansions that render the ultraportability difficult, with wheels and a major technologic advance allowing to transport easily a heavy unit from room to room; laptop technologies are of minor interest inside hospitals (a smart cart making with an overall width of 33 cm); it should be provided with a simple technology, with neither Doppler nor complex modes (harmonics, etc.), allowing immediate use and low cost, *i.e.*, easy to purchase (the cost of a modest car). Our equipment is still manufactured. Some doctors, including the author, work in aircrafts, where hand-held units are mandatory. Usually, we use a compact (14 x 14 x 16 cm), light (1.8 kg) unit.

Second principle

In the thorax, air (pneumothorax) and fluids (effusions) have opposite gravitational directions,

but can be intimately mingled (interstitial edema). The artifacts result from this mingling.

Third principle

Lungs are the most voluminous organ. Standardized areas can be defined. The probe is applied directly on the intercostal space, avoiding traditional subcostal routes. Of four defined stages of investigation, only stage-1 (anterior analysis) and stage-3 (subposterior analysis) are initially used in the BLUE-protocol.

Fourth principle

The fourth principle specifies that all signs arise from the pleural line (Figure 1). Ten signs are necessary for the BLUE-protocol, like a scale allowing, once mastered, to play infinite kinds of music.

Fifth principle

The fifth principle highlights the static signs, *i.e.*, mainly the air artifacts. The normal artifact is the A-line, a horizontal repetition artifact (Figure 1).

Sixth principle

The sixth principle indicates that the lung, a vital organ, always moves, normally generating lung sliding (Figure 1).

Seventh principle

The seventh principle specifies that nearly all acute disorders about the pleural line: pneumothorax, pleural effusions, interstitial edema, and most acute alveolar consolidations.

Used pathologic signs

Interstitial syndrome is central to the BLUE-protocol, although the intensivist was not accustomed to make therapeutic decisions based on this information. The B-line (Figure 2), described in 1994, assessed in 1997, is the sign required to evaluate the interstitial syndrome:⁵ this designates a certain comet-tail artifact arising from the pleural line, hyperechoic (as the pleural line), well-defined (laser like), erasing the physiologic A-lines, spreading without fading to the edge of the screen, and synchronous with lung sliding.



Figure 2.—The B line.



Figure 3.—The alveolar – pleural syndrome.

These seven criteria of description distinguish the B-line from other artifacts (Z-lines first). Several B-lines visible between two ribs are called lung-rockets or B+ lines. Lung-rockets disseminated into the whole anterolateral chest wall define diffuse ultrasound interstitial syndrome. The concordance between ultrasound and interstitial syndrome is complete (thickened interlobular septa, yielding B7-lines as well as ground-glass areas, yielding B3-lines). These observations are confirmed by other studies.^{5,6}

Posterior and/or lateral alveolar and/or pleural syndrome (PLAPS) is a concept aiming at simplifying lung ultrasound, since it does not require any distinctive description of both disorders (Figure 3). Pleural effusions are sought in stage-3. Apart from evident criteria (dependent image above the diaphragm) and unreliable criteria (anechoic tone, that precisely lacks in critical cases: empyema, hemothorax), two signs allow standardization of the test: the quad sign and the sinusoid sign, indicating effusion with accuracy near to computed tomography (CT). Alveolar consolidations about the wall in nearly all cases, making their detection accessible to ultrasound. Two signs, the tissue-like sign, and the shored sign, offer a specificity near to CT. The sensitivity is dependent on the location of the consolidation and its extent to the chest wall. Small or unusual locations can be missed. Most cases are detected on stage-3, however. Finding PLAPS is redundant in some settings, of major relevance in others.

Pneumothorax yields three basic signs: abolished lung sliding, the A-line sign, the lung point.

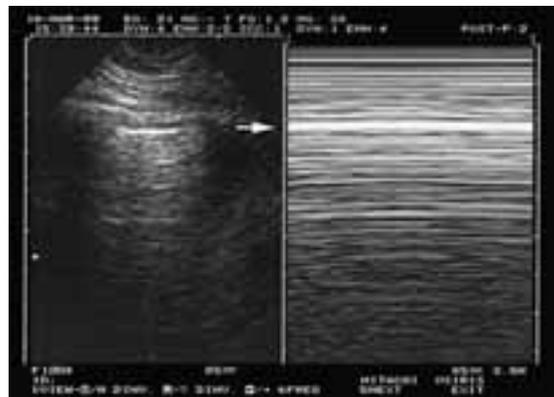


Figure 4.—A pneumothorax.

Abolished lung sliding, sought in stage-1, yields the stratosphere sign (Figure 4). Lung sliding allows pneumothorax to be ruled out. Carefully note that abolished lung sliding is far from meaning pneumothorax in patients with acute respiratory failure this sign has a positive predictive value for pneumothorax of 27%.⁷ Acute respiratory distress syndrome (ARDS), atelectasis, pleural symphysis, fibrosis, phrenic palsy, jet-ventilation, cardiac arrest, esophageal intubation, inappropriate probe, inappropriate settings are factors abolishing lung sliding. The A-line sign in stage-1 analysis is constant in pneumothorax. One typical B-line excludes the diagnosis. The lung point indicates the pneumothorax. It can be lateral, posterior or absent, indicating the pneumothorax volume. It is 100% specific. The lung point indicates that lung sliding abolition is not linked with technical defaults.

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

Each kind of respiratory failure provides a particular ultrasound profile.⁷ In this difficult setting, initial mistakes are frequent.⁸ The BLUE-protocol proposes a step-by-step approach for making accurate diagnosis. By combining three signs with binary answer (anterior lung sliding, anterior lung-rockets, PLAPS), with venous analysis when required, seven profiles are generated, yielding a 90.5% accuracy. This rate is highly enhanced when simple clinical and laboratory data are considered. The BLUE-protocol can be achieved in three minutes, because the use of an advanced technology machine, a universal probe, and standardized points allow major time-saving.

The physiopathology supports these performances. The B-lines plays a main role. Diffuse bilateral anterior lung-rockets indicate pulmonary edema.⁵ Their association with lung sliding generates the B-profile, which is achievable in less than one minute. In patients with acute respiratory failure, the B-profile indicates hemodynamic pulmonary edema with a 97% sensitivity. Briefly, in pulmonary edema, all interlobular septa are thickened by edema and the transudate does not hinder lung sliding. The 95% specificity is due to the fact that the B-profile is sometimes generated by infectious interstitial diseases, exceptionally chronic interstitial diseases. Absent lung-rockets associated with lung sliding indicates asthma or chronic obstructive pulmonary disease. In these diseases, the lung surface is basically normal. In pulmonary embolism also, the anterior lung surface is usually normal (A-profile). In our series, 80% of patients with pulmonary embolism had visible venous thrombosis. Absent lung sliding plus absent B-lines are logical findings suggesting pneumothorax. The numerous causes of pneumonia generate several profiles, mainly asymmetry (from left to right, explaining the A/B profile, from posterior to anterior, explaining the A-profile plus PLAPS), anterior alveolar consolidations (C-profile), and the generation of exudate, that may stick the lung toward the parietal pleura, yielding abolition of lung sliding (B'-profile). The presence and distribution of the B-lines helps in the distinction between hemodynamic and permeability-induced pulmonary edema.⁷

Rare causes of acute respiratory failure (frequency <2%) were excluded, allowing to keep our decision tree simple. Rare diagnoses do not mean difficult diagnoses. Massive pleural effusion or chronic interstitial fibrosis were sometimes seen, but simple traditional tools (history, radiography, and also ultrasound) made little diagnostic difficulty. The BLUE-protocol is contributive even when it is not used. Its combination with clinical and basic paraclinical approach (EKG, D-dimers, etc.) makes a synergic approach.

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

The aim of the BLUE-protocol is to immediately relieve dyspneic patients by giving appropriate therapy, and to decrease the need for irradiating (CT), time-demanding (sophisticated echocardiography-Doppler) or painful (arterial puncture) tests. From our data, 99% of patients without the A-profile had no pulmonary embolism, and 2% of patients with A-profile without venous thrombosis had pulmonary embolism. Since helical CT is asked for detecting the clot as well as for finding alternative causes, simple scintigraphy, far less irradiating,⁹ can be proposed for the diagnosis of pulmonary embolism.

Other applications of lung ultrasound in the critically ill

Radiography or CT in the critically ill: neither?

CT provides a nice overview, extremely useful in ARDS management,¹⁰ but its drawbacks should be mastered. Its cost makes CT unavailable for the majority of patients on Earth. Those who can afford the cost, receive major irradiation.⁹ Delay, transportation, iodine injection, supine position are other problems to be considered in the critically ill patients. Radiographs are easily performed, but they are not designed for being a gold standard, missing to a variable extent the disorders assessed here.¹¹

Ultrasound provides performances similar to, and superior to CT for evaluation of lung sliding,

phrenic function, intra-parenchymal necrosis, dynamic air bronchogram among 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 winning points

Lung ultrasound is highly feasible as this voluminous organ cannot be missed. Moreover, the concordance rate is high after limited training. Our training center provides the keys for efficient training, using suitable material and allowing insertion of chest tubes without complications and only when required.

Of interest in intensive care, anesthesiology and emergency medicine, lung ultrasound can be adopted in pediatrics and Pediatric Intensive Care Units first, but also in cardiology, pulmonology, thoracic surgery, family medicine, not to forget extra-hospital medicine, as already proposed a long time ago.¹² In fact, the ten basic signs of lung ultrasound are found, with no difference, also in the critically ill neonates, making the development of pediatric lung ultrasound an absolute priority.

Keeping with the topic, we cannot cite the main studies nor the numerous confirmatory studies on this subject nor will we deal with the standardized BLUE-points for performing the BLUE-protocol, ultrasound-enhanced thoracentesis, distinguishing pneumonia from atelectasis, help in assessing pneumothorax volume, guiding tracheostomy or airway management, how to reimburse the ultrasound unit in a few weeks, exploiting all its potentials, deal with the few limitations (parietal emphysema, dressings), reverse medicolegal issues, and get rid with the traditional but sticky gel.

Conclusions

Lung ultrasound in the critically ill patients was long available. In a domain where everything must

be fast and accurate, the BLUE-protocol can play a major role in the diagnosis of an acute respiratory failure, usually answering at once to questions where only sophisticated techniques were hitherto used. Simplicity (a simple unit, a simple probe, no Doppler, a dichotomous decision tree) was a key-factor for developing this kind of visual medicine.¹³ The BLUE-protocol uses ultrasound as a genuine stethoscope, as it actually is (the term stethoscope derives, in fact, from *scopein*, Greek for “to observe”, and *stethos*, Greek for “chest wall”).

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