Point-of-Care Ultrasound Evaluation of Respiratory Function

Abdulaziz H. Algain¹†, Florin Costescu², Karoll A. Rodelo Ceballos³

¹Regional Anesthesia and Acute Pain Fellow, Department of Anesthesia, The Montreal General Hospital, McGill University, Montreal, Quebec, Canada; Department of Anesthesia & Critical Care, King Abdulaziz University, Jeddah, Saudi Arabia
²Assistant Professor, Department of Anesthesia, The Montreal General Hospital, McGill University, Montreal, Quebec, Canada
³Supervising author and Assistant Professor, Department of Anesthesia, The Montreal General Hospital, McGill University, Montreal, Quebec, Canada

Edited by: Dr. Subramani Kandasamy, Senior Professor, Surgical Intensive Care Unit, Christian Medical College, Vellore, Tamilnadu, India

†Corresponding author email: abdulazizh.algain@gmail.com

Published 21 May 2024

KEY POINTS

- Lung ultrasound relies on artefacts rather than direct anatomical visualization.
- It is useful in emergencies and also during the peri-operative period.
- Lung point-of-care ultrasound can evaluate pneumothorax, interstitial disease, and pleural effusion, and can assess the diaphragmatic function.
- Protocols, such as the ‘BLUE’ protocol, detect the causes of acute respiratory failure early with 90.5% accuracy.

INTRODUCTION

Lung point-of-care ultrasound (POCUS) is easy, noninvasive, and inexpensive for diagnosis and monitors response to therapy and spares radiation exposure. It results in a 76% change in the therapeutic strategy and identifies new pathology in 31% of cases.¹ Compared to chest radiography, it provides higher sensitivity and specificity in detecting pneumothorax and pleural effusion, it better differentiates between pleural effusion and consolidation,² and it is superior in detecting pneumonia.³ Ultrasonic assessment of the diaphragmatic function has high sensitivity (93%) and specificity (100%) in diagnosing phrenic nerve dysfunction.⁴ This tutorial discusses POCUS indications, the physics of ultrasound, standard exam approach and protocols, terminology, and pathology profiles and explores several applications of lung ultrasonography in monitoring and therapeutic interventions.

PHYSICS OF ULTRASOUND

Due to the different acoustic impedances between air and soft tissue, most waves are reflected at the pleura of a normally aerated lung. It is not possible to visualize normal lung parenchyma in contrast to cases of consolidation or collapse where lung tissue can be directly visualised. Pleural effusions can be visualised by ultrasound. Normally, the pleural layers are indistinguishable, and the hyperechoic pleural line and its artefacts are seen. A-lines are horizontal reverberation artefacts under the pleura at regular intervals, equivalent to the distance between the pleura and the probe.⁵

An online test is available for self-directed continuous medical education (CME). It is estimated to take 1 hour to complete. Please record time spent and report this to your accrediting body if you wish to claim CME points. A certificate will be awarded upon passing the test. Please refer to the accreditation policy here.

TAKE ONLINE TEST

Subscribe to ATOTW tutorials by visiting https://resources.wfsahq.org/anaesthesia-tutorial-of-the-week/
TERMINOLOGY

Table 1 defines terms that are used in lung ultrasonography.

INDICATIONS

Ultrasound of the lung is used in intensive care, in emergency medicine, and in the perioperative settings to evaluate any acute alteration of the respiratory status of critically ill patients. It is applied to diagnose the causes of hypoxia in patients with or without haemodynamic instability. The diaphragmatic ultrasound assessment has been used over the last 25 years to assess readiness for extubation, to detect neuromuscular disease, or to evaluate for potential phrenic nerve injury before and after brachial plexus nerve blocks. The ultrasound assessment of the parasternal intercostal muscle predicts weaning success.

ULTRASOUND SELECTION AND PATIENT POSITIONING

A linear probe has the best resolution and is ideal for analysing pneumothorax or pulmonary oedema, while low-frequency probes examine deep artefacts as in effusions. The small phased array probe is helpful when evaluating small anterior intercostal spaces. The curvilinear probe has good penetration and is useful to check for effusions and it provides adequate views of the costo-phrenic angle, liver, and diaphragm. Patients are usually examined supine. Probes are placed anteriorly to check for pneumothorax, as air in the pleural space builds up anteriorly. When the patient is semiseated, the least dependent area is the apex. However, the clavicles make imaging more challenging. The probe is placed posterolateral when looking for a dependent pathology, such as consolidation, effusion, or hemothorax.

STANDARD EXAM APPROACH

In lung POCUS, we look for pneumothorax, interstitial disease, and pleural effusion, and assess the diaphragmatic function. Six zones are examined (bilateral anterior, posterior, and lateral), and 3 intercostal spaces are examined in each zone (Figure 1). To rule out pneumothorax, B-mode is used to verify lung sliding and ensure the absence of a lung point extensively. We look for B-lines

| A-lines | Under the pleura, horizontal reverberation artefacts at regular intervals, equivalent to the distance between the pleura and the probe. |
| B-lines | Three or more hydroaeric comet-tail artefacts arising from the pleural line to reach the far field; may be normal in dependent areas. |
| C-lines | Hypoechoic subpleural comet-tail artefacts, seen in consolidation. |
| E-lines | Irregular vertical hyperechoic lines arising from the thoracic wall; due to air trapped in the soft tissue in cases of subcutaneous emphysema; obscures the rib shadow and pleural line below it. |
| Lung hepatization | An indicator of substantial consolidation when lung tissue appears isoechoic to liver parenchyma. |
| Lung monster | The atelectatic lung appears as a wedge-shaped echogenic mass within the pleural fluid that moves with respiration. |
| Curtain sign | A crano-caudal movement artefact of the lung during respiration at the fully aerated base. Its reduction or absence could be due pleural effusion, atelectasis, or basal consolidation. |
| Air bronchogram | Aerated bronchi surrounded by fluid-filled alveoli on opaque airless lung; may be dynamic (consolidation) or static (severe atelectasis). |
| Acoustic window | Near-field structures that contribute to wave transmission. The liver and the spleen are basal acoustic windows for the diagnosis of pleural effusion or diaphragmatic dysfunction. |
| Lung sliding | Sliding of the visceral against the parietal pleura, described as ‘marching ants’. It is absent in pneumothorax due to intrathoracic air between the pleural layers. |
| Lung point | A finding at the location where the pneumothorax ends and sliding is resumed. |
| Lung pulse | Transmission of cardiac pulsation to the lung, causing the pleural line to move with the heartbeat. This occurs if lung is not ventilated (as in endobronchial intubation) and is absent in pneumothorax. |
| Seashore sign | The ‘sea’ pattern is the immobile chest wall tissue and muscle layers, while the ‘sand’ pattern is the pleural sliding, maybe normally seen on an M-mode. |
| Barcode sign | M-mode image showing uniform repetitive horizontal lines in cases of pneumothorax where lung sliding is absent. |
| Spine sign | The ability to see the thoracic vertebrae due to the presence of pleural effusion or hemothorax (normally not seen through the aerated lung). |

Table 1. Terminology of Lung Ultrasound
to look for conditions with increased interstitial fluid or thickness, including pulmonary oedema, COVID-19, acute respiratory distress syndrome (ARDS), transfusion-related acute lung injury, and pulmonary fibrosis. The purpose of obtaining a coronal image at the posterior axillary line is to visualize a pleural effusion. An anechoic collection cephalad to the diaphragm indicates pleural effusion. The small size of the spleen makes imaging more difficult on the left side.11

PATHOLOGY PROFILES

Pneumothorax

Static plural air generates total reflection waves, resulting in the absence of lung sliding (sliding of the visceral against the parietal pleura in B-mode, described as ‘marching ants’). It is absent in pneumothorax due to intrathoracic air between the pleural layers (Figure 2). In M-mode, the barcode sign replaces the seashore sign (Figures 3 and 4). Lung sliding is also abolished in endobronchial intubation, pleuro-parenchymal adhesions, subpleural bullae, postpneumonectomy, and after pleurodesis. Lung sliding is therefore sensitive but not specific to pneumothorax. The lung point (a finding at the location where the pneumothorax ends and sliding is resumed) is the most specific (100% specificity) ultrasound finding of pneumothorax (Figure 5). Hence, this should be routinely sought in the absence of sliding to estimate the size of the pneumothorax.16

Figure 1. The 6 scanning zones of the lung (bilateral anterior, posterior, and lateral), and 3 intercostal spaces are examined in each zone.

Figure 2. The upper hyperechoic is the pleural line where lung sliding occurs, whereas the lower horizontal hyperechoic line represents an A-line. Image supplied by Hannah Kopinski (MS4) and Dr Lindsay Davis of NYU Emergency Medicine and Matthew Riscinti, Kings County Emergency Medicine.
Figure 3. M-mode image showing a barcode sign due to pneumothorax. Case courtesy of Maulik S. Patel, Radiopaedia.org, rID: 61141.

Figure 4. M-mode image of a normal lung showing a seashore sign. Case courtesy of Maulik S. Patel, Radiopaedia.org, rID: 61141.
Pleural Effusion

A simple effusion appears as an anechoic space between the pleural layers (Figure 6). Ultrasound can detect as little as 5 to 20 mL of pleural fluid with a sensitivity of 89% to 100% and a specificity of 96% to 100% while in a chest x-ray, this may be evident only if the volume reaches 175 to 525 mL. A large effusion can also show the ‘lung monster sign’ (Figure 7), or the ‘spine sign’ can also be seen (Figure 8).6,11

Pneumonia

Pneumonia increases fluid content and reduces aeration in the lung parenchyma, reducing the acoustic discrepancies between the thoracic wall and lung parenchyma. In lung consolidation, the resultant hepatisation produces heterogeneous hyperechoic regions with irregular, variable-sized and -shaped borders (Figure 9).

Sonographic air bronchograms are caused by extreme perturbation of the air-fluid relationship in the lung parenchyma. The fluid-filled alveoli act as an excellent acoustic medium and allow visualization of the lung parenchyma. The bronchial tree is represented by branching tubular structures, which when patent, appear to contain punctiform to linear foci. These structures may remain fixed in position
(static) throughout the respiratory cycle or be observed to propagate centrifugally with respiration (dynamic). Static air bronchograms indicate isolated, trapped air, diagnostic of resorptive atelectasis. Dynamic air bronchograms represent fluid mixed with air inside larger bronchi. They indicate nonretracible consolidation and have a specificity of 94% and a positive predictive value of 97% for consolidation secondary to pneumonia. Using colour Doppler ultrasonography, the branching pattern of vascular flow within the consolidation can be observed (Figure 10).6

Figure 7. A large septal pleural effusion, showing the irregular and thickened pleura adjacent to the diaphragm. Image supplied by Victor Speidel, Langenthal Regional Hospital, Switzerland.

Figure 8. A right longitudinal subcostal scan, showing a right-sided pleural effusion and a positive spine sign. Case courtesy of David Carroll, Radiopaedia.org, rID: 65725.
Figure 9. The left lower lobe, showing a consolidation with a hepatization echogenic pattern. These abnormal findings are suggestive of pneumonia. Image supplied by Johannes Achenbach.

Figure 10. Air bronchogram within a consolidated lung tissue presenting as echogenic branching structures. Case courtesy of G. Balachandran, Radiopaedia.org, rID: 12505.
Acute Alveolar-Interstitial Syndrome

Fluid leaks into the pulmonary interstitium and alveoli when the lung’s water level is high and the alveolar air content is low as a result of the high water content. This is seen sonologically as B lines, which are 3 or more hydroaeric comet-tail artefacts arising from the pleural line to reach the far field. It may be normal in dependent areas.6

Pulmonary Oedema

Multiple B-lines may precede radiographic changes. These are seen on each image in different zones bilaterally. Three B-lines with a convex probe or 6 B-lines with a linear probe is pathognomonic of pulmonary oedema. The degree of pulmonary oedema will correlate with the number of B-lines. A reduction or disappearance of the B-lines ultrasonographically can be correlated with symptomatic improvement and reduction or clearing of chest x-ray changes (Figure 11).6

Acute Respiratory Distress Syndrome

In ARDS, lung ultrasound will demonstrate multiple B-lines with an irregular pattern, and small posterior and basal consolidations, along with an air bronchogram.6

Diaphragm Dysfunction

The diaphragmatic function assessment is attained by measuring excursions in the subxiphoid view using a curvilinear transducer at the M-mode during deep inspiration. Normal excursion values among men and women during quiet and deep breathing, as well as in the sniffing test, are illustrated in Table 2 (Figures 12 and 13). In partial phrenic palsy, the sniff test shows partial hemidiaphragmatic paresis with a 25% to 75% reduction in caudal movement of the diaphragm (towards the transducer). In complete phrenic palsy, a paradoxical cephalad movement or a 75% or greater reduction in movement is seen. The second method is to

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiet breathing</td>
<td>1.8 ± 0.3 cm</td>
<td>1.6 ± 0.3 cm</td>
</tr>
<tr>
<td>Deep breathing</td>
<td>7.0 ± 0.6 cm</td>
<td>5.7 ± 1.0 cm</td>
</tr>
<tr>
<td>Sniffing</td>
<td>2.9 ± 0.6 cm</td>
<td>2.6 ± 0.5 cm</td>
</tr>
</tbody>
</table>

Table 2. Different Normal Values for Diaphragmatic Excursion
measure changes in the diaphragmatic thickness during inspiration (Figure 14). This is obtained by placing the linear probe in the ninth intercostal space at the anterior axillary line. A thickness of less than 0.2 cm at the end of expiration defines diaphragm atrophy. The formula used to measure the change of thickness (TFdi) at M-mode is (thickness at end-inspiration minus thickness at end-expiration)/thickness at end-expiration. A thickening of less than 20% is consistent with

![Figure 12](image1.png)

**Figure 12.** The diaphragmatic excursion in B-mode resulting in a caudal movement of the diaphragm (towards the transducer) during inspiration (right image) compared to the expiratory phase (left image).

![Figure 13](image2.png)

**Figure 13.** Quantifying the level of the diaphragmatic excursion using the M-mode during deep inspiration in a healthy female volunteer. A dotted line between the point of the end expiratory phase to the point of the maximum inspiration gave a normal value of 5.42 cm.
paralysis. A third method is to monitor the descent of the pleural line with inspiration ‘diaphragmatic displacement’ using a linear probe in the coronal plane at the midaxillary line to obtain a view between the seventh and eighth ribs on the right side or the eighth and ninth ribs on the left side.4

**Parasternal Intercostal Muscle Assessment**

A linear probe is placed 3 to 5 cm lateral to the sternum, in the sagittal plane between the second and third ribs. Starting in B-mode, the muscle is seen as a 3-layered biconcave structure above the pleural line (Figure 15). Thickness is measured between the hyperecho
genic inner and outermost layers midpoint between the ribs. Using the M-mode, the external intercostal muscle thickening during inspiration is seen. TFic can be calculated by this calculation: (TH end-inspiration – TH end-expiration)/TH end-expiration) × 100, where TH = thickness. An excessive inspiratory support causes atrophy of the breathing muscles. TFic more than 8% is seen in patients with diaphragmatic dysfunction, and a value exceeding 10% can predict weaning failure. Once we initiate pressure support or spontaneous breathing trial and patients fail weaning within 24 hours, TFdi and TFic should be measured. Values of TFdi greater than 20% and TFic less than 10% predict weaning success.9

**Subcutaneous Emphysema**

Subcutaneous emphysema is the accumulation of air in soft tissues, both subcutaneous and intramuscular. Air leaks can come from nontraumatic causes or traumatic or iatrogenic injuries, such as rib fractures, airway or esophageal

---

**Figure 14.** Upper image illustrates how to get a diaphragmatic ultrasound image to measure thickness. A linear probe is placed in the ninth intercostal space at the anterior axillary line. Lower image identifies the 3 layers of the diaphragm at B-mode, and measures thickness during inspiration as an indirect measurement for hemi-diaphragmatic paresis.
trauma, gas-forming infections, or chest or endotracheal tube insertion. It can be diagnosed by the presence of soft-tissue oedema, crepitus, and air in the thoracic wall at radiography. Ultrasonography shows subcutaneous emphysema causing several vertical hyperechoic lines (E-lines) arising from the thoracic wall to the pleural line (Figure 16). The E-lines at the screen margin eliminate the pleural line. Sometimes, the anterior cortex of the ribs becomes invisible, causing the typical bat sign to be lost. It should be noticed that E-lines differ from B-lines, which originate from the pleural line. As traumatic subcutaneous emphysema is linked to pneumothorax, it should be looked for in other regions where the pleural line is visible.6

THE BLUE PROTOCOL

This tool usually takes 3 minutes to diagnose the cause of acute respiratory failure with 90.5% accuracy. To find the upper and lower BLUE points, place 4 fingers (except the thumb) of the left hand below the clavicle on the right side of the patient with the fingertips on the sternum. The upper point is at the base of the second and third fingers. The lower point is in the centre of the palm when the right hand is placed below the left with the forefingers touching. Switch sides and repeat. We proceed to scan the base of the lungs only if the scan up to this point is nondiagnostic (Figure 17). To locate this point at the thoracic-abdominal border, move from the lower BLUE point around the chest wall to the posterior

---

Figure 15. Intercostal muscle ultrasound. (a) The probe is placed at the parasternal space. (b) A B-mode image showing the intercostal muscle (ICM). Adapted from Formenti, Paolo, et al. “Ultrasonographic assessment of parasternal intercostal muscles during mechanical ventilation.” *Annals of Intensive Care* 10.1 (2020):1-9. [http://creativecommons.org/licenses/by/4.0/](http://creativecommons.org/licenses/by/4.0/).
The BLUE protocol employs signs and correlates them with a location, resulting in 7 profiles (Table 3); each is associated with a pathology (Figure 18).\(^7\)

**THE BLUE-PLUS PROTOCOL**

There is a significant incidence of lung consolidation and atelectasis during mechanical ventilation in critically ill patients. Due to the BLUE protocol's relatively low sensitivity in identifying pulmonary consolidation, Wang et al\(^{12}\) developed the BLUE-plus protocol. Patients are first made to lie supine so that the BLUE protocol can be used to measure the bilateral upper and lower blue points, the posterior and/or lateral alveolar and/or pleural syndrome points, and the diaphragmatic points. The posterior BLUE points are then measured with the patients in their lateral decubitus position. The midpoint between the vertebral line and the scapular line, just below the scapula, is identified as the posterior BLUE point. The BLUE-plus protocol was found to have higher sensitivity, specificity, and diagnostic accuracy (95.71%, 87.50%, and 94.87%, respectively) to detect lung consolidation and atelectasis, especially for the lesions located in the base of the lung, when compared to the BLUE protocol, bedside chest x-ray, and lung computed tomography scan.\(^{12}\)

**Figure 17.** Left: The upper and lower anterior BLUE points. The diaphragm is located at the bottom of the lower hand. Right: We proceed to scan the base of the lungs only if the scan up to this point is nondiagnostic. Adapted from Lichtenstein, Daniel A. *Lung ultrasound in the critically ill.* Annals of intensive care 4.1 (2014):1-12. https://creativecommons.org/licenses/by/2.0.
ROLES IN MONITORING AND THERAPEUTIC INTERVENTIONS

Monitoring and Drainage of Pleural Effusion

Lung ultrasonography can assist in measuring the volume of pleural effusion and, to some extent, in determining its nature. In the supine position, an interpleural distance at the lung base above 50 mm, as measured between the lung and the posterior chest wall, strongly suggests the presence of a pleural effusion equal to or greater than 500 mL. The accuracy is insufficient for quantifying small (≤ 500 mL) and high (≥ 1000 mL) volumes. The calculation involves the multiplication of the pleural effusion's height by its transversal area. In terms of the nature of pleural effusion, transudates exhibit anechoic characteristics but exudates display echogenicity and loculation. Lung ultrasound enables the safe thoracic drainage of small and/or loculated pleural effusions, can detect pleural adherences, may reduce the risk of intrafissural or intraparenchymal placement of thoracic tubes, and reduces the risk of vascular injuries when a colour Doppler is used.\(^\text{13}\)

---

**Table 3. The 7 Profiles of the BLUE Protocol**

<table>
<thead>
<tr>
<th>Profile</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-profile</td>
<td>Presence of lung sliding and A-lines</td>
</tr>
<tr>
<td>A'-profile</td>
<td>An A-profile in the absence of lung sliding</td>
</tr>
<tr>
<td>B-profile</td>
<td>Presence of lung sliding and B-lines</td>
</tr>
<tr>
<td>B'-profile</td>
<td>A B-profile in the absence of lung sliding</td>
</tr>
<tr>
<td>C-profile</td>
<td>Presence of a C-line or thickening and irregularity of the pleural line, regardless of size and number and regardless of lung sliding</td>
</tr>
<tr>
<td>A/B-profile</td>
<td>A combination of an A-profile at one lung and a B-profile at the other lung regardless of sliding</td>
</tr>
<tr>
<td>PLAPS-profile</td>
<td>Posterior and/or lateral alveolar and/or pleural syndrome (the presence of consolidation or pleural effusion in the posterolateral aspect of the lung)</td>
</tr>
</tbody>
</table>

---

**Figure 18.** The BLUE protocol decision tree. Adapted from Lichtenstein, Daniel A. “Lung ultrasound in the critically ill.” *Annals of intensive care* 4.1 (2014): 1-12. https://creativecommons.org/licenses/by/2.0.

---

Subscribe to ATOTW tutorials by visiting [https://resources.wfsahq.org/anaesthesia-tutorial-of-the-week/](https://resources.wfsahq.org/anaesthesia-tutorial-of-the-week/)
Guiding Diuretic Therapy in Cases With Pulmonary Oedema

The application of lung ultrasound in identifying pulmonary oedema during fluid resuscitation in circulatory shock, known as the ‘fluid administration limited by lung sonography’ (FALLS) protocol, has been well documented. However, the introduction of the reverse-FALLS protocol integrates aspects of lung and inferior vena cava ultrasound to evaluate the extravascular and intravascular compartments, respectively, in order to guide fluid removal. The quantification of pulmonary oedema is achieved by counting the number of B-lines observed in each scan plane. This will help determine whether or not aggressive diuretic therapy is indicated (Table 4), while measuring the minimum and maximum anteroposterior inferior vena cava diameter using the M-mode throughout a full respiratory cycle will help answer whether aggressive diuretic treatment can be tolerated.14

<table>
<thead>
<tr>
<th>Finding</th>
<th>Diagnosis</th>
<th>Action Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-lines with/without 1 B-line</td>
<td>Normal finding</td>
<td>None</td>
</tr>
<tr>
<td>2-3 B-lines</td>
<td>Mild pulmonary edema</td>
<td>Mild diuresis</td>
</tr>
<tr>
<td>4 B-lines or more</td>
<td>Moderate/severe pulmonary edema</td>
<td>Aggressive diuresis</td>
</tr>
<tr>
<td>Whiteout</td>
<td>Very severe pulmonary edema</td>
<td>Very aggressive diuresis</td>
</tr>
</tbody>
</table>

Table 4. The Classification of Pulmonary Edema and the Establishment of Targeted Volume Management

SUMMARY

Lung POCUS is an easy and quick technique that aims to diagnose causes of respiratory failure. The BLUE protocol examines standardized points on each hemithorax to check for certain findings, then, a pathophysiologic profile is created. However, it is more important to examine the whole chest than to follow a certain protocol. Regarding the diaphragmatic assessment for a possible phrenic nerve palsy associated with regional anaesthesia, it is important to take baseline measures in order to compare them with the findings after the block. It is also important to know that when we measure TFDi and TFic as predictive tools for weaning, we should incorporate these measurements with other parameters predictive of weaning failure.

REFERENCES
