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Pediatric Cardiothoracic Point-of-Care Ultrasound: Part II

Ultrasound has emerged as a critical tool for use at the bedside to guide both diagnosis and treatment strategies. In the January 2019 issue, the authors focused on the uses and limitations of cardiac ultrasound in the acute setting. In this article, they discuss cardiac arrest, congenital abnormalities, pneumothorax, pleural effusion, and pneumonia.

— Ann M. Dietrich, MD, FAAP, FACEP, Editor

AUTHORS

Robert Stenberg, MD, Emergency Medicine Resident, Department of Emergency Medicine, University of North Carolina, Chapel Hill

Daniel Migliaccio, MD, Clinical Assistant Professor, Department of Emergency Medicine, and Head, Ultrasound Education, University of North Carolina, Chapel Hill

Daniel B. Park, MD, Associate Medical Director, Pediatric Emergency Medicine; Director, Pediatric Emergency Ultrasound; Assistant Professor, Departments of Pediatrics and Emergency Medicine, University of North Carolina School of Medicine, Chapel Hill

PEER REVIEWER

Aaron Leetch, MD, Assistant Professor, Departments of Emergency Medicine and Pediatrics; Program Director, Combined Emergency Medicine and Pediatrics Residency, University of Arizona, Tucson

STATEMENT OF FINANCIAL DISCLOSURE

To reveal any potential bias in this publication, and in accordance with Accreditation Council for Continuing Medical Education guidelines, we disclose that Dr. Dietrich (editor), Dr. Stenberg (author), Dr. Migliaccio (author), Dr. Park (author), Dr. Leetch (peer reviewer), Ms. Wurster (nurse reviewer), Ms. Coplin (executive editor), Ms. Mark (executive editor), and Ms. Hatcher (editorial group manager) report no relationships with companies related to the field of study covered by this CME activity.

RELIAS MEDIA

Introduction

When a child presents to the emergency department (ED) in obvious shock, it is helpful for providers to know the specific type of shock so they can guide management and direct interventions. A quick, focused echocardiogram can help differentiate types of shock and guide the use of fluids, vasopressors, and inotropes. Point-of-care ultrasound (POCUS) is becoming a frontline tool because it is easily accessible and enhances critical decision-making.

Pulmonary ultrasound is a rapidly growing field with POCUS in pediatrics, including additional applications. Traditionally, it was used to evaluate for pneumothorax and pleural effusions, but now, it is expanding to include pneumonia and beyond. (*See Table 1.*) While applications have continued to evolve, the current focused questions have remained simple and attainable: Is there a pleural effusion? Is there a pneumothorax? Are there pathologic B lines?

Special Situation: Cardiac Arrest

A 15-year-old male with a history of bone cancer presents in cardiac arrest via emergency medical services. The child was found down at home after having had a recent upper respiratory infection. Providers are performing chest compressions. A POCUS of his heart at pulse check reveals a collapsed inferior vena cava (IVC) consistent with hypovolemia likely from sepsis. After two rounds of cardiopulmonary resuscitation and epinephrine, return of spontaneous circulation is obtained. He is resuscitated with fluids, given antibiotics, and admitted to the pediatric intensive care unit (PICU) with septic shock.

POCUS can be helpful in the setting of cardiac arrest.[1-5] Providers can use thoracic ultrasound to evaluate for the reversible Hs and Ts — hypoxia, hypovolemia, tamponade, tension pneumothorax, and thromboembolic event — as potential etiologies of arrest as recommended by Pediatric Advanced Life Support and Advanced Cardiac Life Support.[6] In addition, POCUS also may help providers identify what has been reported in the past as "occult ventricular fibrillation." Reports in the 1980s noted that 6-8% of asystole patients responded to shocks. This was believed to be

Table 1. Findings on Cardiothoracic Point-of-Care Ultrasound

Pathology	Images Required	Images Demonstrate
Pulmonary hypertension/ pulmonary embolism/ Eisenmenger syndrome	• Apical four chamber is most important, followed by parasternal short • IVC	• RV:LV ratio approaches 1:1 • D sign on parasternal short • McConnell's sign • Dilated IVC
Pneumothorax	• Evaluation of more than three lung zones with linear probe	• Absent lung sliding • Lung point • Absence of lung pulse • Barcode sign on M-mode
Pneumonia	• Evaluation of more than three lung zones with curvilinear or phased array probe	• Unilateral B lines • Subpleural consolidation • Bronchograms *Note:* Visualizing two or more of these increases specificity for pneumonia.
Diffuse pulmonary edema	• Evaluation of more than three lung zones with curvilinear or phased array probe	• More than three contiguous B lines in more than two lung fields bilaterally
Pleural effusions	• Evaluation of costophrenic angle on right and left (dependent lung zones) zones with curvilinear or phased array probe	• Hypoechoic fluid representing pleural effusions

IVC: inferior vena cava; RV: right ventricle; LV: left ventricle.

secondary to the ventricular fibrillation having a vector and, therefore, not appearing on multiple leads. The American Heart Association recommended against it, given that it was a rare, potential harm and increased the time the patient was not receiving compressions.[7-10] More recently, as POCUS has evolved, more studies are noting sonographic ventricular fibrillation not seen by electrocardiogram, including successful defibrillation with good neurologic outcome.[11-13] In 2016, researchers found that among 179 cardiac arrest patients in the ED, four patients who were shown to be in asystole on the monitor had ventricular fibrillation on echocardiogram, and three had return of circulation after defibrillation.[3] Conversely, they also found that seven patients believed to have ventricular fibrillation by monitor had no activity by echocardiogram.

If using ultrasound during cardiopulmonary arrest, it is important to do so cautiously, and in particular to minimize pauses in compressions.[14,15] Authors of a single-center study in 2017 noted a significant difference in mean duration pulse checks with ultrasound to be 21 seconds vs. no ultrasound at 13 seconds.[14] This highlights the importance of being cognizant of time and preparation to minimize interruptions in compression if using ultrasound. Researchers now are exploring new ways to help facilitate this, including using transesophageal echocardiography and attempting ultrasound during compressions.[5,16] The authors of a recent Danish study found anesthesiologists were able to obtain useful views during chest compressions 47-58% of the time.[17]

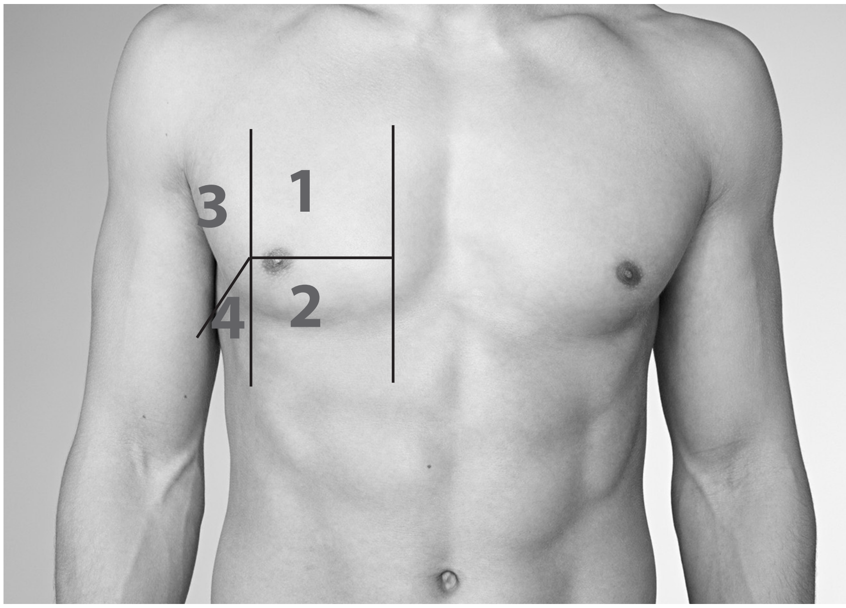
The 2016 critical care consensus recommended that POCUS alone is insufficient to diagnose irreversible cardiac arrest in pediatric patients.[18] Unlike the strong evidence in adults with standstill predicting poor outcomes, the majority of causes of arrest in pediatric patients are respiratory in nature, and there is literature supporting a greater potential for recovery.[19] Newer literature also is showing significant variability in interpretation of cardiac standstill among physician sonographers. There was moderate variability (α = 0.47), with areas of least agreement being changes from mechanical ventilation, valve flutter, weak contraction, and severe bradycardia.[20] Isolated valvular movement is considered cardiac activity in recent studies but not in others.[15,20,21] Overall, this supports the idea that definitions need to be established and further education is needed in the subtleties of standstill.

Congenital Abnormalities

An 8-year-old female with no significant past medical history presents with progressively worsening shortness of breath. She has labored breathing and is tachycardic. Her lungs are clear to auscultation. A faint murmur is detected. A POCUS of her heart reveals right ventricle enlargement consistent with pulmonary hypertension secondary to undiagnosed atrial septal defect (Eisenmenger syndrome), and she is admitted to the cardiac ICU for further management.

Overall, congenital cardiac abnormalities are rare and structurally very diverse. Generally, they are beyond the scope of POCUS and

Figure 1. Lung Zones



Source: Getty Images

should be left to advanced users. The 2016 critical care consensus guidelines recommended against using POCUS for evaluating congenital heart disease. The guidelines also recommended that only advanced users assess for patent ductus arteriosus. The American Society of Echocardiography also recommends that experienced clinicians evaluate patent ductus arteriosus followed by a comprehensive study.[22,23] For example, to evaluate for anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA), one must be able to identify the structure and flow of the left coronary ostium relative to the pulmonary trunk, as well as to note indirect findings, such as a dilated right coronary artery, an increase in coronary collaterals, and mitral regurgitation.[24]

There may be some findings on POCUS that may prompt the clinician to obtain a cardiology-performed echocardiogram. Largely, this can be done by knowing normal anatomy, and then correctly identifying the left and right ventricle (a common pitfall is mislabeling the left and right ventricles).[25] From here, along with applying the clinical scenario, one may note size abnormalities concerning for cardiac structural pathology. Eisenmenger syndrome, a common pathway for multiple congenital abnormalities (i.e., ventricular septal defect, atrial septal defect, and patent ductus arteriosus), likely will have evidence of an enlarged, dilated right side of the heart.[26,27] On the other hand, a hypoplastic left heart syndrome will demonstrate a markedly reduced left ventricle.

Pulmonary Probe Selection, Positioning, and Image Acquisition

Most of the ultrasound probes seen in the ED setting to evaluate the lungs are curvilinear and linear probes. These two important pieces allow clinicians to visualize the pleural line adequately and to see between the ribs. There may be scenarios in which different probes may be better suited. When focusing on lung sliding, a high-frequency linear probe may help focus on the parietal pleural interface. When fully evaluating a larger pleural effusion or assessing B lines, a probe with further depth may be more useful.

From a positioning standpoint, the thoracic ultrasound largely can be performed with the patient in any position. One consideration is where gravity will move air and fluid. Fluid will move to the most dependent position and air to the nondependent location. In most emergency situations, patients will be in the supine position, and pneumothorax evaluation should begin at the superior anterior chest wall (roughly the fourth intercostal space or lung zone 1 in Figure 1) and progress to each of the standard lung zones.

Image acquisition involves checking multiple intercostal spaces. Keeping the rib in the field provides a reference point to help interpret the findings. Maintaining the probe marker in a cranial fashion also helps facilitate this.

Artifacts and Clinical Correlations

A key component of lung ultrasound includes interpreting sonographic artifacts. The ribs appear as circles with associated clean shadowing. Just deep to the ribs, one can see the prominent hyperechoic pleural line. A lines are artifacts that can be seen in multiple conditions including normal lungs; they are reverberation artifacts of the pleural line, making multiple horizontal lines extending down the field.

B lines are artifacts produced by parenchyma creating what appears to be a beam extending from the pleura to the bottom of the screen. Unlike the A line, it is a reverberation in a vertical fashion. Intermittent B lines can be seen in normal lungs, but the appearance of multiple lines can signify multiple pathologies. There must be three or more B lines in one intercostal space to be deemed abnormal. Diffuse B lines can be seen in pulmonary edema, pulmonary fibrosis, acute lung injury, and acute respiratory distress syndrome. Focal B lines can be seen in pulmonary contusion, pneumonia, infarction, and atelectasis. Diffuse interstitial alveolar syndrome is a distinction of more than three B lines in more than two contiguous lung zones and can represent pulmonary edema in the correct clinical context. (*See Figures 2 and 3.*)

C lines are seen as a step-off of the pleural line and are indicative of a subpleural consolidation. E lines are produced by subcutaneous emphysema. This produces an air mucosal surface superficial to the pleural line, therefore making the appearance of almost two pleura. They can be seen in the chest wall and also can obscure the view in the abdominal cavity when trying to evaluate for pleural effusion. (*See Figure 4.*)

Mirror artifact is a common occurrence in normal lungs when viewing at the lung bases in a coronal/sagittal fashion like one would obtain in a focused assessment with sonography in trauma (FAST). It is produced by ultrasound waves striking a reflective surface at an angle. In this view, the reflective surface is the soft tissue and gas interface at the diaphragm. As a result, the liver is mirrored into the lung in the right upper quadrant view. This also is referred to as pseudohepatization, as the lung appears like the liver, but only secondary to the mirror artifact. (*See Figure 5.*)

Lung sliding is an artifact seen at the parietal pleura (pleural line). When the visceral and parietal pleura are intact (no air in between) and respiration is occurring, they slide along each other, producing the appearance of "ants marching on a log." It is important to note that when a patient is in respiratory distress, there is an increased use of accessory muscles. This produces a marked increase in the movement superficial to the pleura, which may confuse users into believing there is lung sliding when there is not. Therefore, it is key to focus looking exactly at the pleural line to evaluate for movement. When there is confusion, some turn to the motion

Figure 2. Ultrasound Demonstrating A Lines

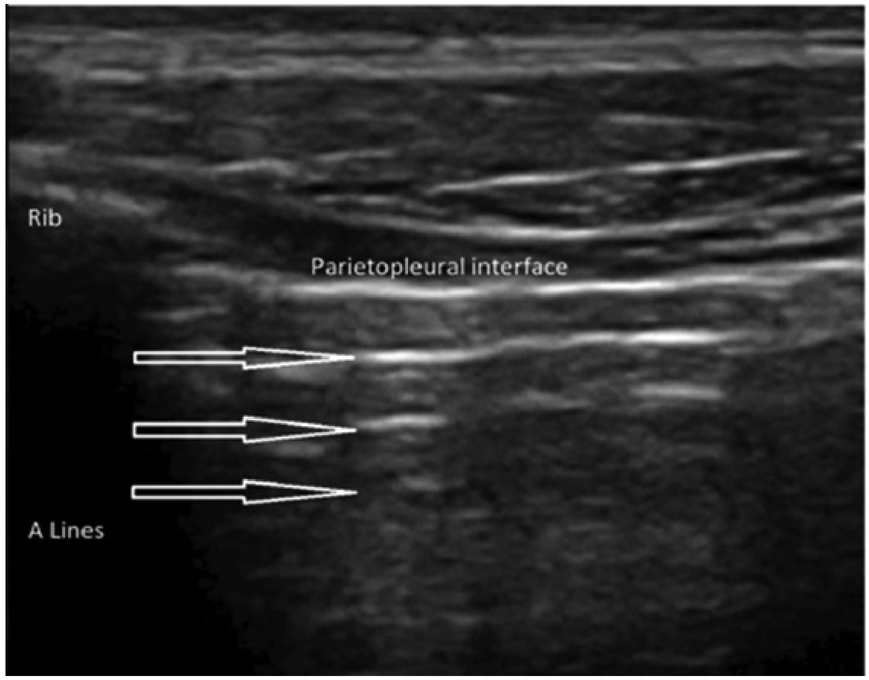


Figure 3. Ultrasound Demonstrating B Lines

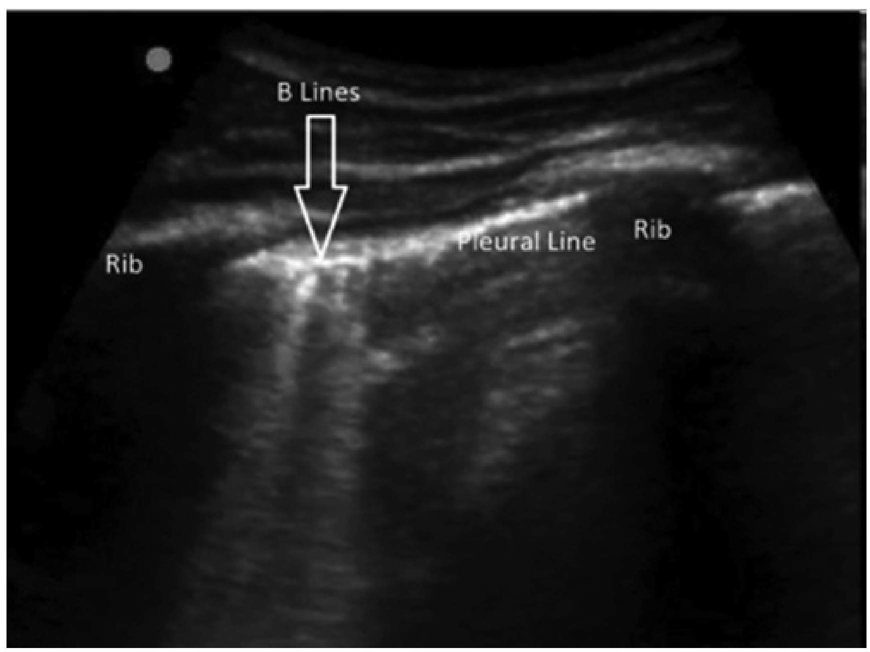


Figure 4. Pleura

To the right of the screen, there appears to be almost two layers of pleura, with the more superficial lines (E lines or white arrow) produced by the subcutaneous emphysema and the gray arrow indicating the pleural line.

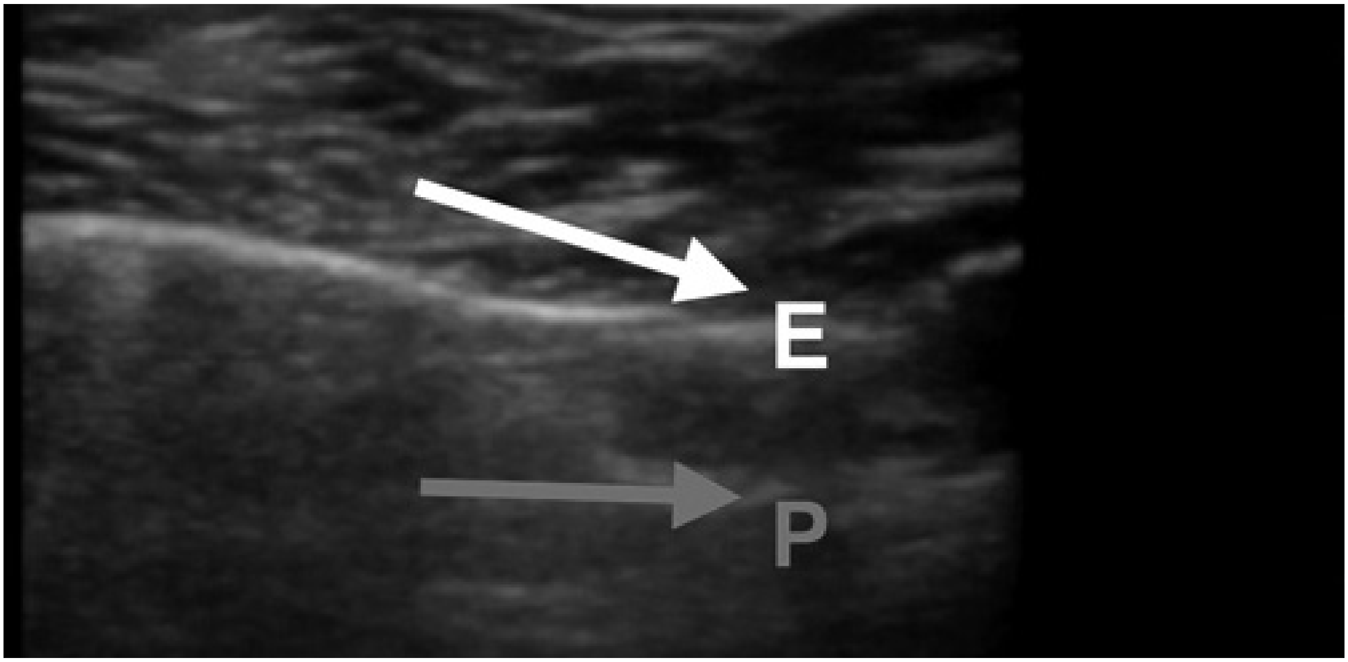


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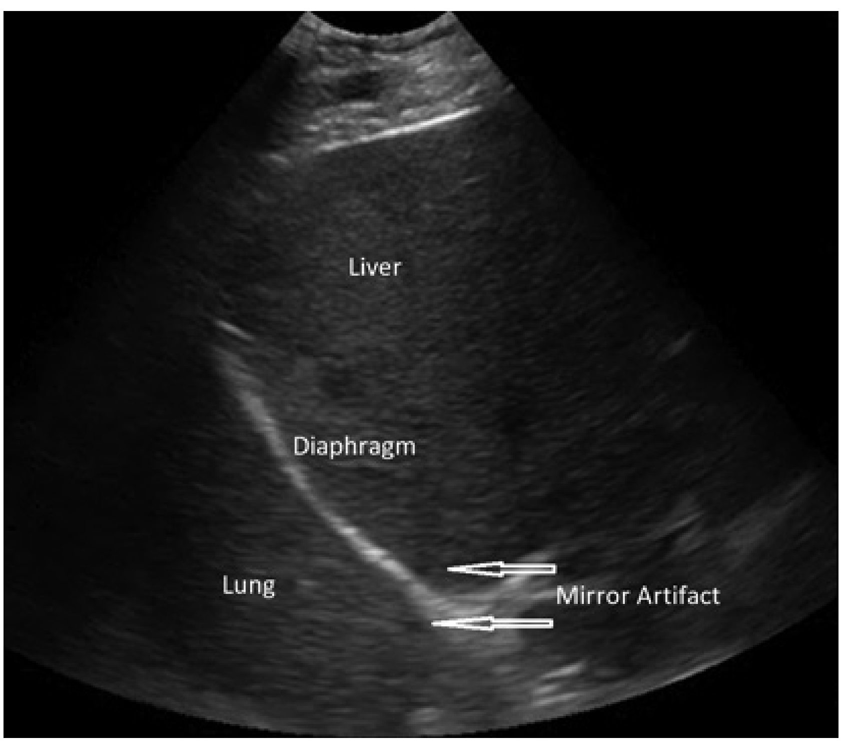
Figure 5. Mirror Artifact

Figure showing mirror artifact, with the distal side of the diaphragm being a mirror image to the side of the liver



mode (M-mode) to observe if there is an artifact over time. Lung sliding will produce a blurred artifact beneath it in this mode, producing what looks like sand (artifact) with the waves above it, which also is known as the seashore sign. If there is no lung sliding, there will be no artifact. One then will see only the waves, which produces what looks like a barcode or stratosphere sign. (*See Figure 6.*)

Although it is seen less often, lung pulse occurs when the two pleura are intact but there is no significant movement of the lung to cause the sliding. One will see what appears to be lung slide in a pulsating fashion correlating with the patient's heart rate (caused by the arterial pulse). If M-mode is applied during lung pulse, one will see the artifact intermittently and it will produce alternating stratosphere and seashore signs. Its clinical relevance plays a role following intubation, since a right mainstem intubation may result in the left lung revealing a lung pulse as the pleura are intact, but the lung is not expanding secondary to no positive pressure in a paralyzed/apneic patient. Also, in a hyperexpanded lung, such as in a patient with severe asthma, lung pulse may be present because the lung is so inflated that there is minimal expansion. (*See Figure 7.*)

Pneumothorax

A 16-year-old male with a history of asthma presents with shortness of breath. He is noted to have increased work of breathing with some faint wheezing in all lung fields. He is tachypneic and tachycardic. A nebulized therapy fails to improve his symptoms. A chest X-ray does not indicate pneumonia or pneumothorax. A POCUS of his lungs reveals the absence of lung sliding consistent with a pneumothorax. He begins to demonstrate signs of tension pneumothorax an hour later, has an emergent chest tube placed, and is admitted to the PICU.

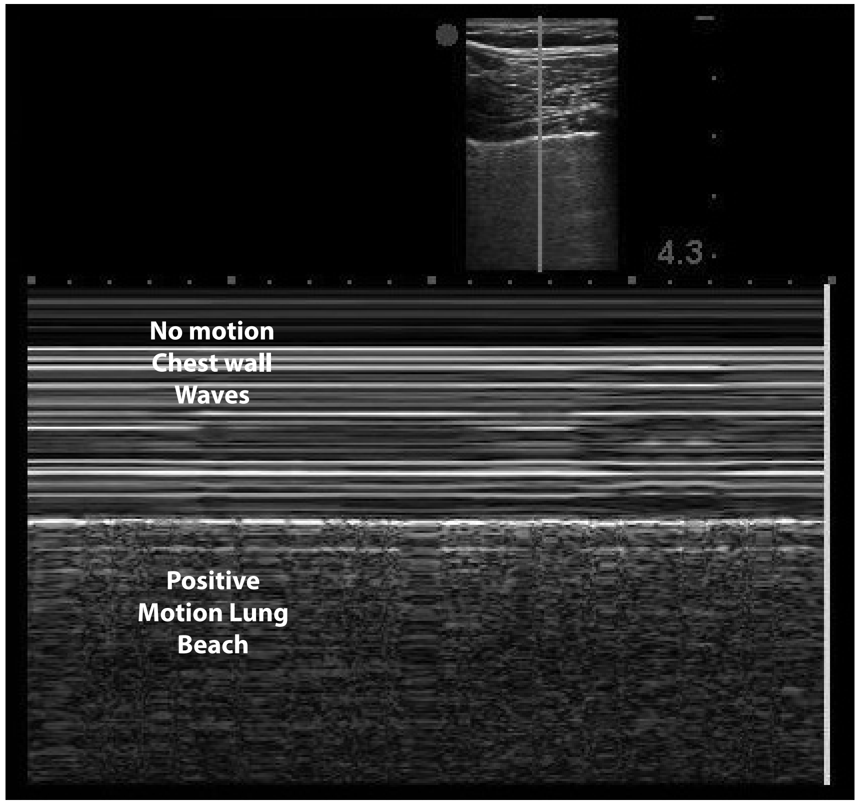
Overall, the use of ultrasound for pneumothorax has been shown to be sensitive and specific, as least as much, if not better, than X-ray, and has been adopted for use with pediatric patients. Many studies note sensitivities and specificities in the high 90s. False negatives typically are caused by emphysema preventing evaluation of the pleura.[28] False positives are seen more often in the adult population, and include blebs or pleural adhesions that prevent sliding (from prior injury or pleurodesis).

Finding a lung point that shows the superior aspect of the lung with air above is specific for pneumothorax and also can assist in determining the size of the pneumothorax. One may see A lines, which signify that there is air in the thorax. B lines and lung pulse in a potentially affected area do not support pneumothorax, as they require an intact visceral and parietal pleura. (*See Figure 8.*) For an video example of a lung point, please go to https://bit.ly/2H699pu.

In an unstable patient with the absence of lung slide, the benefits of thoracostomy may outweigh the risks. On the other hand, for stable patients, often it is better to use detailed criteria to rule in pneumothorax by ultrasound: absence of B lines, absence of lung pulse, no lung slide, and finding a lung point.[25]

Figure 6. Lung Sliding

Normal lung: Seashore sign



Pneumothorax: Barcode/stratosphere sign

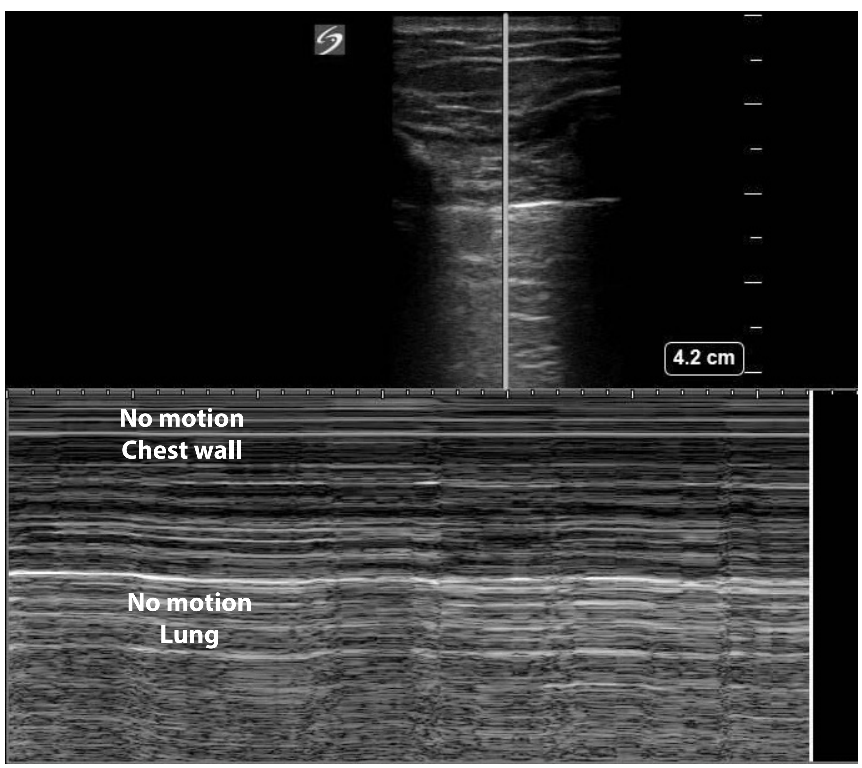


Figure 7. M-Mode

M-mode showing intermittent artifact from lung pulse

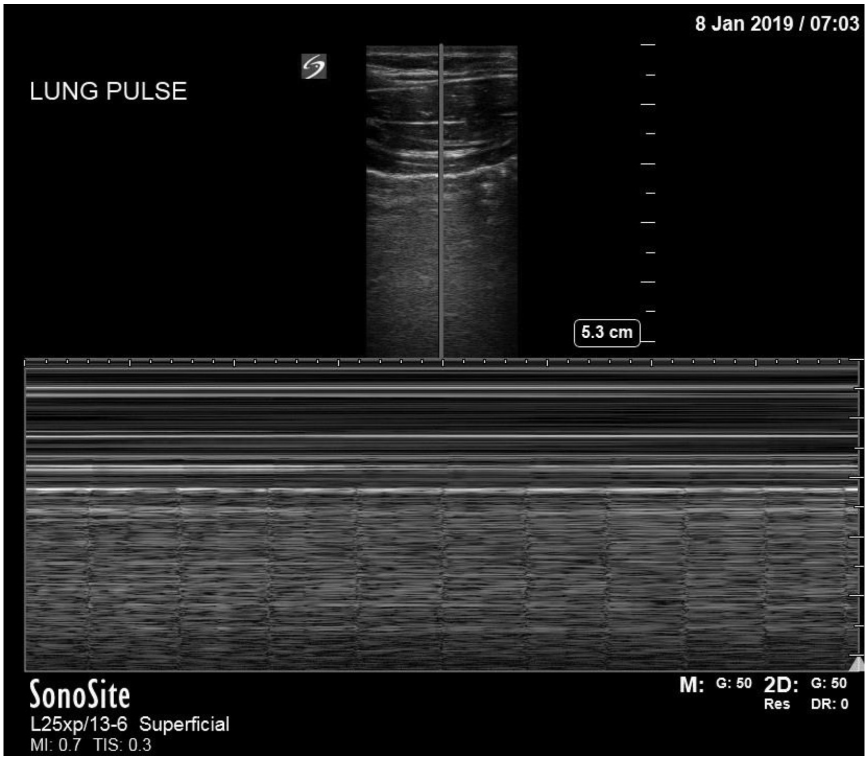
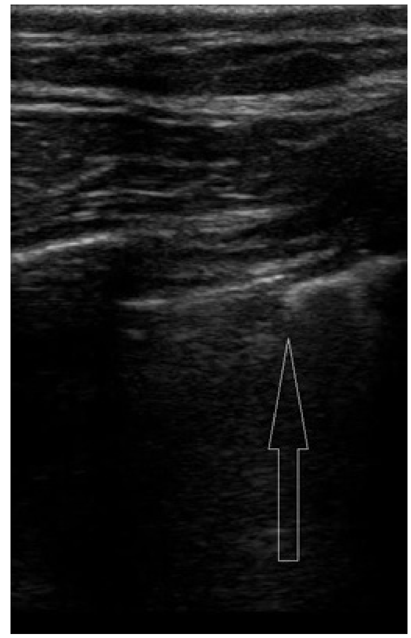


Figure 8. Lung Points

Arrow pointing to the leading edge of the lung that is touching the parietal pleura, the lung point. To the left of the lung point on the screen, there is no motion, and A lines are visualized.



Pleural Effusion

Ultrasound has been established as a good tool for evaluating pleural effusions. Effusions as small as 20 mL can be seen by ultrasound, compared to 175 mL on a supine chest X-ray.[29] Ma and Mateer found a sensitivity of 96.2% and specificity of 100% in detecting hemothorax in trauma patients.[30] There is loss of the mirror artifact, and isoechoic to hypoechoid fluid will be seen near the costophrenic angle. (*See Figure 9.*)

In the clinically relevant pleural effusion, another sign that may be present is the spine sign.[31] The spine sign highlights that in the abdominal cavity, when evaluating in a coronal fashion, the spine is seen along the most posterior aspect. In this view, the vertebral bodies and their associated shadows are not seen over the lung, as the air mucosal surface prevents visualization. When there is fluid replacing where there is usually lung and an air mucosal surface, the vertebra are seen further cranial, past the costophrenic angle. (*See Figure 10.*)

Pneumonia

A 6-year-old female with a history of asthma presents with cough, rhinorrhea, and fever. She is febrile on presentation, with increased work of breathing and poor air entry throughout. She receives an hour of continuous nebulized therapy with only a small improvement in her work of breathing. A chest-X-ray does not demonstrate pneumonia or pneumothorax. A POCUS of her lungs reveals unilateral B lines with a subpleural consolidation consistent with pneumonia. She is started on antibiotics and is admitted for pneumonia with increased work of breathing.

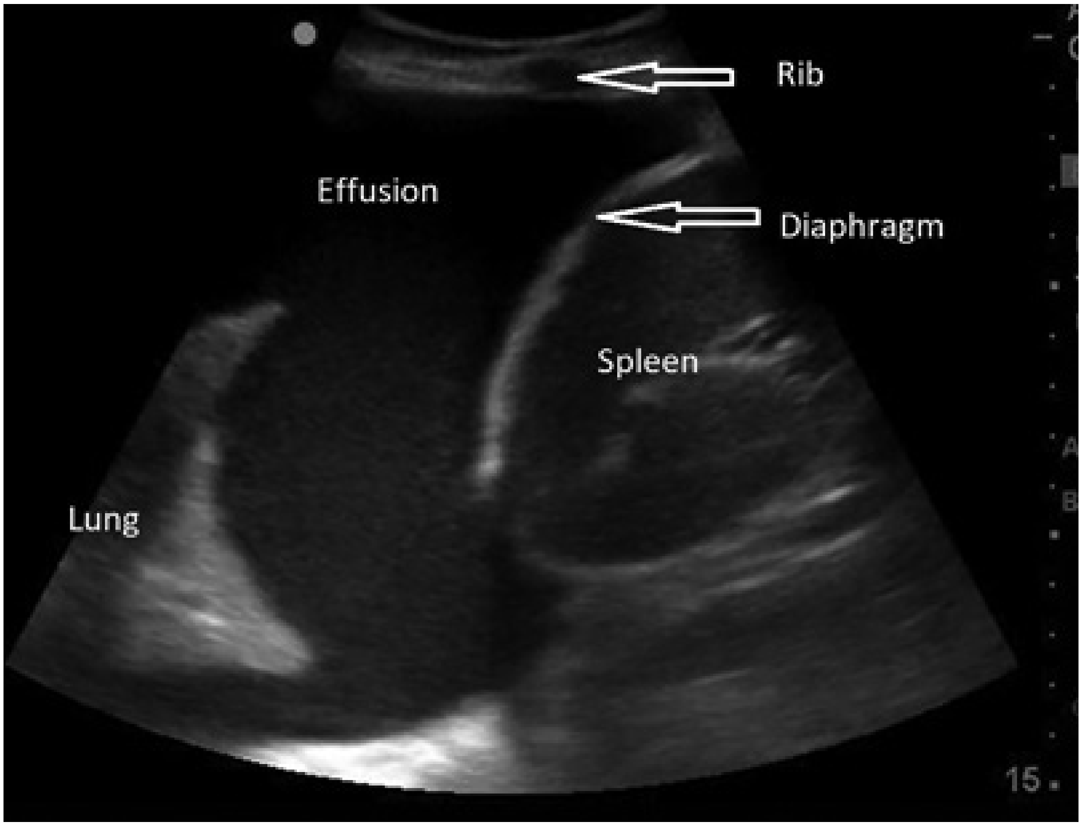
In the past few years, multiple papers have been published describing the use of lung ultrasound for the diagnosis of pneumonia. It shows promise for accurately identifying pneumonia and potentially avoiding X-ray and its associated radiation. In a 2016 study, researchers found novice users were able to reduce chest X-ray use by 30% and advanced users reduced X-ray use by 60%.[32] The most consistent findings associated with pneumonia were consolidation and air bronchograms. Consolidation occurs when the alveoli become filled and are easily visualized by ultrasound. At times, the lung can appear like the liver (hepatization of the lung). Bronchograms show up as hyperechoic spots, but also can signify other processes, such as atelectasis. Dynamic bronchograms, which occur when the bronchograms move during respiration, are thought to be pathognomonic for pneumonia.[33] Sonographic findings consistent with viral pneumonia are B lines, confluent B lines, and subpleural consolidations without associated air bronchograms.[32] Generally, this calls for more portions of the lung to be evaluated with varying protocols. (*See Figures 11 and 12.*)

Conclusion

POCUS is an extremely useful tool to help physicians extend the physical exam. It can assist in the management of the child with undifferentiated shock and can add

Figure 9. Pleural Effusion

Pleural effusion showing hypoechoic area above diaphragm with absence of mirror sign



valuable information when a child's presentation and diagnosis remain obscure. However, it is important to have a means of documentation and quality assurance. Pearls when using POCUS in patient care include staying within the scope of practice of the point-of-care study and including its limitations. It is important to document what is seen, especially any possible anomalies on the ultrasound that need further evaluation or additional imaging. POCUS can become an extension of the physical exam and assist clinicians with safe and appropriate medical decision making.

Figure 10. Pleural Effusion Showing a Positive Spine Sign

The shadows from the vertebrae are seen above the diaphragm, where normally they would not be seen.

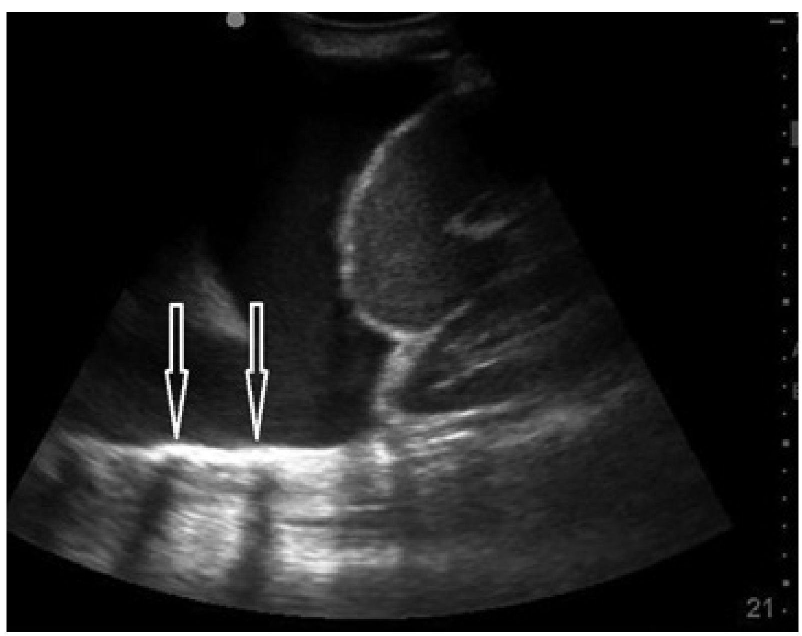


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Figure 11. Air Bronchograms

Thoracic ultrasound showing consolidation of lung as well as air bronchograms

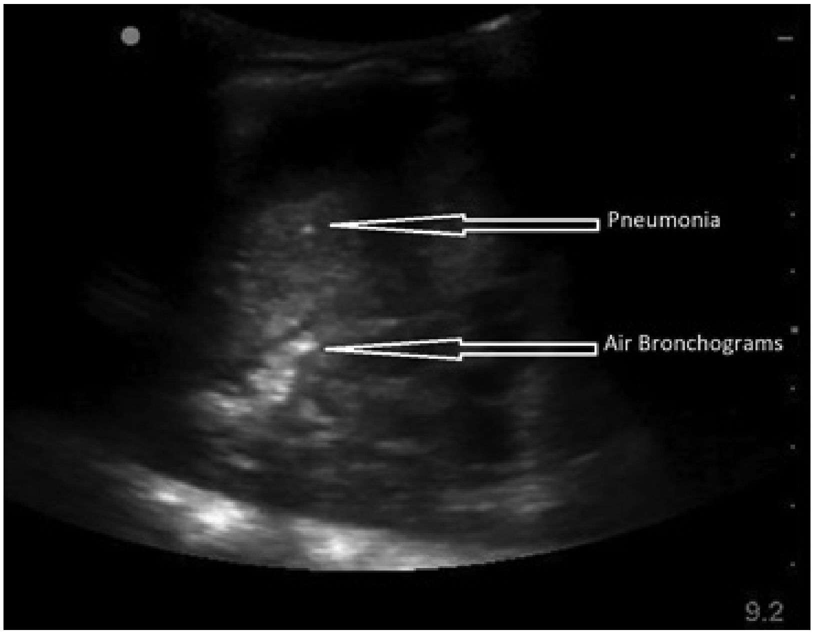
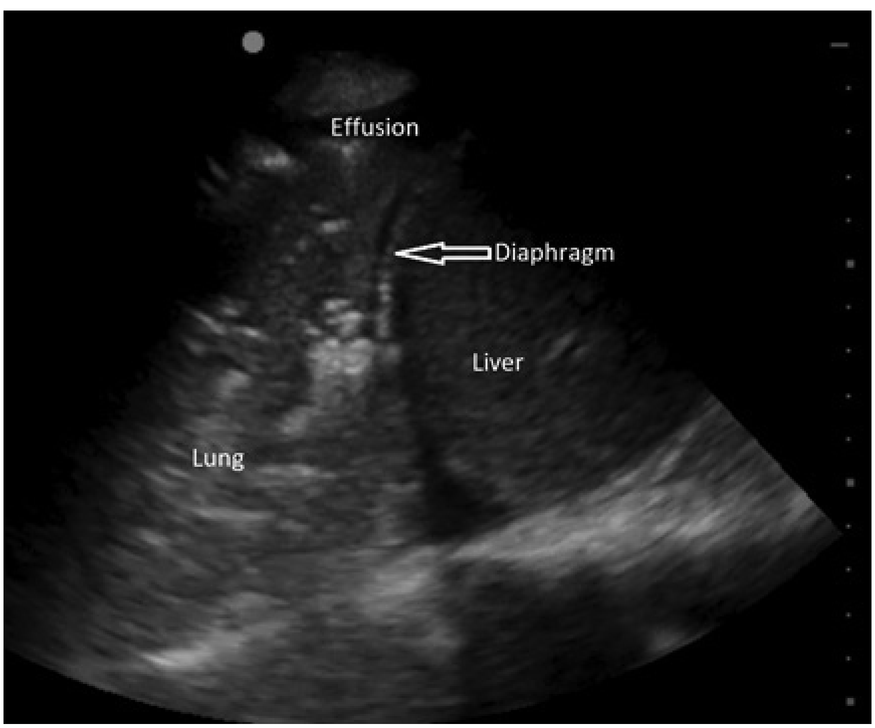


Figure 12. Lung Hepatization

Figure demonstrating lung hepatization associated with pneumonia and small effusion



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CME/CE Questions

1. A 10-year-old female with a history of cystic fibrosis presents with respiratory distress and oxygen saturations in the 60s. You perform ultrasound to rule out pneumothorax. What is the most specific sonographic finding for a pneumothorax?
   a. Lack of B lines
   b. Presence of A lines
   c. Barcode (stratosphere) sign
   d. Lung point

2. A 13-year-old healthy, helmeted male presents as trauma activation after colliding on his bicycle with a motor vehicle and nearly amputating his left leg. Vitals show hypotension of 50/30, heart rate 150 after 20 mL/kg crystalloid, and a successful tourniquet from emergency medical services. Initial trauma survey is benign other than amputation. EFAST shows bilateral lung slide, no pericardial effusion, no free fluid in the abdomen, and a hyperdynamic heart with completely collapsed inferior vena cava. What is the next best step in management?
    a. Proceed with blood product administration
    b. Admit to the PICU
    c. Proceed to CT scanner
    d. Take patient to radiography for a leg X-ray
3. A 6-year-old female presents with cough, fever, tachypnea, and hypoxia with rales in her right lower lobe. Which of the following findings would support a parapneumonic effusion?
    a. Mirror artifact
    b. Vertebra noted inferior to the diaphragm on a coronal view of the right upper quadrant
    c. Pseudohepatization of the lung
    d. Vertebra noted superior to the diaphragm on a coronal view of the right upper quadrant
4. An 11-year-old male with three days of upper respiratory symptoms presents with persistent tachycardia, hypotension, and tachypnea despite antipyretics and fluids. A chest X-ray does not show pneumonia. POCUS shows diminished global left ventricular contractility and a dilated inferior vena cava with minimal respiratory variability. What would be the next best course of action?
    a. Administer a 30 mL/kg bolus, antibiotics, and norepinephrine
    b. Initiate inotropes and admit to ECMO-capable center
    c. Perform pericardiocentesis
    d. Place bilateral chest tubes
5. A 4-month-old male presents with hypoxic respiratory failure with likely bronchiolitis and fails high-flow nasal cannula. The patient is positioned appropriately and is preoxygenated. Subsequently, he is intubated by rapid sequence intubation by a trainee. Immediately following intubation, the patient begins to desaturate. Bedside ultrasound reveals lung slide on the right, with no lung slide on the left. There are associated lung pulses on the left. What is the next best step in management based on these ultrasound findings?
    a. Remove the endotracheal tube and reintubate
    b. Advance the endotracheal tube a few centimeters
    c. Pull back the endotracheal tube a few centimeters
    d. Call for chest X-ray and wait for results
6. A 9-year-old presents with cardiac arrest. Which of the following statements is most true?
    a. Ultrasound cannot help identify reversible causes of cardiac arrest.
    b. It is not possible to see ventricular fibrillation with ultrasound.
    c. If using ultrasound, it is important to minimize interruptions in compressions.
    d. If cardiac standstill is seen in a pediatric patient, that alone is sufficient to stop resuscitative efforts.
7. A healthy, fully immunized 5-year-old female is brought in with fever and cough for six days. The patient is well-appearing, nontoxic, in no respiratory distress, and with normal saturations. Auscultation reveals rales in her left lower lobe. Lung ultrasound shows no pleural effusions, and no pneumothorax. It also reveals in the left lower lobe consolidation with hyperechoic structures that move with respiration. What is the next best course of management?
    a. Bronchodilators with steroids
    b. Chest X-ray
    c. CT chest with contrast
    d. Antibiotics

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- describe the epidemiology, etiology, pathophysiology, and historical and examination findings associated with conditions in pediatric patients presenting to the emergency department;
- formulate a differential diagnosis and perform necessary diagnostic tests;
- apply up-to-date therapeutic techniques to address conditions discussed in the publication;
- discuss any discharge or follow-up instructions with patients.

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Executive Editor: Leslie Coplin
Executive Editor: Shelly Mark
Editorial Group Manager: Terrey Hatcher
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