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Ultrasound

Point-of-care lung ultrasound

Philips tutorial

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Contents

Point-of-care lung ultrasound

1 Introduction

Emergency medicine and critical care clinicians often evaluate critically ill patients who are experiencing severe dyspnea. Prompt identification of the etiology of a patient's dyspnea is essential to ensure appropriate therapeutic intervention.

Point-of-care sonography has emerged as an invaluable tool in the assessment of patients with both traumatic and non-traumatic dyspnea. Many of the most commonly encountered pathologic states leading to severe shortness of breath (pulmonary edema, pleural effusion, pneumothorax, pneumonia) have distinct sonographic appearances, enabling rapid and accurate bedside identification.

2 Clinical cases

Clinical case 1

A 22-year-old male with unknown past medical history is brought to the emergency department (ED) by ambulance following a motor vehicle collision during which he was ejected from the front passenger seat. Paramedics found him unresponsive with evidence of head, chest, and abdominal trauma. He was intubated in the field due to a Glasgow Coma Scale (GCS) of 5. His breath sounds are slightly diminished over the right chest, though supine chest radiography demonstrates adequate endotracheal tube position and no pneumothorax or hemothorax. The patient requires air transport to the nearest trauma facility. You are concerned he may have a radiologically occult pneumothorax that could worsen due to altitude changes and positive-pressure ventilation during the transport. You decide to use lung sonography to evaluate for pneumothorax.

Clinical case 2

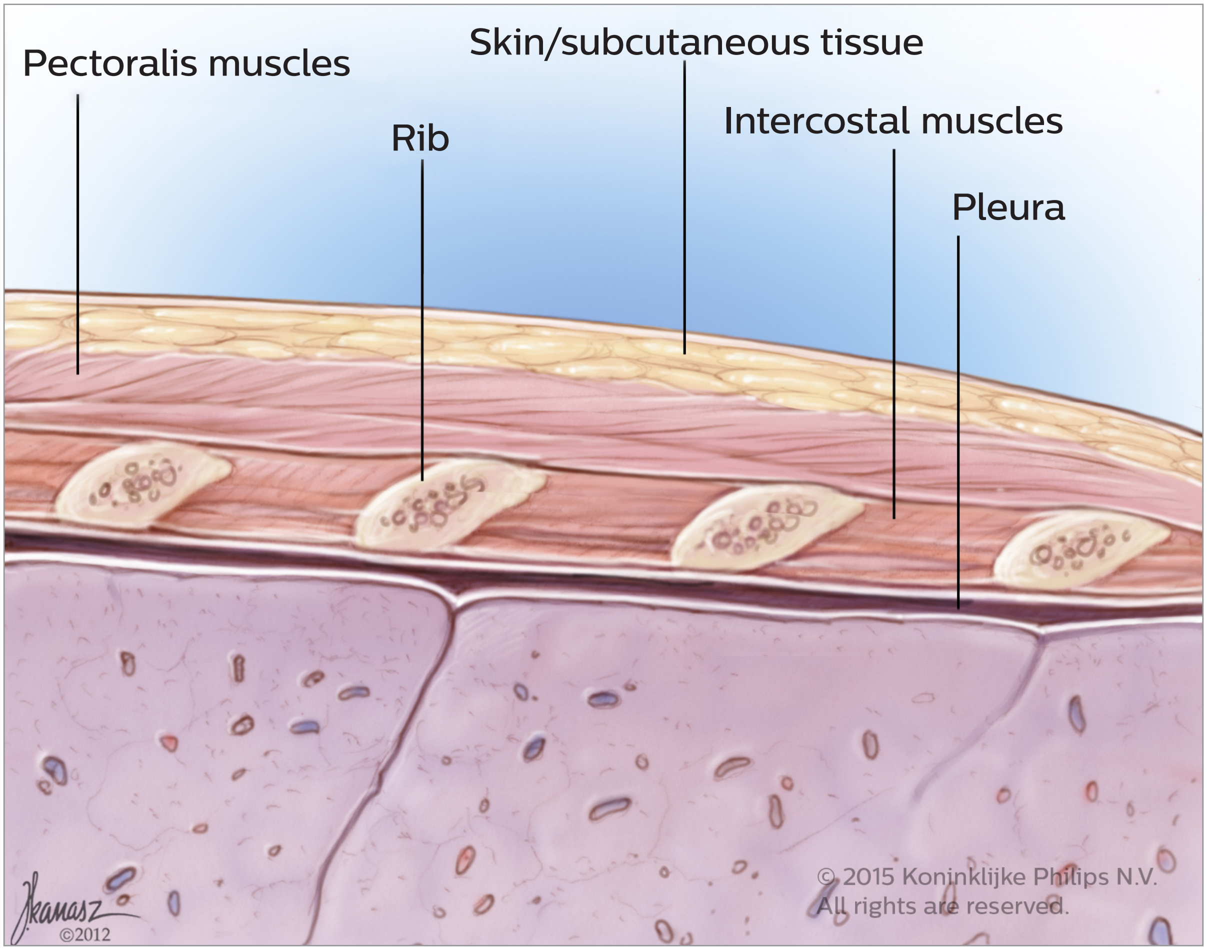
A 72-year-old female with a past medical history of congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), and end-stage renal disease requiring hemodialysis three times per week is admitted to the medical/surgical unit of your hospital for treatment of a suspected catheter-associated bloodstream infection. She is urgently transferred to the intensive care unit (ICU) after an unprovoked abrupt onset of severe dyspnea. Her vital signs are blood pressure 190/110 mm Hg, pulse 115/minute, respirations 32/minute, and oxygen saturation 82% while breathing room air. Examination of the lungs demonstrates bilateral expiratory wheezing. Her oxygenation moderately improves with supplemental oxygen, but her work of breathing is considerable. You decide to use lung sonography to better characterize the etiology of this complicated patient's acute decompensation.

3 Fundamentals

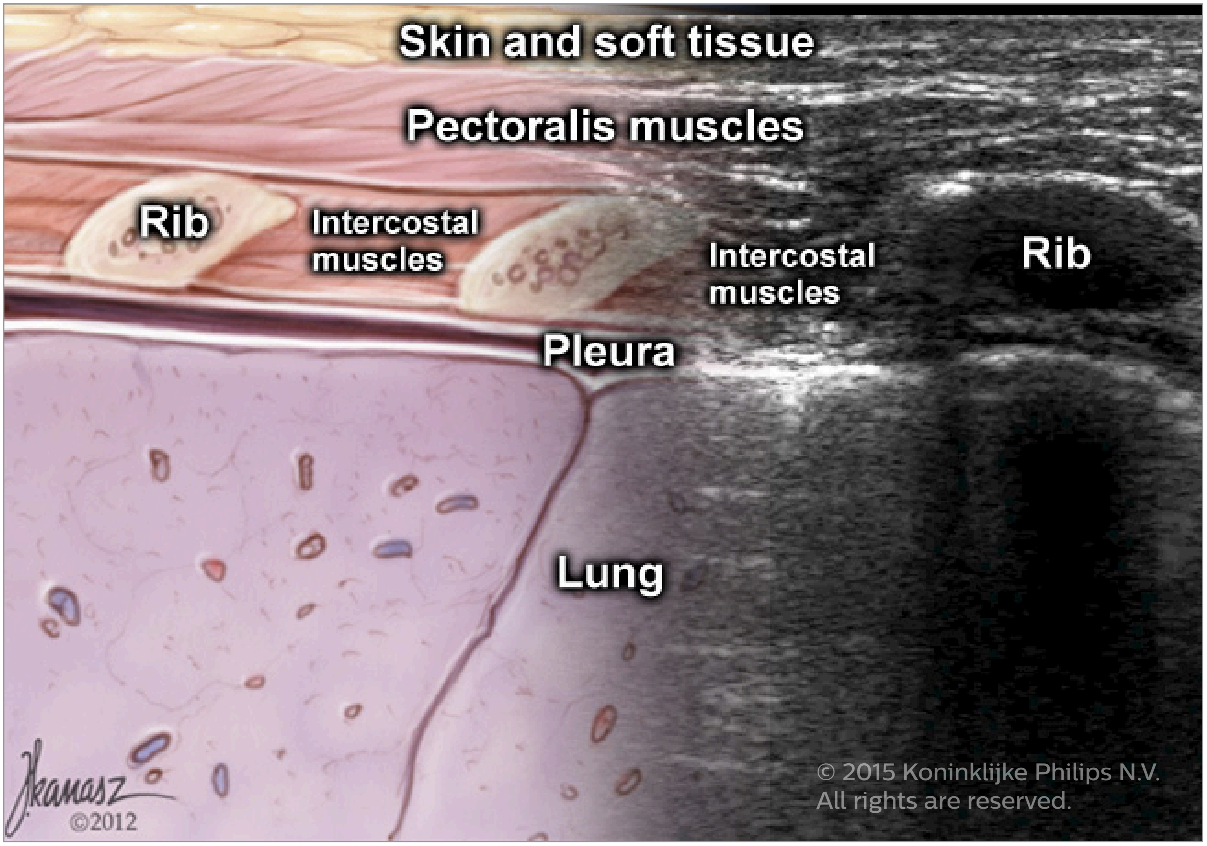
Fundamentals of the lung ultrasound exam

Lung sonography is made feasible by the interpretation of ultrasound artifacts that arise from the chest wall and pleural surface. A brief review of the relevant normal anatomy will provide the framework upon which to build an understanding of the various patterns one may encounter when performing lung sonography.

- Superficial structures (skin, subcutaneous fat, pectoral and intercostal muscles) conduct sound waves well and do not generate artifacts **[Figure 1** and **Figure 2]**.
- The cortex of each rib reflects ultrasound waves and blocks their transmission, resulting in a hyperechoic (bright) appearance to the near-field (superficial) cortex, with distal shadows extending to the edge of the ultrasound screen **[Figure 2]**.
- The parietal and visceral pleurae appear as a single hyperechoic "pleural line" just deep to the internal intercostal muscles. This line will "slide" or oscillate from side to side on the ultrasound screen, representing movement of the pleural surfaces as the lung expands and contracts during the respiratory cycle **[Video 1]**.
- Normal lung parenchyma is not visualized because it is composed primarily of air, which scatters and impedes the transmission of sound waves. The dramatic difference in the acoustic characteristics of soft tissues and the lung makes the lung surface a particularly strong reflector of ultrasound waves, and is responsible for creating a number of reverberation artifacts that lend valuable information about the lung's current pathophysiology.



[Figure 1] **Anatomical drawing of superficial chest wall structures and lung.**



[Figure 2] Anatomical drawing fused with a corresponding ultrasound image demonstrating the superficial chest wall structures.

[Video 1]

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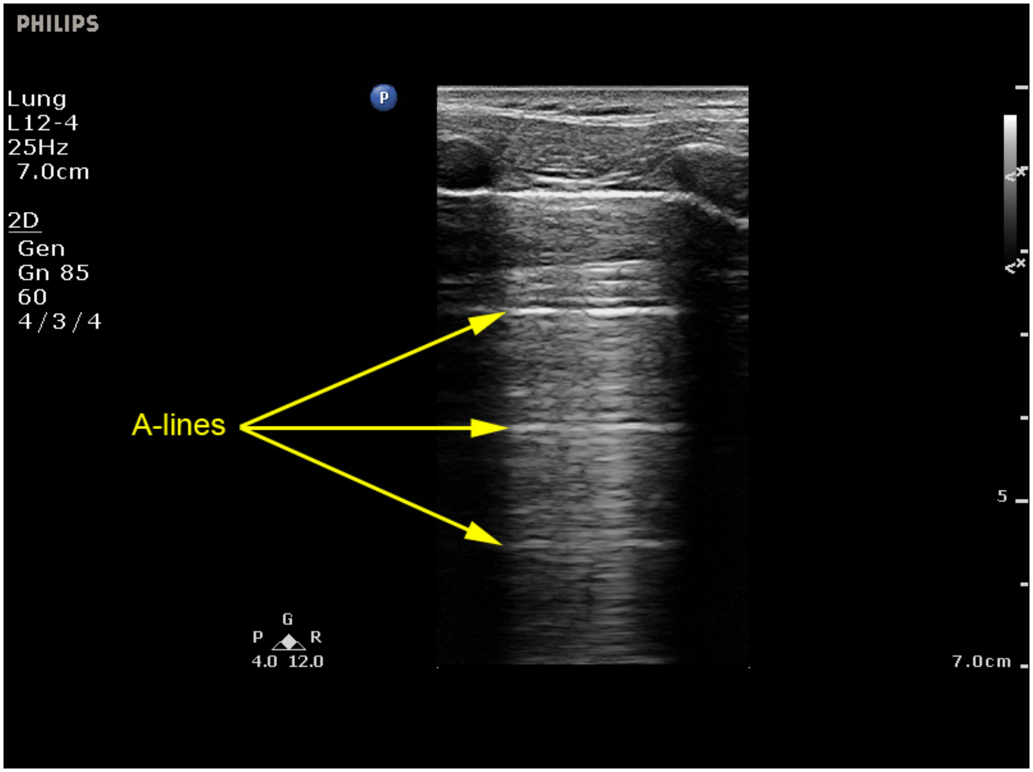
Video demonstrating normal lung sliding. A high-frequency linear transducer was used.

Nomenclature and definition of terms

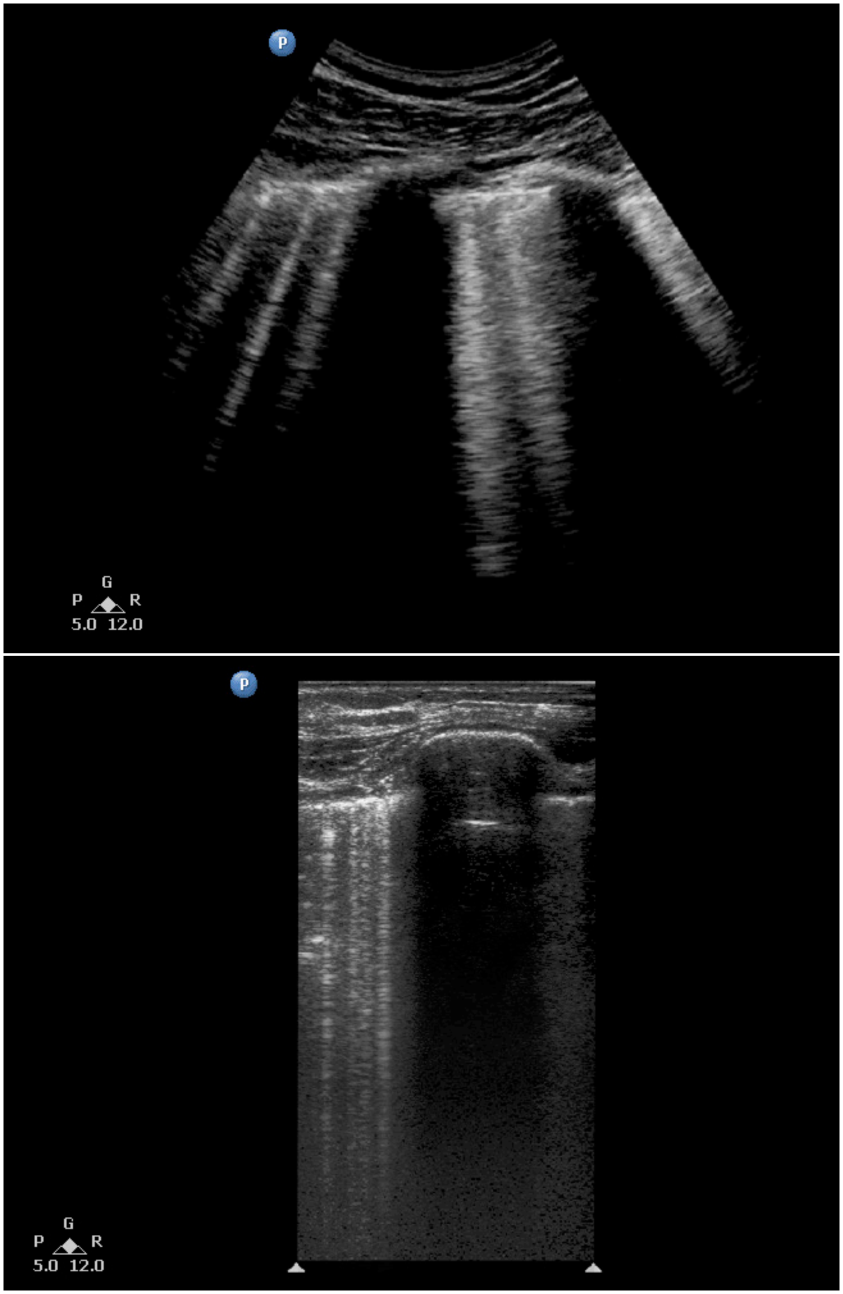
There are two predominant artifact patterns that a clinician may observe and these have been termed "A-lines" and "B-lines." Recognition of the predominant artifact gives valuable information as to the underlying physiologic or pathologic state of the patient's lung.

- A-lines occur when sound waves pass through the superficial soft tissues and cross the pleural line encountering air (as in a pneumothorax) or tissue that is almost completely composed of air (as in normal lung, or pathologic states that do typically affect the lung parenchyma such as asthma or chronic obstructive pulmonary disease). These waves are reflected strongly by this tissue/air interface and reverberate, or "bounce" back and forth, between the transducer and lung surface. Each volley of sound waves returns to the transducer after a longer period of time, and is thus represented as a bright horizontal line deeper and deeper on the display screen. As this is a classic reverberation artifact, the distance from the skin to the pleural line equals the distance from the pleural line to the first A-line, the first A-line to the second A-line, and so forth **[Figure 3]**.



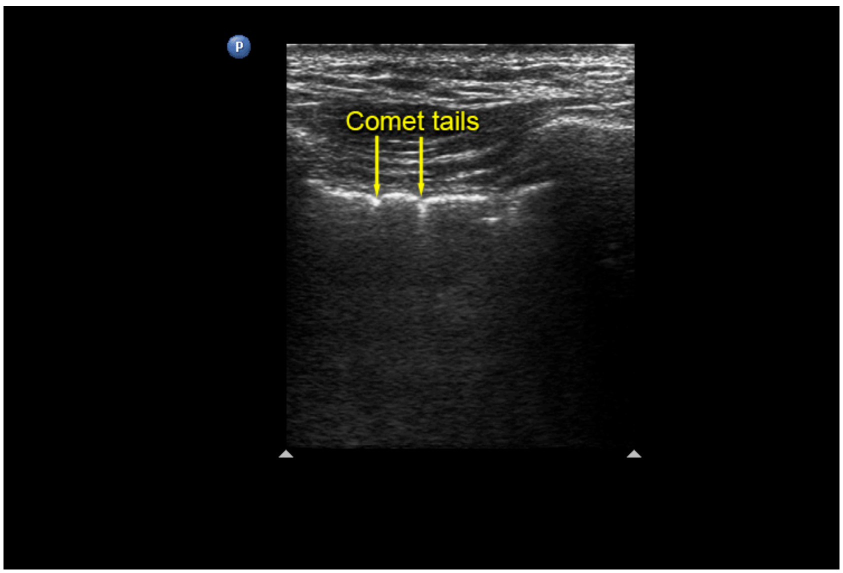
[Figure 3] Ultrasound image demonstrating A-lines. The A-lines are the bright horizontal lines deep to the pleural line. A-lines are a classic reverberation artifact; the distance from the skin to the pleural line equals the distance from the pleural line to the first A-line, the first A-line to the second A-line, and so forth.

- B-lines occur when sound waves pass through the superficial soft tissues and cross the pleural line encountering a mixture of air and water (as in pulmonary edema, pneumonia, lung contusion, ARDS, etc.). In this instance, the mixed density of the lung parenchyma causes reverberation artifact within the lung, giving rise to discrete laser-like vertical hyperechoic reverberation artifacts that arise from the pleural line, extend to the bottom of the screen without fading, and move synchronously with lung sliding **[Figure 4a]**. These artifacts were previously described as "comet tails." B-lines are not to be confused with normal comet-tail artifacts that originate at the pleura but fade (often within a centimeter) before reaching the edge of the screen **[Figure 4b** and **4c]**.
- Historically, clinicians have used a number of terms to describe B-lines, including "comet-tails," "lung comets," and "lung rockets," among others. We recommend the use of the term "B-lines" for clarity's sake, as other comet-tail artifacts may be encountered during lung sonography (e.g., from subcutaneous emphysema) and have different clinical implications. This conforms to expert recommendation from a recent international consensus conference on lung sonography.[1]



[Figure 4a]
Two ultrasound images demonstrating B-lines. B-lines are discrete laser-like vertical hyperechoic reverberation artifacts that arise from the pleural line, extend to the bottom of the screen without fading, and move synchronously with lung sliding. The top image was obtained using a low-frequency curved transducer, the bottom image was obtained using a high-frequency linear transducer.

[Figure 4b]
Ultrasound image demonstrating a B-line in normal patient.



[Figure 4c]
Ultrasound image demonstrating comet-tail artifacts. Note the artifact originates at the pleura but fades.

The air/fluid ratio determines the appearance of the lung and pleura	
Normal lung	Almost entirely air
Pneumothorax	Entirely air
Interstitial syndrome	Mainly air, minimal fluid
Pleural effusion	Entirely fluid
Lung consolidations	More fluid than air (can appear hypoechoic or tissue-like)

4 Transducer selection

There has been a great deal of controversy regarding the optimal choice of transducer for lung sonography. Many of the pioneering studies were performed with a low-frequency micro-convex transducer that is no longer available on the majority of current-generation ultrasound systems. In recent years, however, prospective studies using high-frequency linear, low-frequency curvilinear and low-frequency sector transducers have demonstrated that the performance and interpretation of lung sonography is not transducer-specific.

It is our practice to begin our lung studies with a curvilinear low-frequency transducer as we feel this allows for the clearest determination of an A-line or B-line pattern, and is almost always sufficient to assess the presence or absence of lung sliding. Given its higher spatial resolution of near-field structures, however, the high-frequency linear transducer may be useful for assessing lung sliding if uncertainty remains after the initial exam.

Keep in mind that lower frequency transducers will provide more depth penetration but will sacrifice some image quality; high-frequency transducers will provide better resolution but will sacrifice depth penetration.

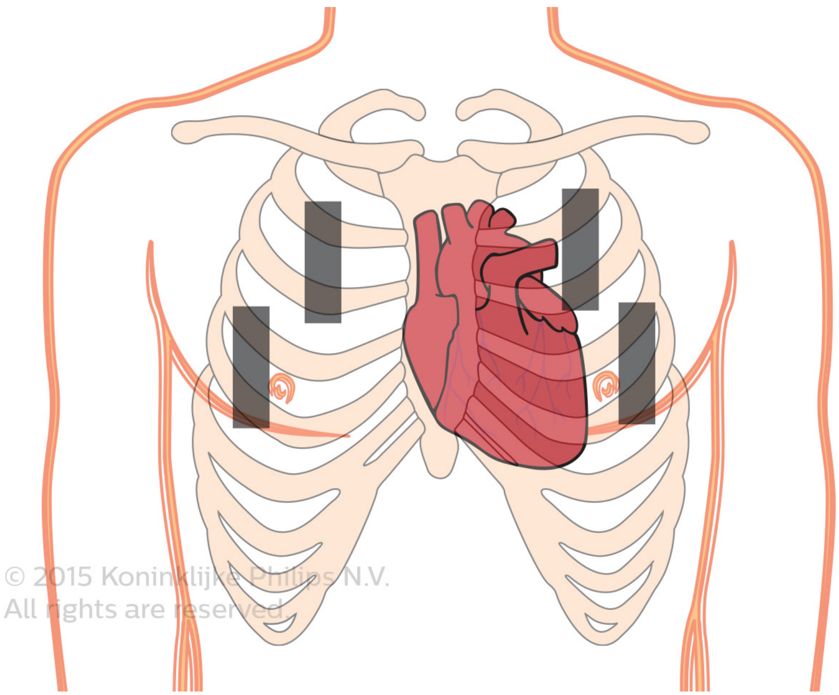
5 Image optimization

Most currently available ultrasound systems utilize algorithms to reduce artifacts, resulting in a clearer tissue image. Lung sonography is unique in that recognition of artifacts is the cornerstone of the exam. As a result, we recommend that features that decrease artifacts such as compound imaging, speckle reduction, etc. are de-activated for the lung exam.

Some newer ultrasound systems have “lung” exam types or presets that have been optimized for lung imaging. These exam types deactivate the software-processing features that decrease artifacts. Using a “lung” exam type or preset also optimizes other ultrasound parameters such as depth, focal zone and gain settings.

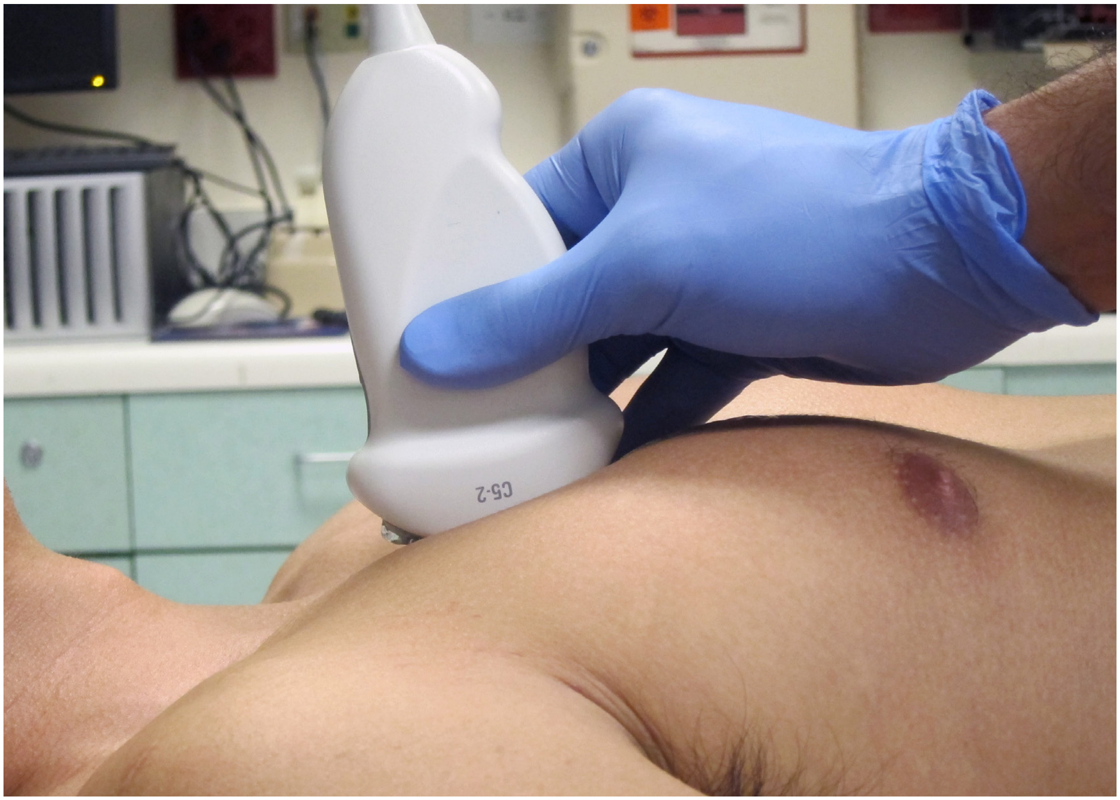
6 The lung exam

The exam can be performed in a systematic manner that investigates the entire anterolateral and posterior lung surfaces bilaterally, or can be performed with a patient-focused abbreviated approach. It is our practice to investigate specific areas of the lung surface depending on the patient's clinical presentation and the most likely etiologies of their dyspnea. Most evaluations include, at a minimum, the anterior and anterolateral portions of the chest wall.



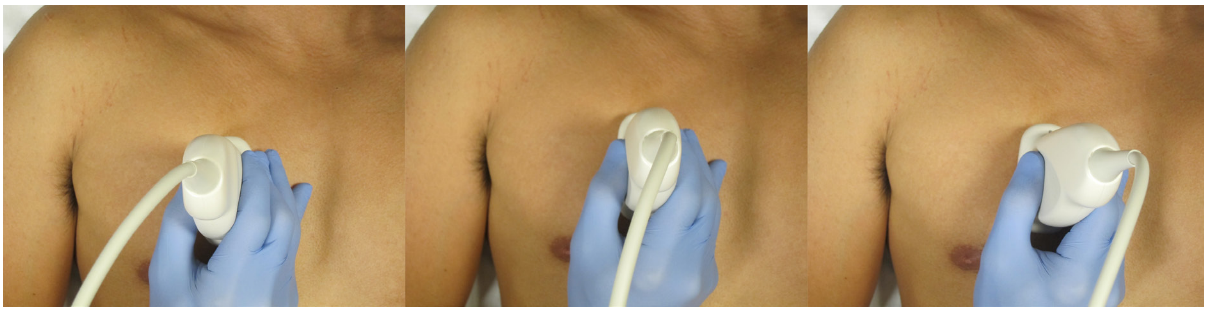
[Figure 5] **Transducer placement for abbreviated lung exam. Note the upper and lower anterior/anterolateral locations on the chest wall: these approximate the upper and lower anterior "blue points" as described by Lichtenstein, et al.**[16]

In most cases, the exam begins in the mid-clavicular line at the 2nd or 3rd intercostal space, with the transducer orientated sagitally and the directional indicator (orientation marker) toward the patient's head **[Figure 6]**.



[Figure 6] **Photo demonstrating the position of the transducer on the patient's chest at the beginning of the lung exam. A low-frequency curvilinear transducer is used in this example. The transducer's directional indicator is oriented toward the patient's head.**

The transducer is adjusted until a view that includes two adjacent ribs, the underlying pleural line, and the predominant artifact pattern (either A- or B-lines) is obtained. This usually requires slowly angling the transducer until the desired view is acquired **[Figure 7a** and **7b]**.



[Figure 7a] **"Bird's eye" view demonstrating the technique of angling of the transducer to obtain the desired ultrasound view.**

Unlike most diagnostic ultrasound exams, once this view is obtained the clinician pauses, holds the transducer still, and simply observes for lung sliding to determine the artifact pattern (A or B) before proceeding to another interspace.

Once the desired view is acquired, fanning or angling of the transducer to "sweep" through the area (while of paramount importance in abdominal imaging) is counter-productive as artifacts are clearly visualized only when sound waves encounter the pleural-lung interface at a perpendicular angle.

[Figure 7b] **Technique for angling the transducer to obtain the desired ultrasound view. Note the transducer's directional indicator oriented toward the patient's head (which is at the bottom of the photos).**

Of note, the operator should be mindful of the curvature of the chest wall, adjusting the transducer angle as the exam proceeds laterally to maintain a perpendicular orientation to the pleural surface **[Figure 8]**.

[Figure 8] **As the exam proceeds laterally, the transducer must be angled to maintain a perpendicular orientation to the pleural surface.**

7 Pneumothorax

Lung sonography is an invaluable tool for the assessment of pneumothorax, with accuracy approaching computed tomography and far exceeding plain radiography.

The patient is supine and the transducer is placed sagitally and anteriorly in the mid-clavicular line **[Figure 9]**. Since air should rise to the anterior chest wall in a supine patient, investigation of the parasternal and mid-clavicular regions throughout the anterior chest wall is sufficient to exclude a significant pneumothorax.

[Figure 9] **The patient is in a supine position with the transducer placed sagitally and anteriorly in the mid-clavicular line.**

If lung sliding is observed, there is no pneumothorax at the interspace at which the transducer is located. If lung sliding is abolished, there are several possibilities:

- **The patient is not ventilating.** This may be observed in cases of accidental esophageal intubation or intubation of a main-stem bronchus. Although sliding with respiration is not visualized, the pleural line can be seen to move slightly with each heartbeat as movement from the heart is transmitted to the pleural line. This has been termed the "lung pulse" and not only excludes pneumothorax but may be a valuable tool to adjust endotracheal tube tip location after accidental mainstem bronchial intubation **[Video 2]**.
- **The patient is ventilating but the lung is not sliding due to a dense lobar consolidation (e.g., pneumonia, lung contusion).** In these patients the underlying lung contains significant water, and as a result there will be a predominant B-line pattern. Since B-line patterns originate from the lung parenchyma, and the lung parenchyma cannot be visualized if there is air interposed between the pleura and the lung, the presence of B-lines also excludes the possibility of a pneumothorax at the interspace in question.

[Video 2]

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Ultrasound video demonstrating "lung pulse." Note the movement of the pleural line with each heartbeat, and the absence of organized lung sliding with respiration.

Key point

Many authorities teach that lung sliding and B-lines exclude the presence of a pneumothorax. In previously healthy acute trauma patients without pneumothorax, the clinician is most likely to encounter lung sliding without an underlying B-line pattern, and should remember that visualization of normal lung sliding is itself absolutely sufficient to exclude pneumothorax. It is our practice to search for B-lines during the traumatic pneumothorax exam only if lung sliding is not visualized.

- **The patient is ventilating but the lung sliding is difficult to observe due to pleural adhesions, bullae, or pleurodesis.** While these patients may have an associated B-line pattern, they may have an A-line pattern as well, which is why **the absence of lung sliding and B-lines is not sufficient to confirm (rule in) the presence of a pneumothorax.**

- **There is a pneumothorax present.** If the clinician encounters a patient in whom there is no lung sliding and the artifact pattern demonstrates A-lines **[Video 3]**, they should proceed to search for a "lung point."
  - To search for a "lung point" move the transducer laterally and/or caudally, observing for an interspace in which lung sliding is intermittently restored and abolished – representing the point on the chest wall where the pneumothorax ends and lung tissue is once again in contact with the pleura **[Video 4]**. Although a lung point is not always identified (i.e., large pneumothoraces where there is no lung tissue in contact with the pleura), **identification of a lung point is necessary to definitively confirm that a pneumothorax is present**. However, in cases of extreme emergency, absent unilateral lung sliding in the appropriate clinical setting may provide sufficient evidence to encourage appropriate therapeutic intervention.

Remember, however, that air that is not in contact with the chest wall (i.e., adjacent to the mediastinum) cannot be visualized with lung sonography and will not result in the abolition of lung sliding.

[Video 3]

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Video with two examples of patients with a pneumothorax. Note the absence of both lung sliding and B-lines. Also note the presence of A-lines.

[Video 4]

Click here to view this video in the online tutorial,
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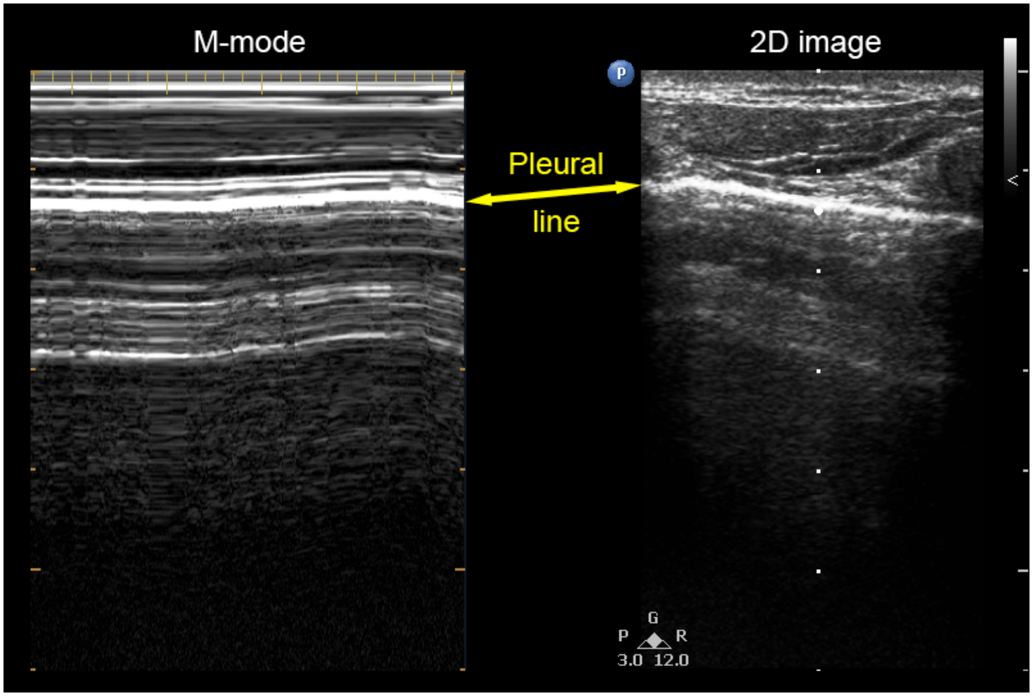
Video with two examples demonstrating a "lung point." Note the alternating absence and presence of lung sliding seen in the same interspace over the respiratory cycle. This corresponds to the anatomic border of the pneumothorax.

8 M-mode and color Doppler

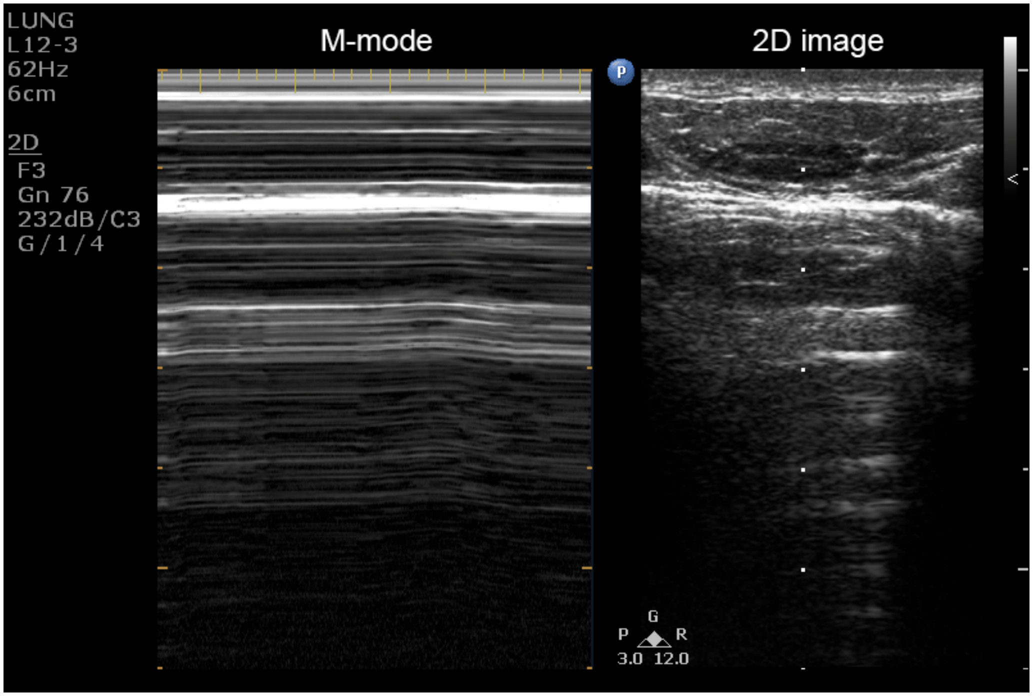
A discussion of the use of lung sonography for the assessment of pneumothorax is not complete without mentioning the use of M-mode and color Doppler. These alternative modes allow the clinician to document in still-image form the presence or absence of lung sliding as well as the presence of a "lung point." It is our practice to utilize M-mode for this purpose, as we feel that it is most easily learned and performed by novice ultrasound clinicians. Color Doppler, in contrast, can produce both false-negative and false-positive results if clinicians have not yet acquired a firm understanding of Doppler principles and machine settings.

When M-mode is applied to the lung exam, the system displays a representation of tissue motion over time. In the case of normal lung sliding, significant scatter results from lung sliding and, therefore, the area on the M-mode tracing deep to the pleural line takes on a granular or "sandy" appearance while the relatively immobile superficial tissues appear smooth and linear **[Figure 10]**. This has been termed the "Seashore Sign," as the superficial tissues resemble waves and the deeper tissues the sandy beach.



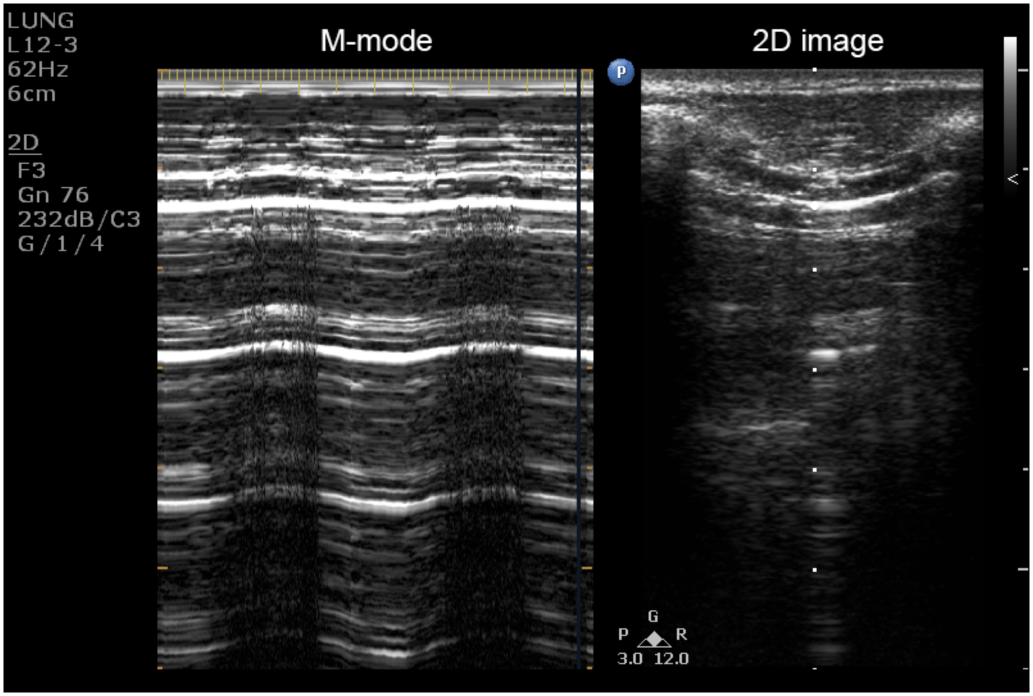
[Figure 10] Side by side M-mode and 2D of the chest wall in a patient without a pneumothorax. On the M-mode the lines deep to the pleural line appear granular or "sandy" while the relatively immobile superficial tissues appear smooth and linear, resulting in the "Seashore Sign."

When lung sliding has been abolished, the superficial and deep tissues both appear smooth and linear, resulting in the classic "Stratosphere Sign" **[Figure 11]**.

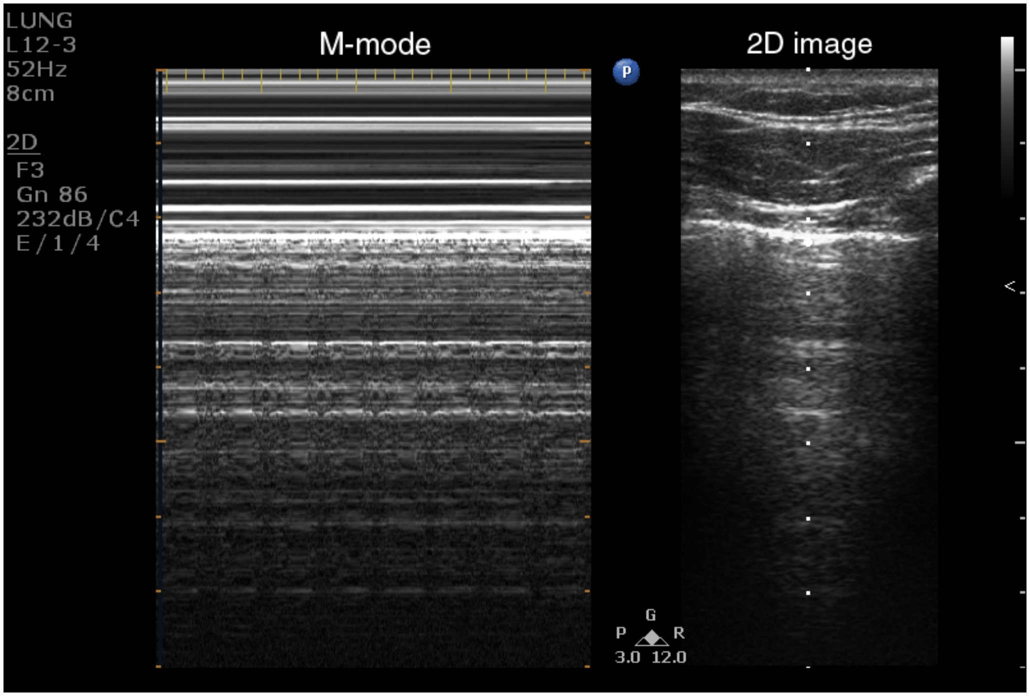


[Figure 11] **Side by side M-mode and 2D of the chest wall in a patient with a pneumothorax. Because lung sliding is absent, the superficial and deep tissues both appear smooth and linear, resulting in the classic "Stratosphere Sign" on the M-mode trace.**

When a lung point is encountered, a pattern that alternates between "Seashore" and "Stratosphere" is seen, as normal lung intermittently slides into the plane of the M-mode tracing **[Figure 12]**.



[Figure 12] **Side by side M-mode and 2D demonstrating a lung point. A pattern that alternates between "Seashore" and "Stratosphere" is seen, as normal lung intermittently slides into the plane of the M-mode tracing.**



[Figure 13] **Side by side M-mode and 2D tracing demonstrating a "lung pulse." On the M-mode, note the rapid, regular, intermittent movement at and below the pleural line, corresponding to the movement of the pleural line with each heartbeat.**

9 Interstitial syndromes

Diffuse interstitial syndromes

Performing point-of-care lung ultrasound in patients with acute respiratory distress can be challenging. The patient should be in a position of maximal comfort. Similar to the evaluation for a pneumothorax, a systematic evaluation of both lung fields is required and must, at a minimum, include the parasternal, mid-clavicular and anterior axillary regions. Care should be taken when evaluating the left lower anterolateral zone, as the presence of the heart can interfere with assessment of lung sliding and underlying artifact analysis.

Patients with decompensated congestive heart failure, pulmonary edema of any etiology, diffuse pneumonia/pneumonitis and pulmonary fibrosis demonstrate diffuse B-line patterns. While occasional B-lines may be encountered in normal subjects, greater than three B-lines in a longitudinal plane between two ribs (a single interspace) is considered a "positive" exam for a B-line pattern **[Video 5]**. Two or more positive regions bilaterally constitute a "positive" exam for interstitial syndrome.

A diffuse B-line pattern does not always enable the clinician to differentiate cardiogenic from non-cardiogenic pulmonary edema, or pulmonary edema from pneumonitis: this requires advanced lung sonography skill and experience, clinical correlation and, in our practice, additional information gained from focused cardiac sonography. Pulmonary fibrosis, however, is often identifiable due to the diffuse B-line pattern in conjunction with an irregular, scalloped pleural surface.

In summary, diffuse B-lines on lung ultrasound indicate that the interstitium is thickened (most often by fluid), but do not precisely indicate the underlying cause.

Focal interstitial syndromes

Focal multiple B-lines may be present posterolaterally in a normal lung and are often seen in the presence of pneumonia, atelectasis, lung contusion, pulmonary infarct, pleural disease, or malignancy.

[Video 5]

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Diffuse interstitial syndrome – video demonstrating two examples of diffuse B-lines.

10 Consolidations

Lung consolidations may be caused by a variety of disease processes including infection, malignancy, atelectasis, contusion or pulmonary embolism. Recognition of a subpleural hypoechoic region or a tissue-like texture indicates that a consolidation is present **[Video 6]**, and differentiation of these entities may be accomplished but requires significant experience and is beyond the scope of this tutorial.

[Video 6]

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Right lower lobe consolidation. Image obtained with a curvilinear transducer located in the right lower mid-axillary line. The liver is on the right side of the screen, and a tissue-like density (the consolidated right lower lobe) is seen on the left side of the screen. Intermittent movement of hyperechoic foci within the lung represents dynamic air bronchograms, consistent with pneumonia.

11 Pleural effusions and thoracentesis

Ultrasound is an outstanding modality for the visualization of pleural effusions and hemothorax. Effusions are best visualized in the dependent posterolateral regions between the chest wall and underlying lung tissue. They are typically anechoic collections, though they may at times be hypo- or iso-echoic to the underlying lung, particularly if they are exudative effusions.

Lung tissue may appear as a solid organ in cases of moderate or large pleural effusions due to atelectasis and consolidation of the lung **[Video 7]**. Ultrasound is an excellent modality to evaluate for loculations within pleural effusions, which will appear as hyperechoic septae **[Video 8]**.

Effusions may be tapped with ultrasound guidance, either with a dynamic technique (for smaller effusions) or a static technique, by marking an appropriate site on the patient's back or chest wall and proceeding without real-time ultrasound guidance.

[Video 7]

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Right pleural effusion. Image obtained with a phased-array transducer located in the right lower mid-axillary line. The liver and kidney are on the right side of the screen, and an anechoic fluid collection (the right pleural effusion) is seen on the left side of the screen. The right lung appears as a tissue-like structure to the far left of the screen due to atelectasis from the adjacent effusion.

[Video 8]

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Loculated right pleural effusion. Image obtained with a curvilinear transducer located in the right lower mid-axillary line. The right hemithorax is filled with a large effusion with internal hyperechoic septae.

12 Clinical case resolutions

Case 1 resolution

Ultrasound of the anterior chest demonstrated absent lung sliding and an A-line pattern **[Video 9]**. A lung point was identified in the right anterolateral chest wall, which prompted the clinician to obtain a computed tomography scan of the thorax. The CT scan confirmed the presence of a moderate right anterolateral pneumothorax. Given the planned aeromedical transport, a tube thoracostomy was performed with a rush of air encountered when entering the pleural space confirming the presence of a pneumothorax. The patient remained in critical condition and was transported uneventfully to the receiving facility.

[Video 9]

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Absent lung sliding as visualized with a high-frequency linear transducer in the anterior mid-clavicular line in a supine patient.

Case 2 resolution

Despite the presence of bilateral expiratory wheezes without rales, lung sonography demonstrated a diffuse B-line pattern throughout both anterolateral lung fields **[Video 10]**. A focused cardiac ultrasound exam demonstrated a dilated hypokinetic left ventricle without pericardial effusion or right ventricular strain pattern. In this context, her lung and cardiac findings strongly suggested acute decompensated heart failure, and non-invasive positive-pressure ventilation was initiated with a high-dose nitroglycerin infusion. Beta-agonists were withheld and the patient's condition markedly improved over the next hour in the ICU.

[Video 10]

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Multiple B-lines visualized in the anterior mid-clavicular line using a low-frequency curvilinear transducer.

13 Summary

Summary and key points

- The interface of the chest wall tissues and the air-filled lung creates a strong reflector of ultrasound waves. This generates a number of reverberation artifacts which lend valuable information about the lung's current pathophysiology.
- Normal lung is air-filled and scatters ultrasound waves.
- Fluid appears anechoic on ultrasound.
- The majority of acute lung disorders involve the lung surface so lung patterns that arise from the pleural line often provide valuable clinical information.
- A-lines are bright horizontal lines located below the pleural line at regular intervals. A-lines are reverberation artifacts.
- B-lines are discrete laser-like vertical hyperechoic artifacts that arise from the pleural line, extend to the bottom of the screen without fading, and move synchronously with lung sliding, abolishing A-lines.
- Three or fewer B-lines in a single interspace can be normal.

- A diffuse B-line pattern may represent cardiogenic or non-cardiogenic pulmonary edema, or pneumonitis.
- Focal multiple B-lines may be present posterolaterally in a normal lung, and are often seen in the presence of pneumonia, atelectasis, lung contusion, pulmonary infarct, pleural disease, or malignancy.
- Pulmonary fibrosis is often distinguishable due to the diffuse B-line pattern in conjunction with an irregular, scalloped pleural surface.
- Air that is not in contact with the chest wall (i.e., adjacent to the mediastinum) cannot be visualized with lung sonography and will not result in the abolition of lung sliding.
- M-mode is a useful tool to document the presence or absence of lung sliding.

Lung ultrasound findings

Normal lung

- Lung sliding present
- Normal artifacts
  - A-lines usually present
  - B-lines may occur (particularly posterolaterally) – three or fewer B-lines in a single interspace

Pneumothorax

- Absent lung sliding
- No B-lines
- Presence of A-lines
- Lung point may be identified (if so, pneumothorax is confirmed)

Interstitial syndrome

- Greater than three B-lines in a single interspace constitutes a “positive” B-line pattern
- Two or more positive regions bilaterally constitute a “positive” exam for interstitial syndrome
- A diffuse B-line pattern does not necessarily enable the clinician to differentiate cardiogenic from non-cardiogenic pulmonary edema, or pulmonary edema from pneumonitis

Effusion

- Anechoic (though occasionally hypo- or iso-echoic) collection between the chest wall and underlying lung tissue
- Lung tissue may appear as a solid organ in cases of moderate or large pleural effusions, due to atelectasis and consolidation of the lung
- Loculations within pleural effusions appear as hyperechoic septae

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