Detection of Pneumothorax with Ultrasound

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Diagnosis of a pneumothorax in the perioperative area can be difficult. Traditional gold-standard modalities may not be available or feasible to institute. Ultrasound guidance allows the anesthesia provider a method of quickly ruling out this potentially life-threatening complication. In this article we detail the use of sonography for fast and accurate diagnosis of pneumothorax. The essential terms relative to the use of ultrasonography to detect pneumothorax are also defined.

Keywords: Bat sign, lung sliding, pleural line, pneumothorax, seashore sign, ultrasound.

Treatment of pneumothorax, the abnormal collection of air between the visceral and parietal pleural layers of the lung, was first detected and treated by a 15th century physician from Anatolia named Serefeddin Sabuncuoglu. His illustrated surgical text written in 1465 first described this phenomenon as a result of trauma to the chest. He first correlated that shortness of breath, cough, and hemoptysis may signal a puncture in the pleura. Treatment of a pneumothorax in the 15th century was called “mihceme,” also known as cupping therapy. The skin over the traumatic area was incised by the physician, and a device was placed over the area to cause aspiration of the abnormal air collection. A flame was placed into the glass tool to burn oxygen and create a vacuum. This negative pressure would then relieve the pneumothorax. Treatment of a pneumothorax was not a standard procedure until World War II. Today, modern technology indicates that the use of ultrasonography is safe, fast, and effective for detecting this complication.

Diagnosis of a pneumothorax has traditionally been obtained through a variety of ways such as patient history, clinical examination, chest radiography, and computed tomography (CT) scanning. During the history, examination, or report, the anesthesia provider should be made aware of any precipitating factors that may put a patient at risk of a pneumothorax. These factors include any instrumentation or needles near the neck, chest wall, or trachea; fractured ribs or crush injury to the chest; blunt trauma to the chest; increased pressure to the airway or bullous lung disease; and nitrous oxide administration.

Many of the mentioned modalities for pneumothorax detection are not readily available while patients are under general anesthesia. The signs of a pneumothorax while a patient is under anesthesia can be nonspecific and difficult to decipher. They may include difficulty maintaining adequate ventilation, hypotension, heart rate changes, distended neck veins, abdominal distention, altered breath sounds on the side of the pneumothorax, and possibly unilateral chest expansion with tracheal deviation. The application of positive pressure ventilation to even a small, asymptomatic pneumothorax can cause progression to a life-threatening tension pneumothorax. Computed tomography is considered to be the gold standard for detecting pneumothoraces; however, it does have drawbacks. Some of these include patient transport to the scanner, the need for a radiation technologist to perform the scan, the need for physician interpretation, and the greatest radiation exposure to the patient of all detection methods. It is also not feasible to obtain a CT scan during a general anesthetic in the operating suite. Traditionally, when a clinician suspects a pneumothorax, a chest radiograph is obtained. This presents problems for the patient under anesthesia. Chest radiographs are best at detecting a pneumothorax if obtained with the patient in the upright position. The radiographic appearance of a pneumothorax is dependent on gravity, and studies have shown that anteroposterior supine radiographs may detect only a large pneumothorax. One study showed more than half of the traumatic pneumothoraces that were detected by CT were missed by supine chest radiographs. Obtaining upright inspiratory and expiratory anterior/posterior and lateral chest radiographs while the patient is under anesthesia would be problematic at best.

Portable ultrasonography has recently been studied for use in the detection of a pneumothorax. An evidence-based review of the literature was done to evaluate ultrasonography vs chest radiography to detect traumatic pneumothoraces. This review found that bedside ultrasonography was a much more sensitive screening test for detection of pneumothorax than supine chest radiography in the trauma patient. Another recent study that
compared ultrasonographic detection of pneumothoraces vs chest radiography found that not only was ultrasonography superior to chest radiography in detection, ultrasonography was able to differentiate between different sizes of pneumothoraces and its diagnostic value rivaled that of the CT scan. Ultrasonographic equipment is now easily portable and quickly produces high-quality images. Sonography is a highly effective diagnostic tool that can lead to prompt intervention when life-threatening situations arise in the operating room, whereas CT scanning may not be available to the anesthesia provider.

Ultrasonography has assisted providers in the detection of pneumothorax for nearly 2 decades. Nearly all early published work originated from the emergency medicine and intensive care medicine journals. Only recently has this interesting topic been adopted by the anesthesia literature. Although chest CT remains the gold standard and many articles still use chest radiography for comparison, the use of ultrasonography to diagnose pneumothorax has numerous advantages. The most important advantage is a dramatic decrease in the time it takes to make a diagnosis. One article claimed that the time to diagnose pneumothorax was about 7 minutes for ultrasonography vs 80 minutes in the x-ray group. They also pointed out the degree of deviation in the x-ray group was ± 66 minutes, meaning it could have been as long as 140 minutes to diagnose this potentially life-threatening complication.

Ultrasonography has been demonstrated to be more accurate than chest CT to diagnose a pneumothorax. One recent article demonstrated impressive success rates ofprehospital medical personnel being trained quickly to identify a pneumothorax on ultrasound. This suggests that other providers can be trained to quickly perform ultrasonographic scanning and to recognize a suspected pneumothorax with sonography. Other advantages include omission of radiation exposure to the staff and patient, reduction in cost, completion of diagnosis without the need for a radiologist (eg, late-night care in tertiary facilities), and ease of use.

There are several drawbacks to the use of ultrasonography in this clinical situation. The first drawback is that bullous lesions and severe chronic obstructive pulmonary disease (COPD) can mimic pneumothorax on ultrasonography. This could lead to a false-positive diagnosis of pneumothorax using ultrasonography compared with the same patient evaluated by chest radiography. The second drawback is that the overall sensitivity and specificity for ultrasonography to diagnose pneumothorax seems to decrease after the first 24 hours, meaning that the same patient with the same symptoms would be less likely to display the necessary ultrasonographic findings after a 24-hour period. Lastly, these scans are also complicated by morbid obesity, as resolution is lost at deeper measurements.

Performing Lung Scans
Performing and interpreting lung ultrasound scans revolve around understanding the ultrasound principle that dense material, such as bone, prevents sound waves from penetrating through it. Therefore, chest scanning with ultrasound must be performed at each intercostal space of interest. The intercostal spaces are bordered by a superior and inferior rib. Between them lies the intercostal space. This space will provide an adequate window to the lung below and can reveal a variety of pulmonary illnesses. Ultrasonography to rule out pneumothorax is a relatively simple and rapid technique to perform. Early literature advocated curvilinear probe use; the current literature routinely uses high-frequency linear probes with initial frequencies around 5 MHz. This disparity may reflect increases in linear imaging technology and the current flexibility of many machine settings.

It is important to consider that pneumothorax air will rise to the highest point. If the patient is in the supine position, the anterior aspect of the chest is the most likely point to make the diagnosis and should therefore be scanned first. Patients who arrive with penetrating injuries to the lateral aspect of the chest should ideally be scanned in the lateral position with the area of injury at the highest position. The chest is divided into sections, and each section is scanned separately. Supine patients should have their scans initiated by placing the ultrasonic probe near the sternal border of the anterior section of the chest. The intercostal spaces of interest are then identified, and the ultrasound beam is placed between the ribs. The posterior section of the chest is best scanned with the patient in the lateral decubitus position. The posterior lung bases, which are protected by the scapulae, cannot be scanned. Imaging the posterior lung bases must therefore be done around the scapulae. This does limit sonographic access to this region; however, in the case of the supine patient, it is of little value. Some authors have described the ultrasonographic chest scan “sectioning” as similar to lung sound assessment with a stethoscope. The images should be compared with images of the opposite side for symmetry. Once the presence of “lung sliding” (the movement of parietal pleura as it joins with the visceral pleura, as described later) has been confirmed in all “lung sections,” the suspicion for pneumothorax is greatly reduced (Figure 1).

Ultrasonographic Terms
Each pulmonary abnormality has a unique sonographic presentation, and there are a few terms that specifically relate to this diagnostic scan. The lung sonogram produces waves that are named like the electrocardiography (ECG) nomenclature. Instead of starting at “P” for “P wave,” it begins with “A” for “A-line.” To interpret these scans, each provider must be familiar with the characteristic signs produced by ultrasonography. The
essential terms include lung sliding, bat sign, pleural lines, A-lines, B-lines, and the lung point. The use of M-mode and B-mode is also briefly discussed as it specifically relates to this topic. The Table summarizes the terms and definitions.

- **B-Mode.** B-mode, or brightness mode, is the ultrasonic mode most commonly used by anesthesia providers. The “brightness” corresponds to the amplitude of reflected sound. B-mode provides real-time imaging of structures that are clearly discernible and is most often used to obtain vascular access or administer regional anesthetics. Traditionally, anesthesia providers use ultrasonographic images in B-mode or brightness mode.

- **Bat Sign.** The bat sign is a basic sonographic landmark that describes a particular pattern seen on the lung scan. This simple sign can be noticed quickly, even

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**Table.** Terms and Definitions Associated With Ultrasonographic Detection of Pneumothorax

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Ultrasound mode</th>
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<tr>
<td>Pleural line</td>
<td>Hyperechoic horizontal line indicating the pleural layers</td>
<td>B- and M-mode</td>
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<tr>
<td>Lung sliding</td>
<td>Dynamic horizontal movement of the pleural line during respiration</td>
<td>B-mode</td>
</tr>
<tr>
<td>Lung point</td>
<td>Precise area of chest wall where lung sliding stops and is replaced by pneumothorax</td>
<td>B- and M-mode</td>
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<tr>
<td>Z-lines/comet tails</td>
<td>Small, vertical tapering hyperechoic lines that diminish distally, caused by air-fluid interface at the pleural line</td>
<td>B-mode</td>
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<td>Seashore sign</td>
<td>Ground-glass or sandy appearance under the pleural line indicating normal lung tissue</td>
<td>M-mode</td>
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<td>Stratosphere/barcode sign</td>
<td>Absence of normal seashore sign below the pleural line; replaced with multiple small horizontal lines indicating pneumothorax</td>
<td>M-mode</td>
</tr>
<tr>
<td>A-lines</td>
<td>Horizontal, hyperechoic lines indicating normal lung surface</td>
<td>B-mode</td>
</tr>
<tr>
<td>B-lines</td>
<td>Larger, hyperechoic vertical lines that diminish toward the bottom of the image</td>
<td>B-mode</td>
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<tr>
<td>Bat sign</td>
<td>Basic sign indicating 2 ribs and the pleural line in short axis</td>
<td>B-mode</td>
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by novices, and represents normal chest anatomy. It is termed bat sign due to its likeness to a bat flying with its wings up, toward the viewer. It consists of an upper rib, a lower rib, and the pleural line. The outer portion of the parietal pleura forms the body of the bat sign. The superficial hyperechoic ribs become the bat’s wings, raised above it, and the body is made up of the pleural line underneath and between the wings (Figure 2).3

• M-Mode. M-mode, or motion mode, does not have a great deal of utility for anesthesia providers except as an application for diagnosing a pneumothorax. M-mode uses acoustic waves to determine a structure’s movement over time. It is a layering of returned ultrasound waves stacked next to each other. Looking at M-mode processing is much like reading an ECG strip, and it reflects activity over time.

An important term relating to M-mode use when diagnosing a pneumothorax is the “seashore sign.” Normal lung scans produce this characteristic seashore sign.8 These normal images are viewed as hyperechoic, horizontal lines that run the entire distance from the left side to the right side of the image. Near the top of the image, the bright-white pleural line will be visible. Below the pleural line, the landscape will change to become granular appearing, like ground glass. The image has been described as one of standing on the beach viewing the sea in the distance. The water appears as thin, horizontal lines that traverse the entire top portion of the screen.

The sign associated with air in the pleural layer is the barcode sign or stratosphere sign. The stratosphere sign is present with a pneumothorax, and the air will produce only the horizontal lines throughout the image (Figures 3 and 4).

• Pleural Line. Identification of the pleural line is important in B-mode and M-mode. The pleural line is a hyperechoic (bright-white), horizontal line indicating the superficial surface of the parietal pleura. Normal pleural lines are thick, horizontal, hyperechoic lines that provide the location for the lung sliding described in the next paragraph. Pleural lines are generally seen lying about 0.5 to 2 cm below the upper portion of the ribs. The pleural line exists below each of the ribs, but ultrasound waves are unable to image below the ribs because of the acoustic shadow that the ribs produce. Essentially, the pleural line can be viewed only at the intercostal space.

• Lung Sliding. Lung sliding is the term describing the movement of parietal pleura as it joins with the visceral pleura. This is a normal finding on healthy patients and is easily identified during respiration. This sign is best seen with the patient breathing spontaneously,9 but can be easily seen in mechanically ventilated patients as well. The pneumothorax air separates the 2 pleural layers, preventing imaging of normal lung sliding. This is the first important dynamic sign to be viewed after normal anatomical findings such as the bat sign and pleural line have been identified. Normal sonograms do not distinguish between the 2 pleural layers, but they do indicate presence of the visceral pleura near the parietal pleura.4 Therefore, the presence of lung sliding rules out pneumothorax at the location of the probe. The scan should reveal this finding about 0.5 to 1 cm below the ribs.3 If air is seen instead of lung sliding, or if lung sliding is absent, pneumothorax is highly suspected.

Severe COPD and bullous lesions can abolish normal lung sliding in certain areas and appear to mimic a pneumothorax on ultrasonography. Other factors that confound ultrasonographic diagnosis of pneumothorax are previous pneumonectomy, pulmonary fibrosis, high-frequency ventilation, and adult respiratory distress syndrome.10 In the absence of normal lung sliding, the lung point (discussed below) should be identified both on B-mode and M-mode, to distinguish the borders of a suspected pneumothorax.

• Lines. The early ultrasonographic literature has described as many as 26 different lines; however, only the basics are covered here. Identification of A-lines and B-lines as well as Z-lines in lung ultrasonography viewed in B-mode are described by Lichtenstein et al. These lines are all described in B-mode.

• A-Lines. A-lines are hyperechoic, repeated, horizontal lines that indicate normal lung surfaces with ultrasonography viewed in B-mode.8 The A-line is essentially a repetition or echo of the pleural line. A-lines will often appear at repeated intervals. These intervals are the same distance from one to another, as the distance found from the skin to the pleural line. If the distance from the skin to the pleural line is 1 cm, the first A-line may appear at 2 cm and may repeat this pattern until the beam is exhausted, or the anatomy changes. A-lines normally indicate subpleural air. The length of an A-line is essentially the same as the pleural line; however, it may appear shorter, and sometimes is not visible.

• B-Lines. There are a variety of B-lines described in the literature. Each one is viewed in B-mode and has unique characteristics and its own significance. The B-line generally appears as a vertical shard of light or “comet-tail” artifact. A single vertical B-line that extends the entire depth of the scan may be a normal variant representing a lung fissure and may extend the entire distance between the pleural line and the deep portion of the image. These lines may or may not move with respiration and have also been described as lung rockets or laser beams. Multiple B-lines appear as sunlight penetrating the deep-water view of an undersea diver. The number of B-lines increases when there is an increase in interstitial edema and diseased lungs.4 B-lines or lung rockets are not only a strong indicator to rule out pneumothorax, but they also have been described as an indicator for elevated pulmonary artery occlusive pressure and pulmonary edema.8 These B-lines
may appear in about 27% of healthy patients, but they have also been associated with the presence of subpleural interstitial edema.8 The B-line is generated by a combination of fluid and air. This occurs when the alveoli become edematous. It is thought that the B-line is created by the ultrasound beam reverberating from the probe to the liquid dense alveoli multiple times.

The B-lines appear in B-mode ultrasonography as thin, vertical beams; however, they are really tiny horizontal lines tightly stacked on top of each other at increasing depth. B-lines that occur in a series of 3 or more have been termed B+ lines.4 The presence of B-lines is especially important to rule out pneumothorax. One B-line indicates contact of the visceral pleura with the parietal pleura. This represents a normal lung surface. However, multiple lung rockets have a high degree of sensitivity and specificity for diagnosing lung interstitial edema.

In summary, A-lines are horizontal items, and B-Lines are vertical items. They are not generally seen together.

- **Z-Lines.** The last in this series of lung ultrasound lines are the Z-lines. Z-lines or, “comet tails,” are viewed in B-mode, and their presence is useful in ruling out pneumothorax. Z-lines differ from B-lines in that Z-lines are small, tapering, hyperechoic lines that diminish distally from the visceral pleura. They occur as reverberation artifacts created by an air-fluid interface. Z-lines can be more confusing. They can occur in normal lung surface, and they have been described as being devoid of meaning. However, they can also be present with a pneumothorax.4

- **Lung Point.** The term lung point represents a precise border of a pneumothorax. This is the area where lung sliding and motionless pleura can be viewed in the same screen. The lung point is the border at which normal parietal and visceral pleural separate to become the pneumothorax. This point is where the absence of lung sliding begins or ends. Identification of the lung point is also a positive sign for pneumothorax, and visualization of it is 100% specific for ruling in pneumothorax.11 However, lung point loses sensitivity when the lung is completely collapsed and no lung point can be visualized.4 Lung point can be seen in either B- mode or M-mode and will demonstrate the contrast between the normal and abnormal signs described earlier (Figure 5).

**Suggested Method for Lung Scanning**

Lung scanning should be logical and methodical. The first thing to consider is the position of the patient. Consider also the patient’s history such as recent blunt or penetrating trauma. The patient’s position for scanning should represent the position most reasonable to diagnose the pneumothorax as described earlier. Select a high-frequency linear probe and set the depth to allow viewing of the deep lung area; on most adults this should be at least 4 cm. Begin by scanning the area most likely to show the pneumothorax. For the typical supine patient this would
be the anterior section of the chest. Select B-mode and place the probe on the anterior part of the chest. Obtain the bat sign showing 2 ribs in short axis and identify the pleural line. Check for lung sliding during any respiration. If absence of lung sliding is seen, switch the ultrasound to M-mode and check for the seashore sign. If a seashore sign cannot be seen, and instead a barcode sign is viewed in the same location as the absence of lung sliding, pneumothorax can be ruled in with high probability.

If the pneumothorax is ruled in, scan the lateral section of the chest and identify the lung point. The presence of a lung point is highly indicative of a pneumothorax. If no abnormalities are seen, move the probe to several intercostal locations covering the anterior aspect of the chest and repeat the process of checking for lung sliding. Compare these images to those from the anterior contralateral side of the chest. After the anterior chest site has been scanned in several locations, begin scanning the lateral aspect of the chest on the contralateral side. Each time an anomaly is seen, the image should be viewed in M-mode to check for the seashore, or barcode signs.

Figure 5. Arrow Indicates the Lung Point in M-mode
This is the region where the intra-pleural air (pneumothorax) ends and normal pleural connection (seashore sign) begins. Note the characteristic streaking of the barcode/stratosphere sign on the lower indicating pneumothorax. The B-mode image (upper portion of image) will reveal the absence of lung sliding on a dynamic ultrasound scan. (Image by Jonathan Kline, CRNA.)

Suggested Systematic Approach for Lung Scanning
A systematic approach for ultrasonographic lung scanning is described here and is depicted in Figure 6.

1. Lung scanning should be logical and methodical. Consider the patient's history and general physical condition, including lung pathologies, lung surgeries, or recent blunt or penetrating chest trauma.

2. Consider the position of the patient. The patient's position for scanning should represent the position most reasonable in which to diagnose the pneumothorax, or the suspected lung region affected. Begin by scanning the area most likely to show the pneumothorax. For the typical supine patient this would be the anterior chest area.

3. Select a high-frequency linear probe and set the depth to allow viewing of the deep lung area; on most adults this should be at least 4 cm.

4. Begin by selecting B-mode and place the probe on the anterior part of the chest.

5. Obtain the bat sign showing 2 ribs in short axis and identify the pleural line. Check for lung sliding during any respiration.

6. Each time an anomaly is seen, the image should be viewed in M-mode to check for the seashore or barcode sign.

7. If a seashore sign cannot be seen, and instead a barcode sign is viewed in the same location as the absence of lung sliding, pneumothorax can be ruled in with high probability. If the pneumothorax is ruled in, continue laterally scanning the lateral part of the chest and identify...
the lung point. The presence of a lung point is highly indicative of a pneumothorax.

8. If no abnormalities are seen, systematically move the probe to the next several intercostal locations covering the anterior aspect of the chest and repeat the process of checking for lung sliding. Use a method similar to a lung sound assessment.

9. Compare these images to the anterior contralateral side of the chest. After the anterior chest area has been scanned in several locations, begin scanning the lateral aspect of the chest on the contralateral side.

Conclusion
Sonographic diagnosis of pneumothorax is rapid, accurate, and easily deployed and can be lifesaving when appropriate interventions are initiated to treat the discovered pneumothorax. The efficacy of ultrasonography as a tool for assessing and diagnosing abnormalities in the chest, including pneumothorax, has been demonstrated and has been adopted by our emergency medicine, critical care, pulmonary, trauma, and radiology colleagues. Ultrasonography technology is being rapidly adopted in anesthesia care for accurate and successful placement of regional anesthesia, central and peripheral venous access, and arterial cannulation. It also avoids concerns with use of CT about radiation exposure, the need for trained radiology technologists to perform CT scans, and the demand for formal training to interpret the CT scans. The international literature, across multiple disciplines, clearly demonstrates the efficacy of ultrasonography utilization in the diagnosis of pneumothorax. The advantages of ultrasonography in diagnosing pneumothorax show tremendous value to anesthesia providers for use in the operating room and outweigh its few limitations. Incorporating it into anesthesia practice seems prudent and beneficial.

REFERENCES

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