Lung Ultrasound in the Critically Ill

Ten signs: the alphabet for performing the BLUE-protocol

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The lung, not suitable for ultrasound?

“The lungs are a major hindrance for the use of ultrasound at the thoracic level”.

In Harrison PR. Principles of Internal Medicine. 1992:1043

Simply wrong

Announced in the body of this article, sent in 1991 to the Journal
The ideal equipment*

Slides regarding these issues have been withdrawn in the document specifically designed for the First World Congress of Ultrasound in Education (Prof. Richard Hoppmann).

Shortly: we use since 1992 a simple unit (no Doppler, one single, universal probe) for lung ultrasound in the critically ill, in a holistic approach including a whole body assessment. This unit starts on in 7 seconds, has a flat, easy-to-clean keyboard and analogic image quality. Height, 27 cm. Width: 33 cm with cart.

For those who have modern equipments, but want to make an idea, we suggest abdominal probes and the by-pass of all filters.

* To withdraw in suitable presentations
The ten basic signs

The bat sign
The A-line
Lung sliding
The quad sign
The sinusoid sign
The tissue-like sign
The shred sign
The B-line (& lung rockets)
The stratosphere sign
The lung point

The mastery of these signs allows control of multiple settings: acute respiratory failure, ARDS management, hemodynamic therapy in shocked patient, neonate assessment, traumatized patient. It works in up-to-date ICUs as well as austere areas or spaceships.

Important note
There is no DVD (in progress). Note meanwhile that dynamic images can be replaced by M-mode acquisition. Lung ultrasound is a standardized field, which can be understood perfectly by reading static images instead of mobile ones. DVD is a minor detail.
The bat sign is a basic step. It allows to locate the lung surface in any circumstances (acute dyspnea, subcutaneous emphysema...)

The pleural line and the upper and lower ribs make a permanent landmark.

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CEURF - D. Lichtenstein - Réanimation Médicale - Hôpital Ambroise-Paré
2) The A-line

Hyperechoic horizontal artifact arising from the pleural line

A-lines indicate air*, whether physiologic or pathologic

* For purists, the term gas is better
3) Lung sliding and seashore sign

The pleural line normally separates two distinct patterns (in M-mode). This demonstrates lung sliding, without Doppler.
4) Pleural effusion: The quad sign

Quad image between pleural line, shadow of ribs, and the lung line (deep border, always regular)

Quad sign and sinusoid sign are universal signs allowing to define any kind of pleural effusion regardless its echogenicity
5) Pleural effusion: Sinusoid sign

- Inspiratory movement of lung line toward pleural line

Sinusoid sign allows not only full confidence in the diagnosis of pleural effusion (associated with quad sign), but also indicates possibility of using small needle for withdrawing fluid.
6) Lung consolidation (alveolar syndrome)
The tissue-like sign

A fluid disorder with a solid appearance
7) Lung consolidation (alveolar syndrome)
The shred sign

A shredded line, instead of the lung line: a specific sign
8) B-lines, lung rockets and interstitial syndrome

The B-line is
1 - a comet-tail artifact
2 - arising from the pleural line
3 - well-defined - laser-ray like
4 - hyperechoic
5 - long (does not fade)
6 - erases A lines
7 - moves with lung sliding

Example of 4 or 5 B-lines
(1992’s technology)

Using these 7 features, the B-line is distinct from all other comet-tail artifacts
8) B-lines, lung rockets and interstitial syndrome
Important semantic note

Diffuse lung rockets
Lung rockets at the four points of anterior chest wall
They define pulmonary edema (hemodynamic or inflammatory - see BLUE-protocol)

Lung rockets
Three (or more) B-lines between two ribs
They define interstitial syndrome (can be focal)

B-lines
A certain type of comet-tail artifact (see definition previous slide)
Defines mingling of air and fluid abutting pleura. Can be isolated and mean normal fissura

Comet-tail artifact
Vertical artifact, visible at the lung surface or elsewhere, can be due to multiples causes (gas, metallic materials), called E-lines, Z-lines (see left), K-lines, S-lines, W-lines....). Includes the B-line, but is not "the" B-line
9) Pneumothorax
Three signs - Signs 1 & 2

1) Abolished lung sliding
   Yielding stratosphere sign on M-mode

2) The A-line sign: already in the scale (see A-line slide)

   One B-line is enough for ruling out the diagnosis, confidently, where probe is applied

   Detection of abolished lung sliding with the A-line sign allows immediate suspicion of all cases of pneumothorax

1982 technology
10) Pneumothorax

Three signs - Sign 3: the lung point

Lung point: specific to pneumothorax, therefore mandatory for accurate and safe use in the critically ill

Sudden, on-off visualization of a lung pattern (lung sliding and/or B-lines) at a precise area where the collapsed expiratory lung slightly increases its surface of contact on inspiration

Lung point indicates volume of pneumothorax

Note that the label "lung point" assumes absent anterior lung sliding and the A-line sign at the anterior chest wall

The lung point allows checking that signs (especially abolished lung sliding) are not due to technical inadequacies of machine (beware modern machines not designed for lung)
Pneumothorax
The diagnosis of air within air
A simple decision tree

Lung sliding*

Present: pneumothorax ruled out

B-lines present: Pneumothorax ruled out

Absent

Only A-lines

Lung point: pneumothorax is confirmed

No lung point: use usual tools (clinical, X-ray or even CT). A solution when situation is critical is under submission

* Or equivalent, such as the lung pulse
### Value of the signs used

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<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Source</th>
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<td>Feasibility and safety of ultrasound-aided thoracentesis in mechanically ventilated patients</td>
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<td>Alveolar consolidation</td>
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<td>Interstitial syndrome</td>
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<td>The Comet-Tail Artifact - An Ultrasound Sign of Alveolar-Interstitial Syndrome</td>
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<td>Complete pneumothorax</td>
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<td>79 - 100</td>
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</table>

* 93/93 in Abstract when compared with radiograph, 100/100 in Results when compared with CT
Some semantic details

Literature can enrich, but sometimes confuse. Please note:

*Lung comets* are not lung rockets. The physiopathologic meaning of these two labels is fully different.

The term *comet-tail artifact* is not representative for interstitial syndrome.

The term *"alveolar-interstitial syndrome"* is radiological, but inappropriate in ultrasound world. Ultrasound detects either interstitial syndrome (lung rockets) or alveolar syndrome (shred sign), fully distinctly.

The term *barcode sign* is sometimes used instead of stratosphere sign, but we suggest to be cautious for avoiding deadly confusions generated by the new barcodes:
Maybe our main message

The whole of these ten signs (also signs not described here, dynamic air bronchogram and lung pulse) are found again with no difference in the critically ill neonate.

These signs have been carefully assessed in the adult, using irradiating tool: CT. We do not intent to publish data in neonates (meaning CT use*, of poor interest for the involved neonate), but invite pediatricians working in neonate ICUs to understand, when they will see a quad sign (shred sign, lung point, etc) in a neonate with normal or ill-defined bedside radiograph, that ultrasound describes the true disorder.

* We currently compile all cases where CT has been already ordered and performed
The instrument
Basic technique
Normal lung
Pleural effusion
Alveolar consolidation
Interstitial syndrome
Pneumothorax

Clinical applications
Lung ultrasound, the sequel...

Many applications are accessible - nature and volume of pleural effusion - pulmonary abscess - distinction between thickened interlobular septa and ground-glass areas - lung contusion - overdistension - alveolar recruitment - immediate diagnosis of atelectasis when still aerated - distinction between hemodynamic and permeability-induced pulmonary edema - phrenic function - ultrasound-assisted thoracenthesis, in mechanically ventilated patients - ETC

Recent works of CEURF:
(Chest 2008) : the BLUE-protocol, a simple approach allowing diagnosis of acute respiratory failure
(Chest 2009) : FALLS-protocol. Lung ultrasound as a method for controlling fluid therapy in the shocked patient
(PCCM 2009) : Lung ultrasound in the critically ill neonate
(Chest 2009) : Distinction atelectasis versus pneumonia using the dynamic air bronchogram
(Critical Ultrasound Journal 2011) : the BLUE-points, standardized areas of investigation used in the BLUE-protocol
The BLUE-protocol

Lung sliding
- present
  - B profile
    - Pulmonary Edema
      - Thrombosed vein
        - Pulmonary Embolism
          - PLAPS
            - Pneumonia
          - No PLAPS
            - COPD or Asthma
  - A profile
    - Venous analysis
      - No direction specified
- A/B or C profile
  - No direction specified
- B' profile
  - A lines
    - Lung point
      - Pneumothorax
    - Without lung point
      - Need for other diagnosis modalities

This decision tree does not aim at providing the diagnosis. It indicates a way for reaching a 90.5% accuracy when using lung ultrasound.

Chest 2008; 134:117-125

Relevance of Lung Ultrasound in the Diagnosis of Acute Respiratory Failure - the BLUE-protocol
Main principle: A simple ultrasound analysis of lungs (and veins in suitable cases) allows to categorize the test in one of seven characteristic profiles. The decision tree allows to obtain the diagnosis of the 5 most frequent causes of acute respiratory failure (that make 97% of cases) in 90.5% of cases. The BLUE-protocol is included in the traditional approach which includes history and physical examination. The combination of both yields better performances. The inclusion of basic tests (EKG, venous blood tests) increases the rate. Simple cardiac sonography again increases this rate.

The first aim of the BLUE-protocol is, by providing an immediate diagnosis, a quicker relief of a dyspneic patient.

The second aim is to decrease the need for heavy tests (CT, sophisticated echocardiography), painful tests (arterial blood analysis) and irradiating tests in particular cases (pregnancy), as well as improving care level in scarce resource areas.
The BLUE-protocol, just one example: Fast diagnosis of pulmonary edema

After history and physical examination (which are enough for the diagnosis in most cases), the probe is inserted on two standardized points of the anterior chest wall (i.e., four for both lungs).

In acute hemodynamic pulmonary edema with respiratory failure, the pattern observed in 97% of cases is diffuse lung rockets associated with lung sliding. This pattern, called the B-profile, is obtained in 20 seconds.

Specificity is 95%. False-negatives are usually cases of acute interstitial pneumonia with still conserved lung sliding.

Cases of chronic interstitial disease are not included since BLUE-protocol included the 97% of patients having the 5 most frequent groups of diseases: pneumonia - pulmonary edema - COPD and asthma - pulmonary embolism - pneumothorax. Countless diseases (including chronic interstitial diseases) make the 3% of remaining cases).

Notes: facing a B-profile, the BLUE-protocol is concluded. Posterior lung and venous analysis can be freely done by the physician after this BLUE-protocol. They are not part of it, usually providing redundant information or showing free veins, but can on occasion have some relevance. The aim of the BLUE-protocol is to provide basic piece of information with maximal simplicity.

(e.g., for diagnosing anyway chronic lung disease, the history is usually a major element. Facing a first episode, some elements from lung ultrasound and, of prime importance, simple cardiac sonography will immediately alert the physician - normal left heart contractility, enlarged right heart, and others).
The BLUE-protocol is holistic ultrasound

One critical example

Venous ultrasound is central to the BLUE-protocol. It is mandated each time there is an A-profile (normal anterior lung pattern).

It does not require vascular probes. Our microconvex probe sharply assesses all veins (femoral, caval...) in all incidences (long axis, short axis).

It carefully focuses on the calf areas, which are usually neglected, but are of high accessibility using our probe and adapted approach. Isolated calf DVT is a frequent finding in massive pulmonary embolism.

Once a DVT is detected, the association of "A-profile plus DVT" provides diagnosis of massive pulmonary embolism with 81% sensitivity & 99% specificity.

This immediately reduces the needs for sophisticated Doppler echocardiographic approach. A simple visualization of the dilated right chambers using our microconvex probe can be performed at this step.

In extreme emergencies (cardiac arrest etc), the same probe will cover all areas of interest.

One probe, one simple cost-saving machine, the adjunction of the lung, the definition of a simple emergency cardiac sonography...

This is holistic ultrasound.

DVT: deep venous thrombosis
And the FALLS-protocol, allowing to define needs in fluid therapy in acute circulatory failure. Can be used even in absence of suitable cardiac window, and in addition provides direct parameter of lung volemia (CHEST 136:1014-1020)
For making one step beyond

Detailed applications are available in “Whole body ultrasound in the critically ill” (2010, Springer, 4th Ed since 1992)

An adapted training to lung ultrasound at the bedside of the critically ill is accessible since 1989 in medical ICU of Hospital Ambroise-Paré, using personalized approach of CEURF (www.ceurf.net)

CEURF (Cercle des Echographistes d’Urgence et de Réanimation Francophones) trains in French and in English. One didactic day details what is holistic critical ultrasound (and why the organs, applications and equipment permanently interact, creating optimal harmony). The bedside stage includes not more than two attendees, at the bedside. One (basic), two (advanced) or three (expert) mornings are accessible. After the session, CEURFers can communicate with the bureau with no limitation in time (advise on given patients, help in publications...). A substitute product for gel is used at CEURF, allowing to make fast protocols (a BLUE-protocol in 3 minutes or less). CEURF is a non-profit association (1901 law), aiming at widespread a different vision of ultrasound.
Additional literature

Since recently (advent of laptops), countless works have been published. All confirm the value of lung ultrasound in the critically ill
Not arguing for a comprehensive list, here are quoted some main authors, apologizing for possibly missing works:


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 131:1013-1018


And many other publications
CEURF

Tomorrow's medicine using yesterday's tools