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BLUE-Protocol and FALLS-Protocol

Two Applications of Lung Ultrasound in the Critically Ill

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This review article describes two protocols adapted from lung ultrasound: the bedside lung ultrasound in emergency (BLUE)-protocol for the immediate diagnosis of acute respiratory failure and the fluid administration limited by lung sonography (FALLS)-protocol for the management of acute circulatory failure. These applications require the mastery of 10 signs indicating normal lung surface (bat sign, lung sliding, A-lines), pleural effusions (quad and sinusoid sign), lung consolidations (fractal and tissue-like sign), interstitial syndrome (lung rockets), and pneumothorax (stratosphere sign and the lung point). These signs have been assessed in adults, with diagnostic accuracies ranging from 90% to 100%, allowing consideration of ultrasound as a reasonable bedside gold standard. In the BLUE-protocol, profiles have been designed for the main diseases (pneumonia, congestive heart failure, COPD, asthma, pulmonary embolism, pneumothorax), with an accuracy > 90%. In the FALLS-protocol, the change from A-lines to lung rockets appears at a threshold of 18 mm Hg of pulmonary artery occlusion pressure, providing a direct biomarker of clinical volemia. The FALLS-protocol sequentially rules out obstructive, then cardiogenic, then hypovolemic shock for expediting the diagnosis of distributive (usually septic) shock. These applications can be done using simple grayscale machines and one microconvex probe suitable for the whole body. Lung ultrasound is a multifaceted tool also useful for decreasing radiation doses (of interest in neonates where the lung signatures are similar to those in adults), from ARDS to trauma management, and from ICUs to points of care. If done in suitable centers, training is the least of the limitations for making use of this kind of visual medicine.

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ABBREVIATIONS: BLUE = bedside lung ultrasound in emergency; FALLS = fluid administration limited by lung sonography; LUCI = lung ultrasound in the critically ill; LUCIFLR = Lung Ultrasound in the Critically Ill Favoring Limitation of Radiation; PLAPS = posterolateral alveolar and/or pleural syndrome

Daily concerns of the intensivist are acute respiratory and circulatory failure. The need for fast and accurate management calls for a visual approach, which is what ultrasound provides. Portable machines suitable for use at the bedside have been available since 1982. This article, therefore, could have been written 33 years ago. Echocardiography has been used for a long time in the ICU and now is currently used inside the thorax through the transesophageal route.[1,2] Echocardiography is an elegant way to solve

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these respiratory and circulatory concerns. This article describes a complementary tool: lung ultrasound.

History

Lung ultrasound originally was not meant to be used in emergent care. Except for echocardiography used in cardiology and sonography used in obstetrics, ultrasound in general was a tool for radiologists, and the lung in particular was not considered suitable for this imaging technology.[3] Since 1989, François Jardin's ICU explored, applied, and made lung ultrasound with a portable unit a standard of care in critically ill patients. Based on our 25 years of experience using lung ultrasound in the critically ill (LUCI), the American College of Chest Physicians and La Société de Réanimation de Langue Française jointly proposed LUCI as a standard of care.[4]

Since 1991, intensivists have been using whole-body ultrasound, including vascular access, search for free blood, and so forth, and lung ultrasound.[5] Gradually, the ICU community understood the relevance of lung ultrasound in critical care. Publications began to emerge and are now quite prevalent in the literature; thus, only a few regarding the lung are quoted in the present article.[6-42]

Tools Used for the BLUE-Protocol

One application of lung ultrasound is the onsite exploration of acute respiratory failure: the bedside lung ultrasound in emergency (BLUE)-protocol. Although the new generation of intensivists benefits from a variety of excellent machines, we keep using our 1992 technology (last updated in 2008) for several reasons: We like its resolution; 32-cm width in settings where each lateral centimeter counts; 7-s start-up time; flat, easy-to-clean, fluid-proof design; 5-MHz microconvex probe allowing whole-body analysis from 0.6 to 17 cm; simple technology based on three clearly identified buttons, instant response, respect of artifacts, and ease of maintenance; intelligent narrow cart (preventing any drop); and low cost. These reasons make up the first of seven principles: The simplest equipment is suitable for lung imaging.[43] Any modern machine can be used, however. We believe that redesigns of the same machine for use in modern facilities (using wireless transmission, Doppler and transesophageal echocardiography, etc) are appropriate as long as these do not interfere with the critical properties of small size, cost-effectiveness, and immediate start-up time. The alternative, which we have been using for 25 years, is to have one simple, cost-effective unit and one comprehensive echocardiographic unit on hand.

The second principle is to use gravity rules (gas toward the sky, fluids toward the earth) to locate disorders. The third principle is to define standardized thoracic points, called BLUE-points, to allow for reproducible analyses[44] (Fig 1), and the fourth is to precisely define the pleural line, the first of 10 basic signatures. The fifth principle in lung ultrasound focuses specifically on artifacts. The A-line is a repetition of the pleural line, indicating gas (Fig 2). The sixth principle analyzes lung sliding, which is a twinkling visible at the pleural line that spreads homogeneously below it (generating the seashore sign in M-mode). Lung sliding and A-lines define a normal

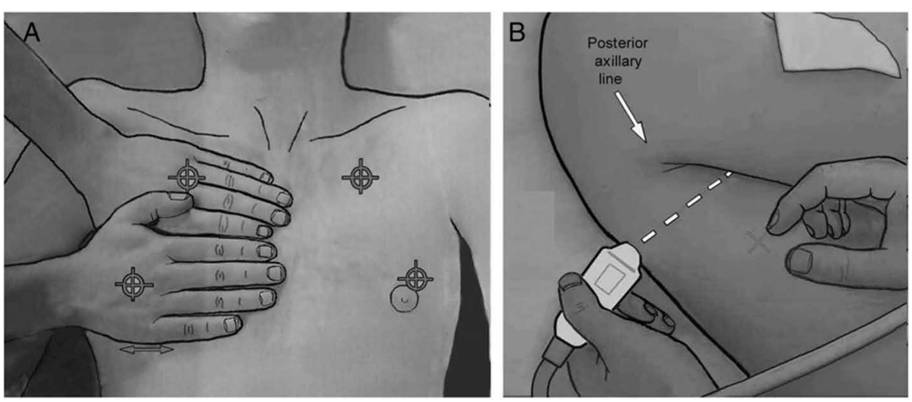

Figure 1 – *A, B, The bedside lung ultrasound in emergency (BLUE)-points. This figure shows the standardized points used in the BLUE-protocol. Two hands (from roughly the patient's size) are applied as follows: upper little finger just below clavicle, fingertips at middle line, and lower hand just below upper hand (thumbs excluded). The point coined "upper BLUE-point" is at the middle of the upper hand. The "lower BLUE-point" is at the middle of the lower palm. These four points roughly follow the anatomy of the lung, and avoid the heart as much as possible. The posterolateral alveolar and/or pleural syndrome (PLAPS)-point is built from the horizontal line continuing the lower BLUE-point and the vertical line continuing the posterior axillary line. The intersection, rigorously, is the PLAPS-point, but the user can move the probe in two directions: (1) as posteriorly as possible in order to get more posterior information in these supine, sedated patients or (2) downward when no PLAPS is detected at first sight. Usually, after two intercostal spaces, the probe scans the abdomen. Like the six spots of ECG, the six BLUE-points help in reproducible analysis. They were sufficient for providing the 90.5% accuracy of the BLUE-protocol. (Adapted with permission from Lichtenstein.[45])*

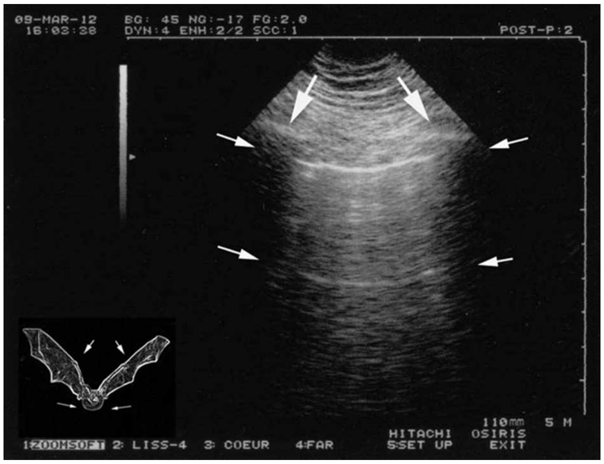

Figure 2 – *Pleural line and A-line. The bat sign: The ribs (vertical arrows) and the pleural line (upper horizontal arrows) outline a silhouette reminiscent of a bat. This allows confident recognition of the pleural line in all circumstances, even in challenging examinations (patients with dyspnea, patients who are agitated, bariatric patients). The pleural line always corresponds to the parietal pleura (and to the visceral pleural only if joined). The Merlin space encompasses the pleural line, the shadow of both ribs, and the lower border of the image. The A-line: Inside the Merlin space, a repetition of the pleural line is seen (lower horizontal arrows), occurring at a standardized distance from skin to pleural line. It indicates gas below the pleural line. A-lines can be complete, as here, or partial (as in Figs 3 and 8).*

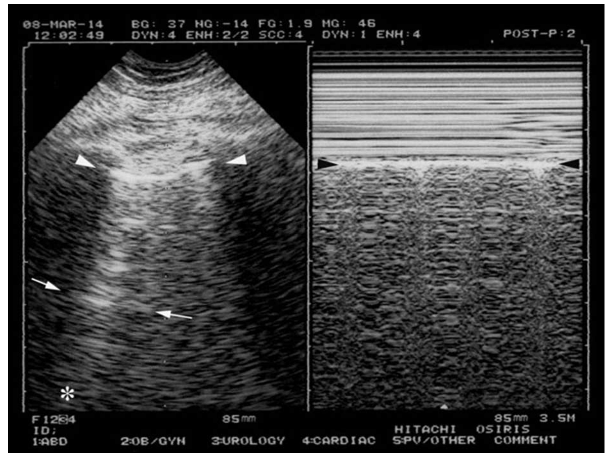

Figure 3 – *Lung sliding. The left image shows the bat sign (arrowheads indicate the pleural line). In the Merlin space, there is a partial A-line (arrows), meaning that there is gas below the pleural line. A partial A-line (or even not visible, a pattern then coined "O-line," for non-A non-B) is a common finding, with unchanged pathophysiologic meaning. Note that a comet-tail artifact is seen arising from the pleural line (*); it is ill defined, not erasing A-lines (arrows); less echoic than the pleural line; short; and standstill (in real time), allowing easy distinction with the B-line (see Fig 7). This artifact, devoid of meaning, is coined "Z-line." The right image shows the seashore sign of lung sliding. Lung sliding is visible in real-time but not in a frozen image (left image). It can, however, be demonstrated using the M-mode. Above the pleural line, the pattern is stratified (motionless soft tissues). Exactly from and below the pleural line (arrowheads), the pattern is sandy, hence, the seashore sign. This indicates that the gas pattern indicated by the A-line in the left image is alveolar gas (ruling out pneumothorax).*

lung surface[46] (Figs 2, 3). The seventh principle is based on the fact that all acute, life-threatening disorders are superficial. This allows to standardize the field (Table 1).

Diagnosis of pleural effusion is an old application of lung ultrasound[51,52] and basically yields two standard signs: the quad sign and the sinusoid sign (Figs 4, 5).[47] Alveolar syndrome (lung consolidation) is also an old diagnostic application of lung ultrasound.[53] This fluid disorder usually is superficial[48] and, thus, accessible to ultrasound, particularly in the diagnosis of nontranslobar consolidations, which yield the fractal (or shred) sign (Fig 5), and translobar forms, which yield the tissue-like sign (Fig 6).[48] Interstitial syndrome generates lung rockets on lung ultrasound (Fig 7).[49] This application is a main point of discussion in this article.

Pneumothorax was first approached in lung ultrasonography using the sole abolition of lung sliding.[54-56] This sign had a poor specificity until it was associated with the A-line sign (Fig 8).[46,57] Abolished lung sliding generates the stratosphere sign in M-mode. Lung sliding (or its equivalent, the lung pulse)[58] or B-lines rule out pneumothorax. The lung point (Fig 9) is a pathognomonic sign.[59] Pneumothorax occurring in patients with severe dyspnea or adherences is beyond the scope of this article.

Patients, Diseases, and Profiles in the BLUE-Protocol

The BLUE-protocol was developed based on the study of 300 consecutive adults with acute respiratory failure who were admitted to our ICU and given a diagnosis. The most frequent cause of respiratory failure was pneumonia (32%) followed by acute hemodynamic pulmonary edema (24%); exacerbated COPD (18%); severe asthma (13%); pulmonary embolism (8%); pneumothorax (4%); and countless rare causes, including easy-to-diagnose ones, such as massive pleural effusion (3%). We excluded rare, unknown, and multiple diagnoses because they generate methodologic issues. The

TABLE 1] Published Performances of Lung Ultrasound in Critically Ill Patients Compared With CT Scanning

Ultrasound	Sensitivity, %	Specificity, %
Pleural effusion[47]	94	97
Alveolar consolidation[48]	90	98
Interstitial syndrome[49]	100	100
Complete pneumothorax[46]	100	96
Occult pneumothorax[50]	79	100

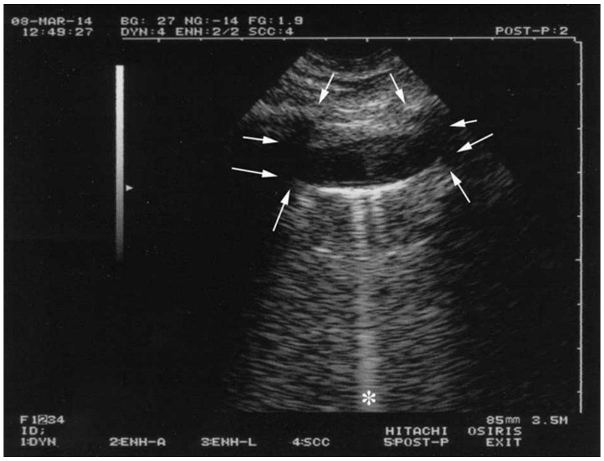

Figure 4 – *PLAPS and pleural effusion. This image at the PLAPS-point shows the quad sign, which is an image outlined by the pleural line (upper horizontal arrows), the rib shadows (vertical arrows), and a clearly defined line (lower horizontal arrows) called the lung line, regular and roughly parallel to the pleural line (± 15°-20°). The lung line indicates the visceral pleura. Note the long comet-tail artifact (*) arising from the lung line but not from the pleural line, hence coined "sub-B-line." This sub-B-line indicates that the lung in contact is aerated, not consolidated (ie, one more piece of information). This effusion is roughly anechoic. Even if echoic, the quad sign is a universal sign of pleural effusion regardless of its echogenicity. In free pleural effusions, the lung line moves toward the pleural line on inspiration, shaping the sinusoid sign, a basic sign that indicates unloculated pleural effusion, and mostly low viscosity of the fluid, indicating that a small needle is suitable if thoracentesis is envisioned. The distance between the pleural and lung lines is roughly 10 mm (the present view taken on expiration). We consider an effusion volume of roughly 75 to 150 mL in adults. In the BLUE-protocol, this pattern of isolated, minute pleural effusion is, sensu stricto, a PLAPS. See Figure 1 legend for expansion of abbreviations.*

Figure 5 – *PLAPS and lung consolidation: nontranslobar consolidation. The shred sign: At the PLAPS-point, a disorder can be described between a lung line (because there is an associated anechoic pleural effusion) (lower horizontal arrows) and a shredded deep border, where this pattern is replaced by gas barriers (all vertical arrows). This shredded line instantaneously demonstrates a lung consolidation. The whole makes another example of PLAPS, here combining free pleural fluid with alveolar fluid, an extremely frequent pattern in critically ill patients. At the step a PLAPS is found (ie, after detection of an A-profile, then of a free venous network), pneumonia is a likely cause of the respiratory failure. The distance between the pleural and lung lines in this standardized view taken on expiration is 25 mm. One can assume that there is more fluid than shown in Figure 4 (between roughly 350 and 700 mL or slightly more, according to our index). The upper horizontal arrows indicate the pleural line. See Figure 1 legend for expansion of abbreviation.*

BLUE-protocol is integrated within the control of acute respiratory failure, which requires an understanding of anatomy, physiology, pathophysiology, clinical signs, traditional imaging, and the biology of dyspnea. The BLUE-protocol is fully based on pathophysiology.

One feature of the BLUE-protocol is the established profiles, that is, signs associated with locations. These profiles are labeled simply to indicate abridged concepts. The A-profile is shorthand for "anterior lung sliding with A-lines profile." The remaining eight profiles follow the same labeling convention: B-profile (hemodynamic pulmonary edema), B′-profile, A/B-profile, C-profile, A-profile without DVT but with posterolateral alveolar and/or pleural syndrome (A-no-V-PLAPS-profile) (pneumonia), A-profile plus DVT (pulmonary embolism), A′-profile (pneumothorax), and nude profile (COPD/asthma).

At the anterior chest wall, lung sliding with predominant A-lines define the A-profile. Lung sliding is explained by the respiratory movements of the visceral pleura against the parietal pleura. The A-line is displayed when normal subpleural interlobular septa are too thin for disturbing the reverberation of the pleural line. The A-profile indicates a normal anterior lung surface. Associated with a DVT, it is connected with pulmonary embolism. The venous step is the longest part of the BLUE-protocol. The anterior lung analysis takes 0.5 min, negative venous scanning 2 min, and posterior lung step 0.5 min by an experienced operator using the standardized BLUE-points.

Lung sliding with lung rockets define the B-profile and usually indicate hemodynamic pulmonary edema. When interlobular septa are enlarged by edema, the ultrasound flow penetrates the lung, but the major impedance gradient between gas and fluids traps the ultrasound flow, hence showing a persistent to-and-fro dynamic, generating the B-line. Three B-lines between two ribs, a pattern called lung rockets, correspond to the anatomic number of subpleural interlobular septa. Hemodynamic pulmonary edema creates a transudative, pressurized pulmonary edema, therefore associating lung sliding with a culminant (anterior) location of lung rockets. Anterior lung rockets associated with abolished lung sliding define the B′-profile. In inflammatory interstitial syndrome (ie, pneumonia), each subpleural interlobular septum should exudate fibrin, behaving like glue, resulting in abolishing lung sliding. Unilateral lung

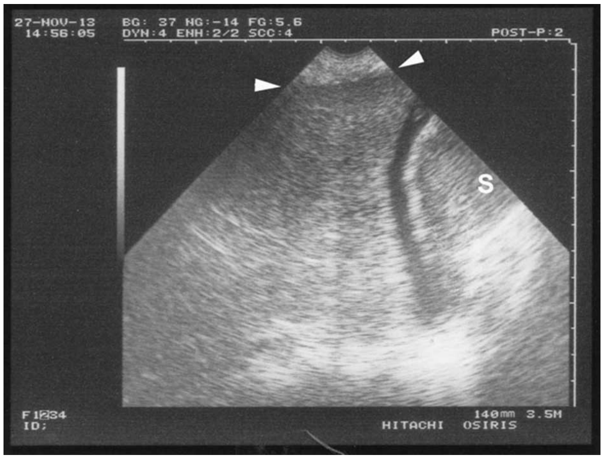

Figure 6 – *PLAPS and lung consolidation: translobar consolidation. The tissue-like sign: This huge tissue-like image (similar to the spleen [S]) at the PLAPS-point touches the pleural line (arrowheads); there is no (or almost no) pleural effusion. The deep limit is the mediastinal line, which is not sharply defined in this image, but another sign can be used here: The interpleural distance in this image is 10 to 11 cm, a size not compatible with a pleural effusion. This image definitely indicates a consolidation. Note the other features. The location is the left lower lobe, totally hepatized. The tissue-like sign is homogeneous; necrotic areas are unlikely (they would appear as hypoechoic, rounded areas). There is no air bronchogram and no loss of volume (as an atelectasis would cause). There are some drops of subpulmonary effusion. Real time would have shown an abolished lung sliding (this patient had a pneumonia). See Figure 1 legend for expansion of abbreviation.*

rockets define the A/B-profile. This asymmetry of interstitial signs is also linked to pneumonia.

Anterior lung consolidation, regardless of number and size (up to simply a thick, irregular pleural line), defines the C-profile. In the BLUE-protocol, the C-profile is associated with pneumonia. Following the second principle of lung ultrasound, consolidations seen in hemodynamic pulmonary edema or pulmonary embolism are posterior.[60]

Anterior A-lines associated with abolished lung sliding define the A′-profile. The A′-profile suggests pneumothorax—the lung point is mandatory. In pneumothorax, the abolished lung sliding is explained by the absence of visceral pleura and the A-line by the absence of any fluid structure abutting the parietal pleura. The lung point is explained by the slight inspiratory increase of volume of the collapsed lung and, therefore, an increased parietal contact making an abrupt ultrasound change.

At the posterior chest wall, lung consolidations and pleural effusions are assessed together for simplicity because both disorders usually come together, hence the practical term “PLAPS” (Fig 5). The A-no-V-PLAPS-profile is connected with pneumonia. The A-profile with no DVT and no PLAPS (ie, nude profile) is linked with asthma and COPD (two bronchial diseases with similar therapy combined for simplification).

In developing the BLUE-protocol, all study patients, including the excluded ones, benefited from receiving a profile. The A-profile was seen in 53.8%, the B-profile in 27.3%, the A′-profile in 3.4%, the B′-profile in 3.4%, the C-profile in 7.6%, and the A/B-profile in 4.6%.

The BLUE-Protocol: When and How Is it Used, What Occurs Practically, With How Much Accuracy?

The BLUE-protocol is done each time the physician has clinical doubts after the physical examination. The machine is brought to the bedside, the probe applied at

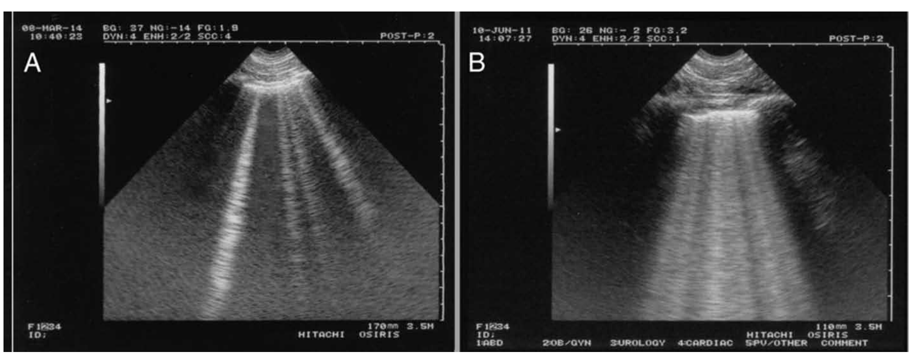

Figure 7 – *A, B, Lung rockets. An elementary signature of interstitial syndrome, the B-line, can be described by seven criteria. This is always a comet-tail artifact and always arises from the pleural line. It always moves in concert with lung sliding. Almost always (roughly 95% for each of these last four features), it is long and up to the edge of the screen (in the left image, some do not reach the 17-cm depth); is well defined, like a laser; obliterates the A-lines; and is hyperechoic like the pleural line. Usually, all seven criteria are present (always the first three ones) and define the B-lines with a precision that avoids confusion with other comet-tail artifacts, such as Z-lines and E-lines. (E-lines are comet-tail artifacts with most criteria of B-lines but arising above the pleural line, indicating subcutaneous emphysema.) Lung rockets, defined as three B-lines or more between two ribs, demonstrate interstitial syndrome. The left image shows septal rockets. Three or four B-lines can be counted between two ribs (ie, roughly 6 or 7 mm apart, the anatomic distance between two subpleural interlobular septa in adults). Septal rockets indicate the thickening (usually edematous) of these septa. The right image shows ground glass rockets. One can count here twice as many B-lines than on the left image. Ground glass rockets are correlated with scanographic ground glass areas. Lung rockets are used in daily routine to assess acute respiratory or circulatory failure, among other uses.*

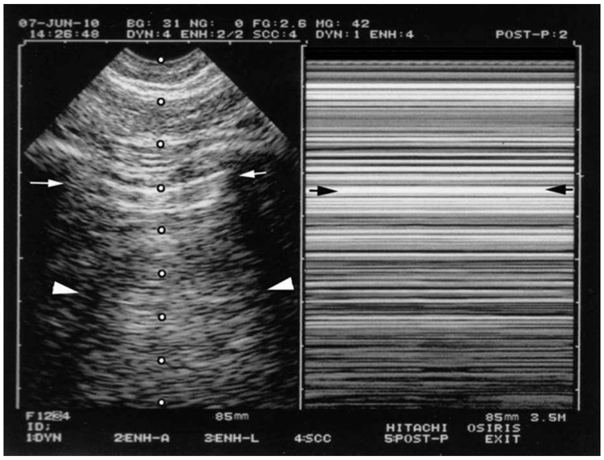

Figure 8 – *Pneumothorax and A′-profile. The diagnosis of pneumothorax requires a two-step approach. The first step is to detect the A′-profile, associating the A-line sign with the abolition of lung sliding. The left image shows the A-line sign. The Merlin space always displays A-lines (arrowheads), meaning gas below the pleural line (arrows). The A-line shown here is ill defined, again more like an O-line, but there is definitely no B-line. The dots delineate the M-mode shooting line. The right image shows the stratosphere sign. This homogeneous, stratified pattern demonstrates what is seen on real-time imaging (ie, the constant and complete abolition of lung sliding). The arrows indicate the pleural line. The A′-profile is very sensitive but not specific to pneumothorax. Note that the two images are not only side by side but also exactly side by side (take a ruler at the pleural line) without any lag that may generate, in acute conditions, one element of confusion. This case is of a eupneic pneumothorax and represents a first step for learning (the signs of dyspneic pneumothorax are standardized too but add one more degree of complexity because they obey the rules of shooting at a mobile target).*

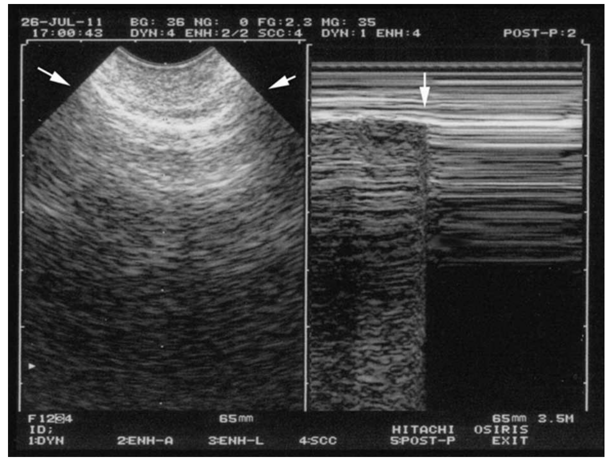

Figure 9 – *Pneumothorax and lung point. The lung point: Each time an A′-profile is detected (at the anterior wall, by definition), the search for the lung point is the second mandatory step, time permitting. At a certain location of the thorax (lateral, posterior), probe standstill, lung patterns such as lung sliding and lung rockets replace the A′-profile. The change in rhythm with respiration is abrupt (arrow in right image). The lung point is pathognomonic for pneumothorax, indicating its volume. (In this patient, the lung point was roughly located at the PLAPS point, corresponding to a radiovisible pneumothorax.) It indicates that the equipment is suitable (real-time instant-response acquisition, suitable resolution, mastery of filters). Arrows in the left image indicate the pleural line. See Figure 1 legend for expansion of abbreviation.*

the anterior standardized points, and the BLUE-protocol begun (Fig 10), first searching for lung sliding. If lung sliding is present, the association with predominant A-lines defines the A-profile, and a venous scan is done following a sequential order.[62] An A-profile associated with a DVT is 99% specific to pulmonary embolism. For this reason, the veins are analyzed before the rest of the lung. PLAPS are common to several causes, the veins must preferably be assessed before searching for PLAPS. Finding a DVT after detecting an A-profile makes sense. If no DVT is found, PLAPS are sought for the PLAPS point. If present, the A-no-V-PLAPS-profile is defined, suggesting pneumonia. If absent, the nude profile (all items normal) is defined, suggesting COPD or asthma. The A′-profile requires the search for a lung point, which if positive, rules in pneumothorax. The B-profile makes hemodynamic pulmonary edema the priority diagnosis. The B′-profile, A/B-profile, C-profile (anterior consolidations) highly suggest pneumonia. Eighty-six percent of ARDS cases have one of the four profiles of pneumonia.[61] All in all, the BLUE-protocol provides a 90.5% accuracy,[61] with detailed accuracies ranging from 81% to 100% (Table 2).

Frequently asked questions are answered in Lichtenstein.[45] For example, a frequent question is, "Why is the heart not included?" Looking at the heart to solve a pulmonary failure is a legitimate, yet indirect approach. The suffering organ is the lung, so lung ultrasound provides a direct approach. Echocardiography is associated but not included (searching for left-sided heart anomalies in the absence of lung rockets makes less sense because pulmonary edema has been ruled out as a cause of respiratory failure). Small anterior lung consolidations (C-lines) suggest pneumonia 18 times more frequently than pulmonary embolism.[61]

Of importance, the BLUE-protocol is only designed to be piloted by the physician's common sense and integrated with other basic data. A nude profile will sometimes require confident elimination of pulmonary embolism (CT scan, scintigraphy); an anterior small consolidation will, rarely, be one sign of pulmonary embolism. Used this way, the BLUE-protocol shows maximal efficiency.

A Development of the BLUE-Protocol: Lung Ultrasound for Diagnosing Acute Circulatory Failure—the FALLS-Protocol

For this major concern, successive tools have been used, with echocardiography currently being one of the most popular.[1,2] Many others are competing,

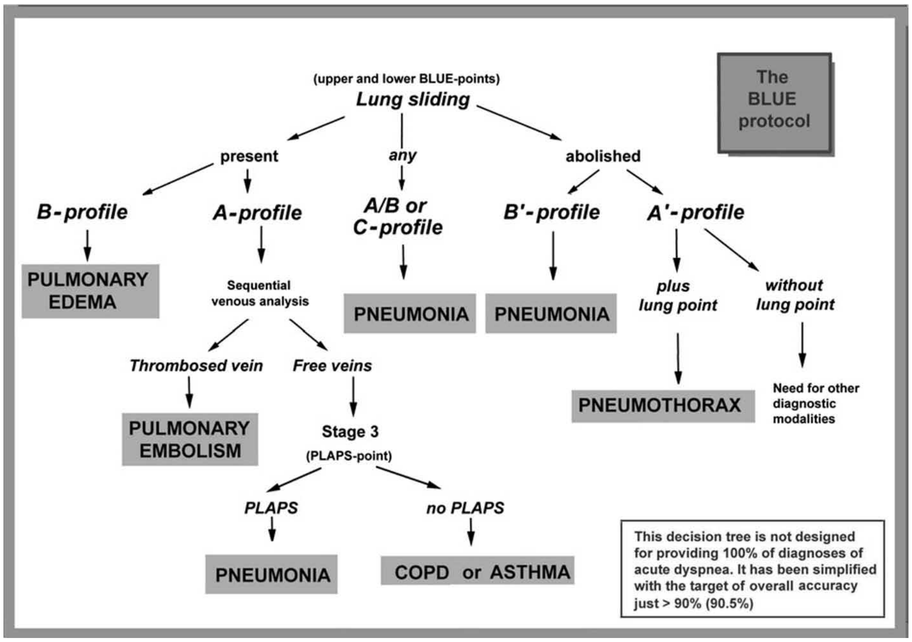

Figure 10 – *BLUE-protocol decision tree showing the practical steps of the BLUE-protocol. See Figure 1 legend for expansion of abbreviations. (Adapted from Lichtenstein and Mezière.[61])*

providing an impressive list of parameters when combined, suggesting that no gold standard is currently available. The fluid administration limited by lung sonography (FALLS)-protocol is not yet supported by clinical studies but should be considered as a potential source of help in difficult situations. It is based on sequential concepts: Pulmonary edema generates a thickening of the interlobular septa of which their subpleural end is accessible using lung ultrasound[63,64]; A-lines transform into B-lines at a pulmonary artery occlusion pressure threshold of 18 mm Hg at the anterior chest wall in critically ill patients[65]; and no artifact has ever been described between A-lines and B-lines, indicating that B-lines appear (and vanish) all of a sudden, making septal thickening an on-off parameter. The use of lung artifacts allows for a direct assessment of lung water, more specifically interstitial lung water (what no bedside tool can do). The FALLS-protocol assumes that pulmonary edema is the most harmful consequence of fluid overload in an extreme emergency (see limitations presented later in this section).

The FALLS-protocol follows the Weil classification of shock.[66] The best of simple cardiac sonography and some BLUE-protocol are used. With the same unit and the same probe, we first search for a substantial pericardial

TABLE 2] Accuracy of the BLUE-Protocol

Mechanism of Dyspnea	Profiles of BLUE-Protocol	Sensitivity, %	Specificity, %	PPV, %	NPV, %
Acute hemodynamic pulmonary edema	B-profile	97	95	87	99
Exacerbated COPD or severe acute asthma	Nude profile (A-profile with no DVT and no PLAPS)	89	97	93	95
Pulmonary embolism	A-profile with DVT	81	99	94	98
Pneumothorax	A′-profile (with lung point)	88	100	100	99
Pneumonia	The four profiles	89	94	88	95
	B′-profile	11	100	100	70
	A/B profile	14.5	100	100	71.5
	C-profile	21.5	99	90	73
	A-no-V-PLAPS-profile	42	96	83	78

BLUE = bedside lung ultrasound in emergency; NPV = negative predictive value; PLAPS = posterolateral alveolar and/or pleural syndrome; PPV = positive predictive value. (Adapted from Lichtenstein and Mezière.[61])

effusion (assimilated to tamponade), then an enlarged right ventricle (assimilated to pulmonary embolism) (if poor cardiac windows, the BLUE-protocol can be used instead), and then an A′-profile (suggesting a tension pneumothorax). At this step, obstructive shock can reasonably be ruled out.

The B-profile is sought next. In its absence, a cardiogenic shock from left origin (ie, the far majority) can be ruled out by definition.

The next step is performed in patients with neither the A′-profile nor the B-profile. The A-profile or equivalent (A/B-profile mainly) usually is seen, indicating that the patient is a FALLS-responder. Only hypovolemic and distributive shock are remaining causes, and the therapeutic part begins, which is fluid resuscitation. The A-profile shows that fluids can be administrated, a notion of interest for intensivists who use volume resuscitation in distributive shock. Intensivists who would rather use vasopressors may appreciate that the FALLS-protocol allows them to avoid giving these drugs in underestimated hypovolemia (ie, a safety factor useful at the initial step). The improvement of clinical/biologic signs of circulatory failure with an unchanged A-profile under fluid therapy reasonably defines hypovolemic shock. The FALLS-protocol as a new tool for diagnosing hypovolemia should be appreciated in these complex settings (prolonged surgery, prolonged intensive care) occurring in complex, challenging, and bariatric patients.

If no clinical improvement occurs, fluid therapy continues. The apparition of anterior B-lines (one can search more laterally) means that an iatrogenic interstitial syndrome likely has been generated by the fluid administration. Interstitial edema is an early step, preceding alveolar edema.[67,68] This step is clinically and biologically silent[23] and is the FALLS-end point (ie, the time to discontinue fluid therapy). Schematically, the FALLS-protocol rules out obstructive, then cardiogenic, then hypovolemic shock to expedite the diagnosis of the last remaining cause, distributive shock (ie, usually septic shock) (Fig 11).

At this step, one must acknowledge that the fluid therapy has positioned the (left-side) heart at the inflection point of the Frank-Starling curve. Blood tests are performed, including blood cultures (fully indicated here), as well as other maneuvers to withdraw this slight fluid excess (reversal of initial passive leg raising [a variant labeled FALLS-PLR-protocol], diuretics, or other options).

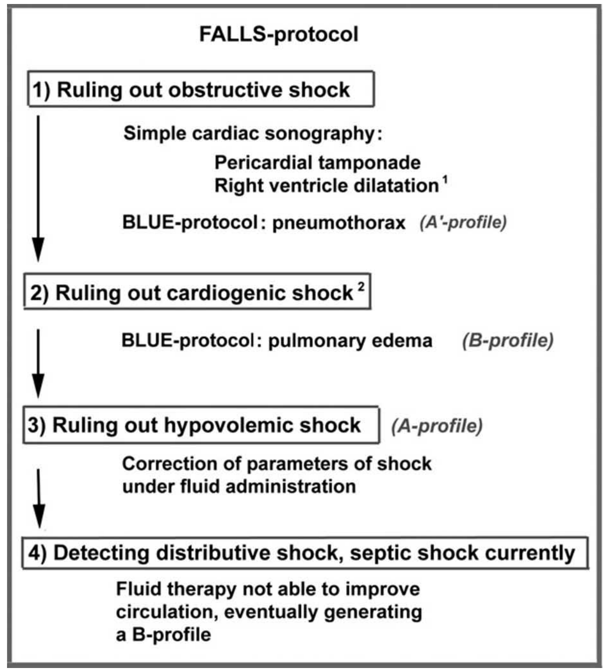

Figure 11 – *FALLS-protocol decision tree. This is a schematic, simplified decision tree of the FALLS-protocol, an approach to an acute circulatory failure without strong diagnostic orientation. (1) In the absence of cardiac window, the section "pulmonary embolism" of the BLUE-protocol can be used. (2) It is assumed that cardiogenic shock is of left origin. For the rare cases of cardiogenic shock of right origin (ie, with a low pulmonary artery occlusion pressure [right-sided myocardial infarction usually]), an ECG is routinely done, solving most issues, and fluid therapy is an otherwise familiar therapeutic option. If lung rockets are present on admission and the diagnosis of cardiogenic shock not clinically satisfying, echocardiography and caval veins analysis, among other tools, can be used. FALLS = fluid administration limited by lung sonography. See Figure 1 legend for expansion of other abbreviation.*

Previous guidelines recommended early and massive fluid therapy in sepsis.[69] The FALLS-protocol allows an earlier fluid therapy (on admission) hours before the sepsis is confirmed and provides the fluid volume just necessary to generate an infraclinical, infrabiologic step of interstitial edema (ie, likely an appropriate volume). Fluid administration is discontinued once the last tolerable drop has been given. The FALLS-protocol aims at decreasing high mortality from septic shock.

The main limitation of the FALLS-protocol is the presence of diffuse lung rockets (B-profile, B′-profile) on admission because no transformation from A-lines to B-lines can occur. To simplify this preliminary approach, conventional tools are used. Similarly, each time isolated, fully asymmetric right-sided heart failure is suspected, one is free to associate right ventricle and caval veins assessment.[1,2,70] Bear in mind that pulmonary embolism has been discounted at this step. It should also be understood that the FALLS-protocol is not devoted to defining the need for fluid in a given critically ill patient but to expediting a diagnosis.

The FALLS-protocol does not appear to have any drawbacks relative to other hemodynamic tools,[71] but any criticism is welcome. Based on pathophysiology, and above all pragmatism, the FALLS-protocol can be used when the usual tools fail (eg, limited cardiac windows). Furthermore, the FALLS-protocol cannot be compared directly with these tools because it does not monitor cardiac output changes, yet both approaches have a common bond: providing therapeutic orientations. Like traditional tools, the FALLS-protocol suggests who should receive fluids and when to discontinue fluids based on pathophysiology. Many questions are answered in Lichtenstein.[45]

The FALLS-protocol requires a simple unit without Doppler and has a steep learning curve. It can be of interest to not only those who have not yet mastered expert echocardiography but also those who do not yet (or will never) have echocardiographic units.

How Can These Protocols Affect the Routine of Several Disciplines?

Lung ultrasound in critical care is a holistic tool. A concept is holistic when the understanding of each of its multiple components is necessary to fully understand the whole.[45] The result generates a whole-body approach in addition to the main vital organ. This allows for simplification of expert domains such as echocardiography, if associated with lung ultrasound. In the case of suboptimal cardiac windows, the B-profile suggests pulmonary edema and the A-profile hypovolemia, schematically. Using simple equipment and appropriate training, lung ultrasound is an accessible discipline for physicians.

These fast protocols can help in cases of cardiac arrest where each second is precious for sequentially pinpointing reversible causes, including pneumothorax, pulmonary embolism, bleeding, pericardial tamponade, and others.[72] This application does not require urgent validation because it uses already-validated fields; simply, all elements optimizing the speed (narrow units, a 7-s starting time, the universal probe, etc) as well as a logical sequence (ie, first scanning the lungs, a 4-s step) are adopted in determining the diagnosis.

Apart from critical care, lung ultrasound will affect several disciplines. In the critically ill neonate, the 10 to 12 signs assessed in adults are found, with no difference.[73,74] In anesthesiology and emergency medicine, where moderate dyspnea is managed, we see similar profiles for pneumonia, pulmonary edema, COPD, asthma, and pneumothorax. In the case of small pulmonary embolisms, infarctions may be more frequent. The respirologist can assess for pleural effusions, safe thoracentesis,[47] an early diagnosis of chronic interstitial diseases, and lung consolidations in oncology. Expert approaches are available in Mathis[75] and Reissig and Kroegel.[9]

Disciplines including pediatrics, cardiology, nephrology, neurology, and internal medicine, will find interest in lung ultrasound. The use of lung ultrasound by these disciplines is made without complex adaptation because of the simplicity of the equipment and the same signs used for diagnosis. To define a normal lung, only two signs are necessary, regardless of where the probe is applied, which is not the case in cardiac, fetal, and abdominal ultrasound. For this reason, lung ultrasound is probably far less operator dependent. This means that priorities can be reconsidered. One may, for instance, initiate a curriculum with the normal lung and become rapidly operational for basic applications (pneumothorax, pulmonary edema) and then learn expert echocardiography, taking as long a time as necessary. The feasibility of ultrasound of this superficial organ is $>$ 98%[76]; even in bariatric patients the anterior approach provides basic data.

Medical irradiation (and costs) can be drastically reduced, which is of critical interest in neonates and young women. The Lung Ultrasound in the Critically Ill Favoring Limitation of Radiation (LUCIFLR) project aims to limit, not eradicate, one-third of urgent bedside radiographs and two-thirds of urgent CT scans in the next three decades,[77] which can be considered a reasonable target. The LUCIFLR project does not require independent confirmatory studies. Bedside radiography has demonstrated an inaccurate sensitivity for most life-threatening disorders. With a roughly 60% to 70% sensitivity, it appears to be a suboptimal tool in critical care.[78,79] Urgent CT imaging offers a strong overview yet at the cost of severe drawbacks (need for transportation, anaphylaxis, etc).[80,81] Lung ultrasound has proven to be a quite similar diagnostic tool in most cases[47-50,57] and sometimes superior, particularly with better detection of pleural septations,[77] necrosis within consolidations,[82] real-time assessment of lung sliding with no bedside equivalent,[57] dynamic air bronchograms,[83] and diaphragmatic analysis.[29,41] Ultrasound provides quantitative data for all disorders (as shown in the figure legends in this article) and helps to quantify pleural effusions,[15,19,61] and monitor lung consolidation, which are of interest for intensivists who use positive end-expiratory pressure for lung recruitment.[32] Pneumothorax volumes are indicated by the lung point location.[26,39,50] For these reasons, lung ultrasound should be considered a reasonable bedside gold standard. Each time that the clinical question is focused (ie, pneumothorax or not) and irradiating tests are avoided, not in theory but while practically using ultrasound, physicians take part, aware or not, in the LUCIFLR project.

Ultrasound, a multifaceted tool, can be used in sophisticated ICUs, outpatient settings,[84] and rural areas. We remain discreet on a nonscientific, but significant benefit: the comfort of the physician when using this visual approach to the patient.

Conclusions

The BLUE-protocol and the FALLS-protocol, two main applications of LUCI, are simple to use at each step, beginning with the choice of equipment (one simple unit, one microconvex probe for the whole body). The BLUE-protocol directly scans the lung to assess the cause of a respiratory failure. The FALLS-protocol considers a direct marker of fluid overload at the lung surface in patients with septic shock. With these applications, lung ultrasound appears once again as a visual stethoscope (from "stethos," meaning chest wall), and should be tailored as a new kind of visual medicine.[85]

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References

1. Jardin F, Farcot JC, Boisante L, Curien N, Margairaz A, Bourdarias JP. Influence of positive end-expiratory pressure on left ventricular performance. *N Engl J Med*. 1981;304(7):387-392.
2. Vieillard-Baron A, Slama M, Cholley B, Janvier G, Vignon P. Echocardiography in the intensive care unit: from evolution to revolution? *Intensive Care Med*. 2008;34(2):243-249.
3. Weinberger SE, Drazen JM. Diagnostic procedures in respiratory diseases. In: Kasper DL, Braunwald E, Fauci AS, Hauser SL, Longo DL, Jameson JL, eds. *Harrison's Principles of Internal Medicine*. 16th ed. New York, NY: McGraw-Hill; 2005:1505-1508.
4. Mayo PH, Beaulieu Y, Doelken P, et al. American College of Chest Physicians/La Société de Réanimation de Langue Française statement on competence in critical care ultrasonography. *Chest*. 2009;135(4):1050-1060.
5. Lichtenstein D, Axler O. Intensive use of general ultrasound in the intensive care unit. Prospective study of 150 consecutive patients. *Intensive Care Med*. 1993;19(6):353-355.
6. Dulchavsky SA, Hamilton DR, Diebel LN, Sargsyan AE, Billica RD, Williams DR. Thoracic ultrasound diagnosis of pneumothorax. *J Trauma*. 1999;47(5):970-971.
7. Maury E, Guglielminotti J, Alzieu M, Guidet B, Offenstadt G. Ultrasonic examination: an alternative to chest radiography after central venous catheter insertion? *Am J Respir Crit Care Med*. 2001;164(3):403-405.
8. Rowan KR, Kirkpatrick AW, Liu D, Forkheim KE, Mayo JR, Nicolaou S. Traumatic pneumothorax detection with thoracic US: correlation with chest radiography and CT—initial experience. *Radiology*. 2002;225(1):210-214.
9. Reissig A, Kroegel C. Transthoracic sonography of diffuse parenchymal lung disease: the role of comet tail artifacts. *J Ultrasound Med*. 2003;22(2):173-180.
10. Mayo PH, Goltz HR, Tafreshi M, Doelken P. Safety of ultrasound-guided thoracentesis in patients receiving mechanical ventilation. *Chest*. 2004;125(3):1059-1062.
11. Kirkpatrick AW, Sirois M, Laupland KB, et al. Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the Extended Focused Assessment with Sonography for Trauma (EFAST). *J Trauma*. 2004;57(2):288-295.
12. Jambrik Z, Monti S, Coppola V, et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. *Am J Cardiol*. 2004;93(10):1265-1270.
13. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. *Acad Emerg Med*. 2005;12(9):844-849.
14. Roch A, Bojan M, Michelet P, et al. Usefulness of ultrasonography in predicting pleural effusions > 500 mL in patients receiving mechanical ventilation. *Chest*. 2005;127(1):224-232.
15. Vignon P, Chastagner C, Berkane V, et al. Quantitative assessment of pleural effusion in critically ill patients by means of ultrasonography. *Crit Care Med*. 2005;33(8):1757-1763.
16. Mathis G, Blank W, Reissig A, et al. Thoracic ultrasound for diagnosing pulmonary embolism: a prospective multicenter study of 352 patients. *Chest*. 2005;128(3):1531-1538.
17. Volpicelli G, Mussa A, Garofalo G, et al. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. *Am J Emerg Med*. 2006;24(6):689-696.
18. Soldati G, Testa A, Silva FR, Carbone L, Portale G, Silveri NG. Chest ultrasonography in lung contusion. *Chest*. 2006;130(2):533-538.
19. Balik M, Plasil P, Waldauf P, et al. Ultrasound estimation of volume of pleural fluid in mechanically ventilated patients. *Intensive Care Med*. 2006;32(2):318-321.
20. Bouhemad B, Zhang M, Lu Q, Rouby JJ. Clinical review: bedside lung ultrasound in critical care practice. *Crit Care*. 2007;11(1):205.
21. Copetti R, Cattarossi L. The 'double lung point': an ultrasound sign diagnostic of transient tachypnea of the newborn. *Neonatology*. 2007;91(3):203-209.
22. Fagenholz PJ, Gutman JA, Murray AF, Noble VE, Thomas SH, Harris NS. Chest ultrasonography for the diagnosis and monitoring of high-altitude pulmonary edema. *Chest*. 2007;131(4):1013-1018.
23. Gargani L, Lionetti V, Di Cristofano C, Bevilacqua G, Recchia FA, Picano E. Early detection of acute lung injury uncoupled to hypoxemia in pigs using ultrasound lung comets. *Crit Care Med*. 2007;35(12):2769-2774.
24. Frassi F, Gargani L, Tesorio P, Raciti M, Mottola G, Picano E. Prognostic value of extravascular lung water assessed with ultrasound lung comets by chest sonography in patients with dyspnea and/or chest pain. *J Card Fail*. 2007;13(10):830-835.
25. Volpicelli G, Caramello V, Cardinale L, Mussa A, Bar F, Frascisco MF. Bedside ultrasound of the lung for the monitoring of acute decompensated heart failure. *Am J Emerg Med*. 2008;26(5):585-591.
26. Soldati G, Testa A, Sher S, Pignataro G, La Sala M, Silveri NG. Occult traumatic pneumothorax: diagnostic accuracy of lung ultrasonography in the emergency department. *Chest*. 2008;133(1):204-211.
27. Copetti R, Soldati G, Copetti P. Chest sonography: a useful tool to differentiate acute cardiogenic pulmonary edema from acute respiratory distress syndrome. *Cardiovasc Ultrasound*. 2008;6:16.
28. Noble VE, Murray AF, Capp R, Sylvia-Reardon MH, Steele DJR, Liteplo A. Ultrasound assessment for extravascular lung water in

patients undergoing hemodialysis. Time course for resolution. *Chest*. 2009;135(6):1433-1439.

29. Lerolle N, Guérot E, Dimassi S, et al. Ultrasonographic diagnostic criterion for severe diaphragmatic dysfunction after cardiac surgery. *Chest*. 2009;135(2):401-407.
30. Gargani L, Doveri M, D'Errico L, et al. Ultrasound lung comets in systemic sclerosis: a chest sonography hallmark of pulmonary interstitial fibrosis. *Rheumatology (Oxford)*. 2009;48(11):1382-1387.
31. Via G, Lichtenstein D, Mojoli F, et al. Whole lung lavage: a unique model for ultrasound assessment of lung aeration changes. *Intensive Care Med*. 2010;36(6):999-1007.
32. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. *Am J Respir Crit Care Med*. 2011;183(3):341-347.
33. Caiulo VA, Gargani L, Caiulo S, et al. Lung ultrasound in bronchiolitis: comparison with chest X-ray. *Eur J Pediatr*. 2011;170(11): 1427-1433.
34. Via G, Storti E, Gulati G, Neri L, Mojoli F, Braschi A. Lung ultrasound in the ICU: from diagnostic instrument to respiratory monitoring tool. *Minerva Anestesiol*. 2012;78(11):1282-1296.
35. Volpicelli G, Elbarbary M, Blaivas M, et al; International Liaison Committee on Lung Ultrasound (ILC-LUS) for International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med*. 2012;38(4):577-591.
36. Tsung JW, Kessler DO, Shah VP. Prospective application of clinician-performed lung ultrasonography during the 2009 H1N1 influenza A pandemic: distinguishing viral from bacterial pneumonia. *Crit Ultrasound J*. 2012;4(1):16.
37. Reissig A, Copetti R, Mathis G, et al. Lung ultrasound in the diagnosis and follow-up of community-acquired pneumonia: a prospective, multicenter, diagnostic accuracy study. *Chest*. 2012;142(4):965-972.
38. Shah VP, Tunik MG, Tsung JW. Prospective evaluation of point-of-care ultrasonography for the diagnosis of pneumonia in children and young adults. *JAMA Pediatr*. 2013;167(2):119-125.
39. Oveland NP, Lossius HM, Wemmelund K, Stokkeland PJ, Knudsen L, Sloth E. Using thoracic ultrasonography to accurately assess pneumothorax progression during positive pressure ventilation: a comparison with CT scanning. *Chest*. 2013;143(2):415-422.
40. Caiulo VA, Gargani L, Caiulo S, et al. Lung ultrasound characteristics of community-acquired pneumonia in hospitalized children. *Pediatr Pulmonol*. 2013;48(3):280-287.
41. Matamis D, Soilemezi E, Tsagourias M, et al. Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications. *Intensive Care Med*. 2013;39(5):801-810.
42. Xirouchaki N, Kondili E, Prinianakis G, Malliotakis P, Georgopoulos D. Impact of lung ultrasound on clinical decision making in critically ill patients. *Intensive Care Med*. 2014; 40(1):57-65.
43. Lichtenstein D. *Lung Ultrasound in the Critically Ill. Yearbook of Intensive Care and Emergency Medicine*. Berlin, Germany: Springer-Verlag; 2004:625-644.
44. Lichtenstein D, Mezière G. The BLUE-points: three standardized points used in the BLUE-protocol for ultrasound assessment of the lung in acute respiratory failure. *Crit Ultrasound J*. 2011;3(2):109-110.
45. Lichtenstein D. *Whole Body Ultrasonography in the Critically Ill*. Berlin, Germany: Springer-Verlag; 2010.
46. Lichtenstein D, Mezière G, Biderman P, Gepner A. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. *Intensive Care Med*. 1999;25(4):383-388.
47. Lichtenstein D, Hulot JS, Rabiller A, Tostivint I, Mezière G. Feasibility and safety of ultrasound-aided thoracentesis in mechanically ventilated patients. *Intensive Care Med*. 1999;25(9):955-958.
48. Lichtenstein DA, Lascols N, Mezière G, Gepner A. Ultrasound diagnosis of alveolar consolidation in the critically ill. *Intensive Care Med*. 2004;30(2):276-281.
49. Lichtenstein D, Mézière G, Biderman P, Gepner A, Barré O. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med*. 1997;156(5):1640-1646.
50. Lichtenstein DA, Mezière G, Lascols N, et al. Ultrasound diagnosis of occult pneumothorax. *Crit Care Med*. 2005;33(6): 1231-1238.
51. Dénier A. Les ultrasons, leur application au diagnostic. *Presse Med*. 1946;22:307-308.
52. Joyner CR Jr, Herman RJ, Reid JM. Reflected ultrasound in the detection and localization of pleural effusion. *JAMA*. 1967;200(5): 399-402.
53. Weinberg B, Diakoumakis EE, Kass EG, Seife B, Zvi ZB. The air bronchogram: sonographic demonstration. *AJR Am J Roentgenol*. 1986;147(3):593-595.
54. Rantanen NW. Diseases of the thorax. *Vet Clin North Am Equine Pract*. 1986;2(1):49-66.
55. Wernecke K, Galanski M, Peters PE, Hansen J. Sonographic diagnosis of pneumothorax [in German]. *Rofo*. 1989;150(1): 84-85.
56. Targhetta R, Bourgeois JM, Chavagneux R, Marty-Double C, Balmes P. Ultrasonographic approach to diagnosing hydropneumothorax. *Chest*. 1992;101(4):931-934.
57. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. *Chest*. 1995;108(5):1345-1348.
58. Lichtenstein DA, Lascols N, Prin S, Mezière G. The "lung pulse": an early ultrasound sign of complete atelectasis. *Intensive Care Med*. 2003;29(12):2187-2192.
59. Lichtenstein D, Mezière G, Biderman P, Gepner A. The "lung point": an ultrasound sign specific to pneumothorax. *Intensive Care Med*. 2000;26(10):1434-1440.
60. Lichtenstein D, Loubières Y. Lung sonography in pulmonary embolism. *Chest*. 2003;123(6):2154-2155.
61. Lichtenstein DA, Mezière GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure. *Chest*. 2008;134(1): 117-125.
62. Lichtenstein D. The BLUE-protocol, venous part: deep venous thrombosis in the critically ill. Technique, results for the diagnosis of acute pulmonary embolism. In: Lichtenstein D, ed. *Lung Ultrasound in the Critically Ill*. Berlin, Germany: Springer-Verlag; 2015:116-140.
63. Kerley P. Radiology in heart disease. *BMJ*. 1933;2(3795):594-597.
64. Lichtenstein D. Diagnostic échographique de l'oedème pulmonaire (Lettre à la rédaction). *Rev Im Med*. 1994;6:561-562.
65. Lichtenstein DA, Mezière GA, Lagoueyte JF, Biderman P, Goldstein I, Gepner A. A-lines and B-lines: lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. *Chest*. 2009;136(4):1014-1020.
66. Weil MH, Shubin H. Proposed reclassification of shock states with special reference to distributive defects. *Adv Exp Med Biol*. 1971;23(0):13-23.
67. Staub NC. Pulmonary edema. *Physiol Rev*. 1974;54(3):678-811.
68. Guyton CA, Hall JE. *Textbook of Medical Physiology*. 9th ed. Philadelphia, PA: WB Saunders Company; 1996:496-497.
69. Rivers E, Nguyen B, Havstad S, et al; Early Goal-Directed Therapy Collaborative Group. Early goal-directed therapy in the treatment of severe sepsis and septic shock. *N Engl J Med*. 2001;345(19):1368-1377.
70. Hill NS, Klinger JR. Pulmonary hypertension in the intensive care unit: critical role of the right ventricle. *Crit Care Med*. 2007;35(9):2210-2211.
71. Lichtenstein D, Karakitsos D. Integrating lung ultrasound in the hemodynamic evaluation of acute circulatory failure (the fluid administration limited by lung sonography protocol). *J Crit Care*. 2012;27(5):533.e11-533.e19.
72. Lichtenstein D. The SESAME-protocol. In: Lichtenstein D, ed. *Lung Ultrasound in the Critically Ill*. Berlin, Germany: Springer-Verlag; 2015:240-251.
73. Lichtenstein DA. Ultrasound examination of the lungs in the intensive care unit. *Pediatr Crit Care Med*. 2009;10(6):693-698.
74. Lichtenstein DA, Mauriat P. Lung ultrasound in the critically ill neonate. *Curr Pediatr Rev*. 2012;8(3):217-223.

75. Mathis G. *Chest Sonography*. Heidelberg, Germany: Springer Verlag; 2008.
76. Lichtenstein D, Biderman P, Chironi G, et al. Faisabilité de l'échographie générale d'urgence en réanimation. *Réan Urg*. 1996;5(6):788 (SP 50).
77. Lichtenstein D. The LUCI-FLR program. In: Lichtenstein D, ed. *Lung Ultrasound in the Critically Ill*. Berlin, Germany: Springer-Verlag; 2015:206-213.
78. Hendrikse KA, Gratama JW, Hove Wt, Rommes JH, Schultz MJ, Spronk PE. Low value of routine chest radiographs in a mixed medical-surgical ICU. *Chest*. 2007;132(3):823-828.
79. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. *Anesthesiology*. 2004;100(1):9-15.
80. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med*. 2007;357(22):2277-2284.
81. Lauer MS. Elements of danger—the case of medical imaging. *N Engl J Med*. 2009;361(9):841-843.
82. Lichtenstein D, Peyrouset O. Is lung ultrasound superior to CT? The example of a CT occult necrotizing pneumonia. *Intensive Care Med*. 2006;32(2):334-335.
83. Lichtenstein D, Mezière G, Seitz J. The dynamic air bronchogram. A lung ultrasound sign of alveolar consolidation ruling out atelectasis. *Chest*. 2009;135(6):1421-1425.
84. Lichtenstein D, Courret JP. Feasibility of ultrasound in the helicopter. *Intensive Care Med*. 1998;24(10):1119.
85. van der Werf TS, Zijlstra JG. Ultrasound of the lung: just imagine. *Intensive Care Med*. 2004;30(2):183-184.