EB MEDICINE

EM Critical Care

UNDERSTANDING AND CARING FOR
CRITICAL ILLNESS IN EMERGENCY MEDICINE

Emergency Ultrasound In Patients With Respiratory Distress

Abstract

Emergency ultrasound is a highly valuable and readily learned tool that has expanded rapidly since its introduction more than 20 years ago. In the past decade, emergency ultrasound has progressed from 6 to 11 primary indications. The earliest applications of emergency ultrasound answered questions regarding the presence or absence of life-threatening clinical conditions and enhanced patient safety through procedural guidance. More recently, it has lent itself to the evaluation and management of critically ill patients through the incorporation of multiple ultrasound examinations within a single patient encounter. The information gained can provide crucial, time-dependent information at the bedside, which can enhance diagnostic certainty and guide management. This issue of *EMCC* provides an evidence-based approach to the use of ultrasound in the evaluation of the critically ill patient with respiratory distress and hypotension. Two clinical scenarios are presented: the progressively dyspneic patient with a history of chronic obstructive pulmonary disease (COPD) and decompensated heart failure and the acutely dyspneic patient with hypotension. These scenarios were chosen because they are commonly encountered in clinical practice and require rapid, complex decision making that is augmented with the use of emergency ultrasound. The evidence supporting emergency ultrasound for diagnosis of pulmonary edema, pneumothorax, left ventricular (LV) dysfunction, and right ventricular (RV) dysfunction is presented, and the technique for image acquisition is discussed.

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Authors

Christine B. Irish, MD, FACEP
Associate Director of Emergency Medicine and Director of Emergency Ultrasound, Maine Medical Center, Portland, ME; Assistant Professor, Tufts University School of Medicine, Boston, MA

Liisa O. Carden, MD
Department of Emergency Medicine, Maine Medical Center, Portland, ME

Peer Reviewers

Haney Mallemat, MD
Assistant Professor, Department of Critical Care / Emergency Medicine, University of Maryland Medical Center; Department of Critical Care, Shock Trauma Center, Baltimore, MD

Scott J. Millington, MD
Chef de Clinique, Service de Médecine Intensive Adulte, Centre Hospitalier Universitaire Vaudois, Lausanne, Suisse, Switzerland

Daniel J. Singer, MD
Fellow, Emergency Ultrasound, Mount Sinai School of Medicine, New York, NY

CME Objectives

Upon completion of this article, you should be able to:

1. Recognize the unique sonographic features of and utilize the basic technique for image acquisition of each of the following disease processes: decompensated heart failure, PE with right heart strain, pericardial tamponade, and pneumothorax.
2. Describe the advantages to each of several different transducers types and select the appropriate transducer for the various pulmonary and cardiac examinations discussed within the article.
3. Describe basic sound wave principles, physics, and common artifacts that are relevant to emergency ultrasound.
4. Summarize the emerging role of point-of-care ultrasound in patients with acute respiratory failure and/or hypotension.

Prior to beginning this activity, see "CME Information" on the back page.

Case Presentations

You are the single-coverage physician on overnight duty at a rural, community ED. Your shift is running seamlessly until 2 patients in respiratory distress come into your critical care bay within 20 minutes of each other. While examining patient #1, you are notified of the impending arrival of another peri-code patient, patient #2, with an ETA of 10 minutes.

***Patient #1:** A 68-year-old woman unknown to you or the EMS transport team arrives sitting upright in the tripod position with a nonrebreather in place. EMS reports an oxygen saturation at her home of 85% on room air. She's afebrile, hypertensive to 200/100 mm Hg, tachypneic to 28 breaths per minute, and tachycardic with an ECG en route revealing rapid atrial fibrillation with a heart rate of 120 beats per minute but no apparent ischemic changes. The patient is alert and nodding her head in response to questions. She is in severe respiratory distress with accessory muscle use. She is obese and jugular venous distension is difficult to appreciate. On auscultation, she is tachycardic with an irregular rate and rhythm, and you note poor air movement with scattered wheezes and a prolonged expiratory phase. Her skin is dry, with peripheral cyanosis and 1+ lower extremity edema bilaterally. After your initial assessment, the patient's daughter arrives and provides additional history. The patient is visiting from out of state and has not seen a doctor in several years. The patient was told at one time that she had a "heart attack" and has a fifty pack year smoking history. Over the last several days, however, the patient's daughter noted that she seemed more short of breath than usual, with an increasing cough. You call the respiratory therapist to initiate NIV and consider your options for further management and therapy. Your leading diagnoses are COPD exacerbation or decompensated CHF. Before initializing therapy for either, you order an ECG, appropriate labs, and a portable chest x-ray. Your suspicion for PE is low at this point, but you are considering myocardial ischemia and give the patient 325 mg of aspirin. While waiting for results, your thoughts turn to the imminent arrival of patient #2 and wish for an expedient method to focus the diagnosis on your current patient. You remember the recent* EMCC *article you read on the use of thoracic ultrasound and you decide to look for your department's ultrasound machine...*

***Patient #2:** A 40-year-old woman arrives to your critical care bay supine with eyes closed. EMS relays her chief complaint of dyspnea, and vitals en route were significant for tachycardia (heart rate of 110 beats per minute), hypotension (BP of 80/40 mm Hg), and tachypnea (RR of 24 breaths per minute). The patient is hypoxic as well, with an oxygen saturation of 90% on 6 L NC. She is morbidly obese, is alert to voice, and answers questions appropriately. Pertinent exam findings reveal a midline trachea without appreciable jugular venous distension, no murmurs by auscultation, and clear breath sounds without accessory muscle use. The abdominal exam is unremarkable. Extremities are poorly perfused without evident lower extremity edema. She has a history of lupus, for which she just restarted taking her daily steroids. She is otherwise healthy, uses no other medicines, and does not smoke or drink alcohol. She states that she was in her regular state of health until earlier today when she began to feel short of breath and had chest discomfort. She recently recovered from a mild respiratory infection with resolved symptoms of pharyngitis, cough, and clear rhinorrhea. She denies other pertinent symptoms. During the physical exam, the patient's mentation declines, and her extremities become increasingly mottled...*

Introduction

Dyspnea is a frequent presenting complaint to emergency departments (EDs), comprising between 3% and 4% of all United States ED visits in data from recent years.[1] The differential diagnosis of dyspnea in ED patients is broad and may be classified into cardiogenic and noncardiogenic causes. In particular, disease processes such as decompensated heart failure, pneumothorax, pericardial tamponade, pneumonia, exacerbations of chronic obstructive lung disease, and pulmonary embolism (PE) require urgent and accurate diagnosis, which is challenging for even the most astute clinician, given the frequent overlap of preexisting pulmonary and cardiac diseases as well as the variation in presenting symptoms. Patients with pericardial tamponade, severe sepsis, PE, pneumothorax, and cardiogenic shock can all present with dyspnea and hypotension. Physical examination and current test characteristics are also limited by low sensitivity and specificity. Findings such as rales, peripheral edema, and jugular venous distension (JVD) are invariably present and may result from multiple different physiologic derangements.[2,3]

Mortality is high in patients presenting with acute respiratory failure, with estimates of up to 20% in patients greater than 65 years of age. In patients with both respiratory failure and associated hypotension, mortality increases. Inappropriate initial diagnosis is also associated with increased mortality and may occur in up to 20% of patients presenting with acute respiratory failure.[3] Given the predictable intersection in symptom presentation, physical examination findings, and possible diagnoses in a patient with acute respiratory failure and/or hypotension, diagnosis and treatment can be aided by assessment of intravascular volume status. Evaluation of intravascular volume in hypotensive patients was historically achieved through the use of pulmonary arterial catheters, which provided continuous hemodynamic data but exposed patients to complications due to the invasive nature of the procedure, and it did not have any demonstrated benefit in large trials.[4]

Emergency ultrasound can narrow diagnostic considerations and guide treatment in patients with acute respiratory failure and hypotension and enables clinicians to estimate intravascular volume status through noninvasive means. In patients with respiratory distress, emergency ultrasound has many roles that may be exploited by the clinician assessing the critically ill patient. This issue of *EMCC* will focus on the use of emergency ultrasound in patients with acute respiratory failure. Evidence will be explored that supports the use of emergency ultrasound in this patient population, and the technique for relevant bedside thoracic and cardiac ultrasound examinations will be presented.

Critical Appraisal Of The Literature

A comprehensive search of the literature was performed using OVID MEDLINE® and PubMed from 1950 to present. The following topics and search headings were used: *ultrasound in shock, thoracic ultrasound, ultrasound and pneumothorax, ultrasound and dyspnea, ultrasound and pulmonary edema, ultrasound and pleural effusion, ultrasound and pulmonary embolism, ultrasound in critical care, sonographic B lines, ultrasound comet tails, ultrasound and lung sliding,* and *emergency echocardiography.* More than 150 articles were reviewed. In addition, the 2001 and 2008 American College of Emergency Physician (ACEP) Ultrasound Guidelines were also consulted.[5,6]

Patient Selection And Special Considerations

Emergency ultrasound in critically ill patients is an attractive technology for many reasons. All patients with acute respiratory failure may have an emergent ultrasound examination performed. There is little risk to the patient from the examination itself. As opposed to computed tomography (CT), there is no risk from radiation or contrast exposure. In the pediatric patient, there is no necessity for sedation in order to obtain the study. Patient selection is relatively unrestricted, and all patients with undifferentiated hypoxemia are potential candidates. Image quality can be limited in obese patients, and patients with distorted chest wall anatomy or underlying diseases (bullous emphysema) may have false positive studies. Images can be obtained in either the supine or upright position, which may be an important consideration in the hypoxic patient who is unable to lie supine for CT or other diagnostic studies.

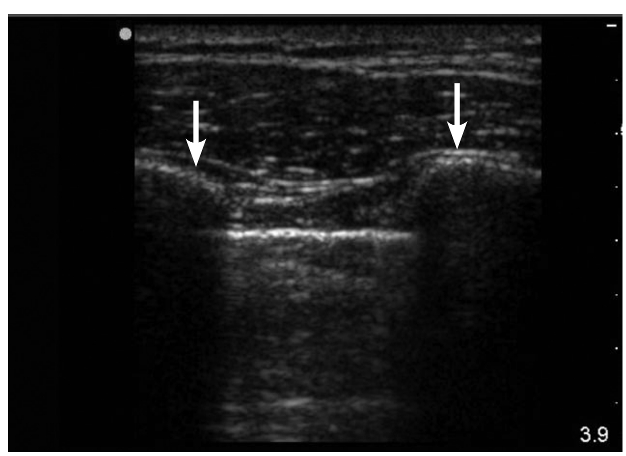
Emergency Ultrasound Basics

Emergency ultrasound is unique in the fact that the clinician has a dual role, serving as both the sonographer generating the images and interpreter of the acquired images. In order to maximize image quality and minimize misinterpretation, the clinician should be familiar with a few fundamental concepts of ultrasound physics as well as common artifacts that may be encountered during a focused examination. This section will present several relevant definitions and ultrasound properties.

The "gray scale" designation of diagnostic ultrasound refers to the image shade on a black-white color scale and depends on multiple factors, such as wave amplitude (intensity), attenuation (loss of energy), and reflection. Attenuation is the loss of sound energy as waves travel through a given medium and is affected by tissue density (impedance), wavelength, and the number of interfaces encountered. **(See Table 1.)** Tissues such as bone, diaphragm, and pericardium have the greatest impedance, which results in greater reflection back to the transducer, producing images that are hyperechoic (bright white). **(See Figure 1.)** Tissues with moderate impedance generate hypoechoic (gray) images, as demonstrated with organs such as the liver, spleen, and uterus. **(See Figures 2 and 3.)** Fluids such as unclotted blood, urine, and ascites generally produce anechoic (black) images. **(See Figure 3.)** The various densities of tissues within the human body allow for detailed image generation and distinction of neighboring structures.[7,8]

Refraction is redirection of sound waves as they cross tissues of various densities. Refraction may occur from direct reflection or from scatter due to poor scanning angle or presence of air and gas within tissues. Scatter results in indistinct, poorly resolved images. The sonographer can minimize scatter by scanning perpendicular to the patient's skin. Ultrasound velocity (the product of frequency and wavelength) is the speed of the sound wave and remains constant for a given medium. Since velocity

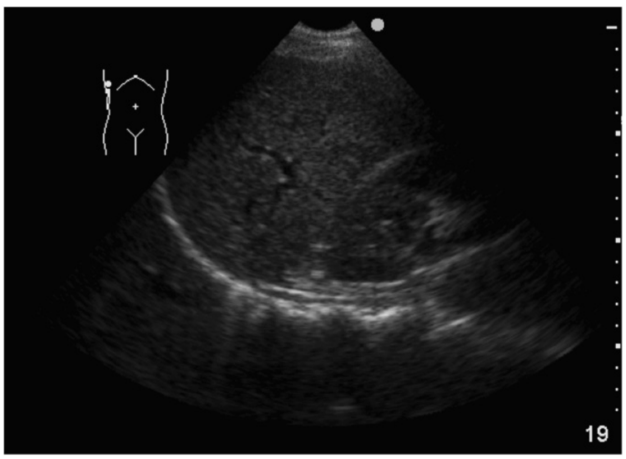
Figure 1. Ultrasound With High Impedance



Bony cortex of ribs (arrows) with high impendence, resulting in a hyperechoic signal generated at the cortical margin. Deep to this signal is a characteristic rib shadow.

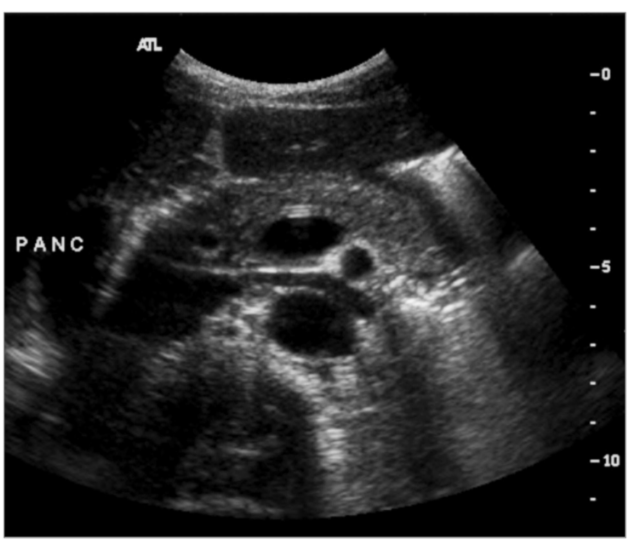
is constant for a given tissue, the sonographer must manipulate frequency (and inversely wavelength) to optimize image acquisition and tissue penetration. Resolution is the ability to discriminate between two objects that are closely spaced within a tissue; it may be improved by selection of higher frequency transducers. Lower frequency transducers have deeper tissue penetration and decreased image resolution. In clinical practice, this translates to the selection of high frequency probes for optimal visualization of small, superficial structures (such as blood vessels and nerves) and the selection of low frequency probes for imaging of deeper abdominal and cardiac structures. **(See Figures 4A-D and 5A-D.)**

Figure 2. Ultrasound With Moderate Impedance



The liver has moderate impedance and is reflected along the middle of the gray scale color spectrum.

Figure 3. Ultrasound Showing Moderate And Low Impedance



Anechoic abdominal vasculature and hypoechoic pancreas demonstrate moderate (pancreas) and low (abdominal vasculature) impedance.

Artifacts are echoes on the ultrasound screen that do not correspond to true anatomic findings. It is important to recognize common artifacts to prevent misinterpretation of acquired images. We will briefly discuss 4 artifacts: reverberation, mirror, shadowing, and enhancement. Reverberation occurs with multiple reflections of sound waves at the same interface and appears as numerous horizontal hyperechoic lines on the screen. This is commonly exhibited in scans of the bladder and lung pleura. **(See Figure 6.)** Mirror is a duplicate representation of an image at an incorrect location and occurs when a structure is in front of a strong reflector, such as the diaphragm. When scanning the right upper quadrant, mirror artifact created by the diaphragm often produces the false impression of hepatic tissue in the costophrenic angle above the diaphragm. **(See Figure 7.)** Posterior acoustic enhancement is demonstrated when tissues that are posterior to a fluid-filled structure appear more hyperechoic. The fluid-filled structure creates minimal attenuation and results in enhanced echoes posteriorly. This is commonly demonstrated with imaging of the urinary bladder. **(See Figure 8.)** Shadowing is defined as an anechoic signal produced when sound waves fail to pass through a tissue. This is often demonstrated in tissues that have higher densities, such as bony cortex or gallstones. **(See Figure 1.)**

Tools And Techniques

There are several basic principles of machine usage and transducer selection that are important for a clinician to understand in order to optimize image quality. Transducers create sound waves by creating vibration across crystals located within the probe, which may be arranged in various configurations for sound wave propagation. As noted in the previous section, each transducer has a range of frequencies that may be adjusted depending on desired resolution (increase frequency) and penetration (decreased frequency). The transducer's "footprint" is the portion of the probe that contacts the patient's skin. A transducer with a small footprint should be selected when imaging areas such as the thorax, upper abdomen, and

Table 1. Image Characteristics Of Various Human Tissues

Medium	Image Characteristics
Air	Poor quality due to scatter
Water	Anechoic (black)
Blood	Anechoic (black)
Fat	Hypoechoic to isoechoic (dark to lighter gray)
Muscle	Isoechoic (lighter gray)
Bone	Hyperechoic (bright white)

heart to minimize shadowing artifact created by ribs.

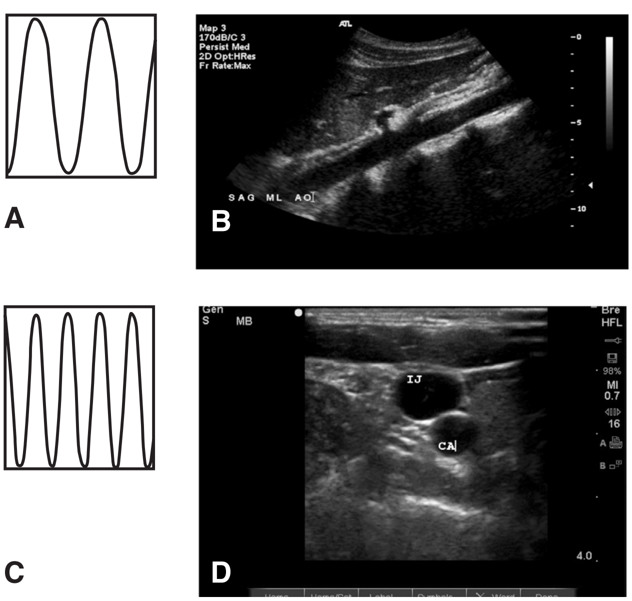
Another key to successful image acquisition is appropriate preparation, with lights turned down, patients positioned appropriately, and attention to patient privacy. Images should be labeled with relevant information, including name, date, and medical record number. The sonographer should also ensure that the probe marker and screen marker are correctly aligned. **(See Figure 9.)**

Clinical Course In The Emergency Department

Patient #1: Emergency Department Approach To The Progressively Dyspneic Patient

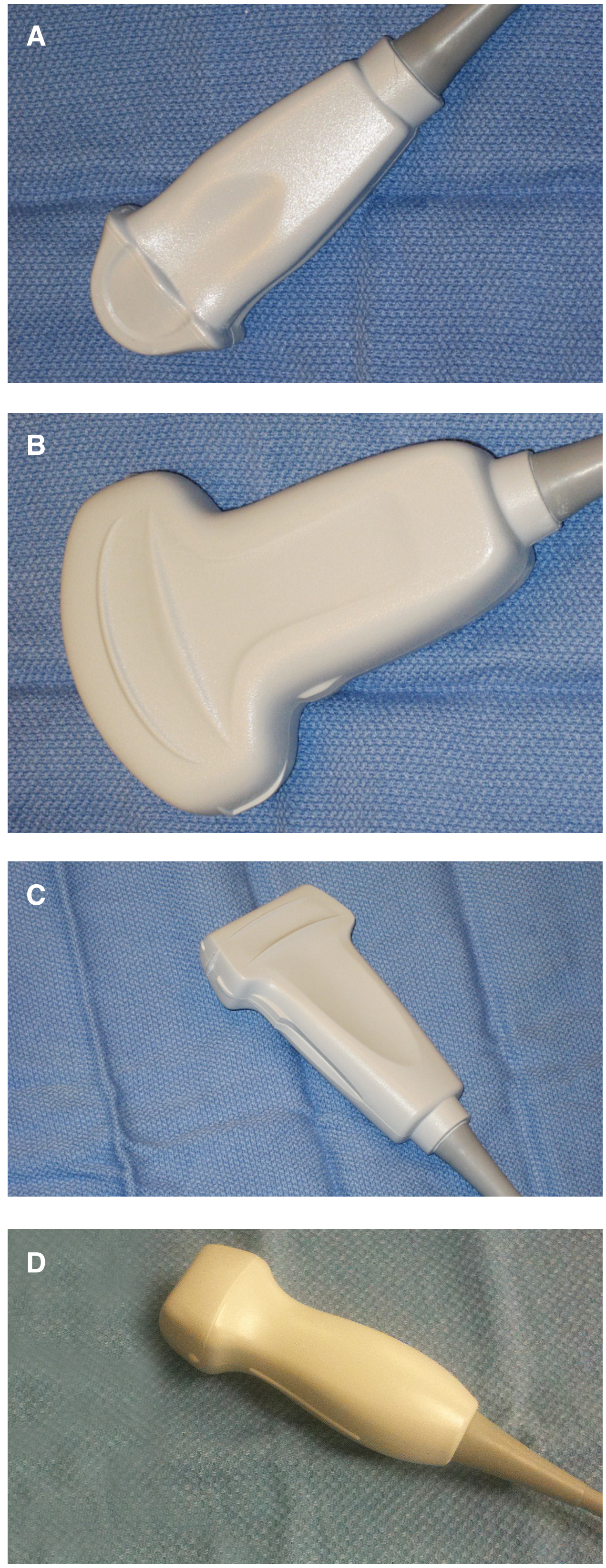
Patient #1 represents a common presentation to the critical care bay of an ED. This patient may arrive to your ED on bi-level noninvasive ventilation, unable to provide verbal answers to your questions regarding a history of coronary artery disease, congestive heart failure (CHF), or COPD. Acutely decompensated CHF can present with a multitude of clinical symptoms, and studies have shown the difficulty in relying on clinical parameters, chest x-ray, or laboratory tests to accurately diagnose decompensated CHF in the ED.[4,5,9] Overall sensitivity of chest radiography is limited by film technique, time of symp-

Figure 4. Relationship Of Wave Frequency And Tissue Penetration



A. Lower frequency wavelength provides higher penetration but with lower resolution; B. abdominal aorta as an example of higher abdominal penetration from low frequency transducer; C. higher frequency wavelength provides lower penetration and higher resolution; D. superficial vascular structures demonstrating higher resolution with high frequency transducer.

Figure 5. Transducers

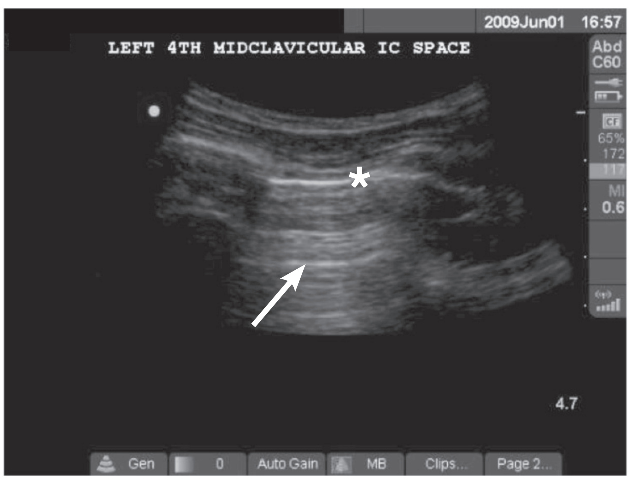


A. Microconvex low-frequency transducer with small footprint; B. curvilinear low-frequency transducer; C. linear high-frequency transducer; D. phased array transducer.

tom onset, and variation in provider interpretation. Laboratory tests such as brain natriuretic peptide (BNP) have high predictive values when levels are high or low, but a large zone of diagnostic uncertainty exists with mid-level BNP results.[10]

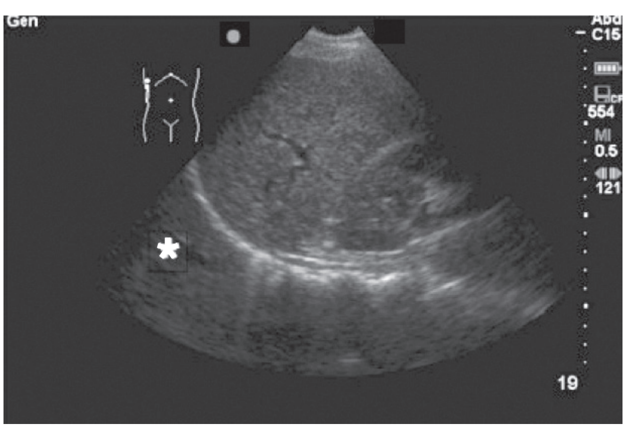
As emergency physicians, we must rely on clinical diagnostics, portable imaging, and laboratory tests to provide effective care. Point-of-care ultrasound has been shown to be more accurate than physical examination, chest radiography, or laboratory testing to distinguish CHF from COPD in critically ill patients.[9,11-15] In addition to visualizing pulmonary edema, point-of-care ultrasound can strengthen the diagnostic certainty with additional findings of pleural effusions and/or LV dysfunction.

Figure 6. Reverberation Artifact



Reverberation artifact created by duplication of pleural line (*) in equally spaced intervals (arrow).

Figure 7. Mirror Artifact Created By Diaphragm



Hepatic parenchyma is falsely reproduced above the diaphragm (*).

COPD Versus CHF

Defining Features

COPD is a noncardiogenic cause of dyspnea. An acute exacerbation of COPD results in progressive worsening of the patient's baseline symptoms of dyspnea and cough; it is often secondary to an inciting factor such as infection or other environmental exposure. Airway inflammation intensifies, which results in reduced expiratory airflow and a worsening of alveolar gas exchange; these patients present clinically with mild to severe symptoms of respiratory distress.

CHF is a cardiogenic cause of dyspnea. The clinical syndrome of decompensated heart failure is characterized by secondary organ dysfunction, including but not limited to pulmonary edema. Cardiogenic pulmonary edema leads to progressive deterioration of alveolar gas exchange and subsequent respiratory failure. Without prompt recogni-

Figure 8. Posterior Acoustic Enhancement Beyond Urinary Bladder (*)

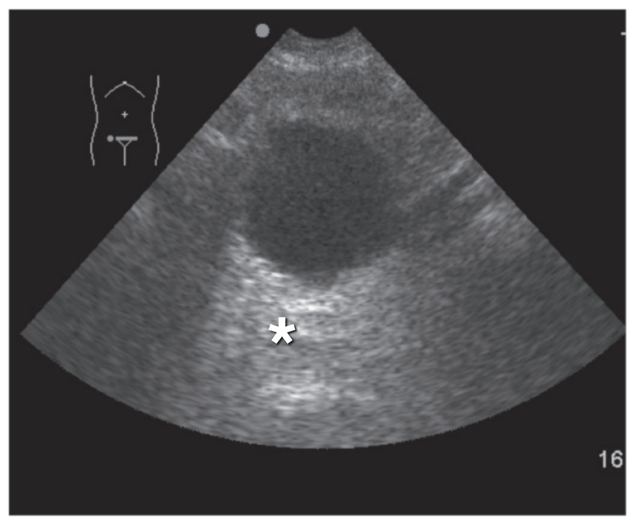
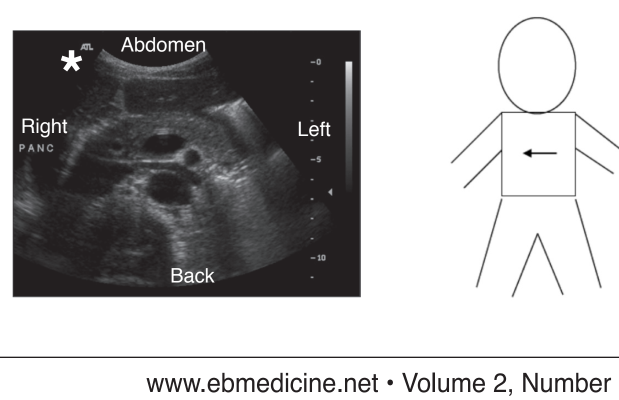


Figure 9. Alignment Of Transducer Marker Dot With Screen Marker (*) And Corresponding Anatomic Orientation (Transverse View Of Upper Abdomen Pictured)



tion and treatment in the ED, a patient's condition can deteriorate rapidly.

Presentation

The signs and symptoms of COPD and CHF may be similar. Predominant symptoms include exertional dyspnea and, in severe cases, dyspnea at rest. Orthopnea and paroxysmal nocturnal dyspnea are more specific for CHF but are not sensitive enough for reliable diagnosis. Physical examination findings that distinguish the 2 disease processes are also unreliable. Body fluid retention in decompensated CHF with left heart dysfunction is reflected in physical signs of congestion, such as lower extremity edema, JVD, and pulmonary rales. In patients with longstanding COPD, there is an element of right-sided heart failure (cor pulmonale) that results in similar signs of bodily congestion, including lower extremity edema and JVD without pulmonary edema. The pulmonary wheezing heard on auscultation of patients with COPD may be confused with the "cardiac wheeze" in patients with decompensated CHF.[4,16,17]

Point-of-Care Ultrasound

Evidence: Lichtenstein et al first described the sonographic diagnosis of alveolar-interstitial syndrome as diffusely visible sonographic B lines.[11,18] B lines are characterized by several identifying features that must exist before becoming significant in the diagnosis of pulmonary edema. **(See Table 2.)** In Lichtenstein et al's 1998 prospective study, they found a sensitivity of 100% and specificity of 92% for the detection of pulmonary edema with thoracic ultrasound. This study looked for bilateral detection of "disseminated" B lines at the anterolateral lung surface or at the lateral lung surface.[18] Further studies have found similarly favorable results in the use of ultrasound in the diagnosis of pulmonary edema, including a correlation of sonographic B lines with wedge pressure and extravascular lung water.[12,19-21]

False positives have been noted, in particular caused by B lines that are confined to the very inferior portion of the lateral lung surface above the diaphragm. B lines in this location can be present in normal lungs.[11,22] Volpicelli et al have since declared the necessity of identifying characteristic B lines in at least 2 of the 4 zones on each side of the chest to make the sonographic diagnosis of pulmonary edema.[13,22] They simplified a standard sonographic scanning technique, which is further described in the **Probe Selection and Positioning** section and in **Figure 10** to facilitate these diagnostic criteria. The "Volpicelli" scanning technique and criteria for diagnosis **(Table 2)** has since been validated in a prospective study, which found that the accuracy of the diagnosis is similar with 2 positive zones on each side of the chest compared to all 8 positive zones of the chest.[14]

There are several potential benefits of point-of-care thoracic sonography over other imaging modalities. Chest radiography is often not immediately available in the critical care scenario. Baseline findings of chronic illness (either COPD or CHF) may be present on chest radiography and can be potentially misleading in the acutely dyspneic patient.[9] Anterior-posterior portable chest radiographs are difficult to interpret, and inaccurate diagnostic anchoring in these critically ill patients can be detrimental.[5] Transporting the critically ill patient to CT is difficult at best, and it was shown in a small prospective study of 32 patients that CT concordance with sonographic detection of interstitial edema is 100%.[23]

Studies comparing accuracy of sonographic B lines to chest radiography and final discharge diagnoses have also been performed. Sensitivities range between 86% and 93%, and specificities range between 93% and 98%.[11,13,19,24,25]

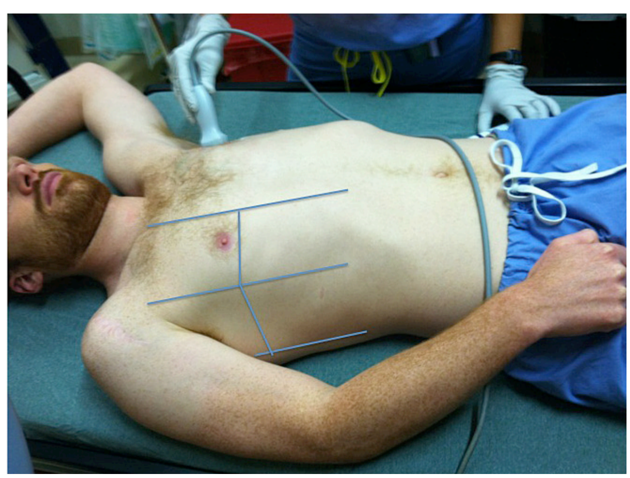
Serum BNP (or NT-proBNP) is a sensitive marker of CHF, though recent studies have questioned its sensitivity in the acute setting of the ED.[26-28] A prospective observational study directly compared serum BNP and thoracic ultrasound in

Table 2. Requirements For Sonographic Diagnosis Of Pulmonary Edema

1. B lines are seen in at least 2 of the 4 zones on each side of the chest
2. All of the 6 defining features* of B lines are met

*The 6 defining features of B lines are: (1) vertically directed beams, (2) originate at the pleural line, (3) spread without extinction to the far edge of the screen, (4) synchronous with lung sliding, (5) ≥ 3 B lines are visualized per scan/screen image, and (6) each B line is distanced from the other by ≤ 7 mm.

Figure 10. Depiction Of The 4 Lung Zones, Divided By A Parasternal Line, Anterior Axillary Line, And Posterior Axillary Line



the diagnosis of pulmonary edema and found that sonographic findings alone are adequate in facilitating the diagnosis, and they performed similarly to the serologic use of BNP. Notably, the specificity of thoracic ultrasound is superior to that of BNP.[14]

The sonographic evaluation of pleural effusions and LV dysfunction are adjuncts to the evaluation of the dyspneic patient in whom CHF is a primary concern. The sensitivity of sonographic detection of pleural effusions is nearly that of CT imaging and is superior to the supine chest x-ray. Bedside chest radiography fails to detect most effusions < 525 mL.[21,29] The sensitivity and specificity of detecting pleural effusions by ultrasound are 93% when CT is used as the gold standard. When thoracentesis is used as the gold standard, the specificity is 97%.[30] Sonographic evaluation of the inferior vena cava (IVC) may be used as a surrogate marker for central venous pressure (CVP) and, more practically, it can provide useful information on overall volume status and is discussed in detail later in this article.

Lastly, focused echocardiography allows the emergency physician to visually estimate LV function. This facilitates clinical decision making and therapeutic interventions in the patient with impaired systolic function.[31] The goal for the emergency physician is to obtain a global assessment of LV systolic function, which can be categorized as "normal," "moderately depressed," or "severely depressed." These descriptive terms, when used by emergency physicians, have high correlation with echocardiographer interpretations.[32,33] Emergency physicians are less accurate when assessing valvular dysfunction, regional wall motion abnormalities, and subtle findings of RV dysfunction.[32,34]

Probe Selection And Positioning: Any of the common transducers, regardless of frequency, (including the linear, curved, and phased array transducers) may be used to carry out thoracic ultrasound in assessing for B lines and have similar accuracies. Lichtenstein, the founding father of thoracic ultrasound, considers the 5 MHz microconvex transducer to be the best probe for detecting pulmonary pathology.[15] His enthusiasm for this transducer can be related to its ability to maneuver the rib cage (with minimal bony artifact) and successfully analyze interstitial artifacts. It also allows the sonographer to use the same probe for both thoracic ultrasound and echocardiography.

There are several techniques for assessment of B lines; the uniting principle of each technique is to scan bilaterally and diffusely for a global assessment of the lungs. For simplicity, we will describe the Volpicelli technique in this article.[13,14,22] The sonographer will scan the chest on both sides, in the anterior and lateral positions, collecting images in a total of 8 zones. The borders of each zone are denoted in **Figure 10**.

To detect pleural effusions, a low frequency (phased, curved, or microconvex) transducer can be used in the semi-supine patient to visualize dependent lung regions at the inferolateral base at the level of the last intercostal space. Longitudinal views of the right and left costophrenic angles should be obtained, similar to the focused assessment with sonography for trauma (FAST) examination. This transducer placement allows visualization of the hyperechoic diaphragm and the effusion, if present, above it.

Focused echocardiography of the dyspneic patient can be performed with the phased array probe, with the patient in the supine or left lateral decubitus position. The probe will be positioned to visualize the left ventricle in the parasternal long and short views, the apical view, and the subxiphoid view, as will be discussed later in this article.

Sonographic Findings: Identification of 2 specific sonographic artifacts is helpful in distinguishing COPD from CHF. Recall that air causes scatter of ultrasound waves while fluid facilitates transmission. COPD is a disease of the bronchi, yielding a normal lung surface. CHF is a disease of the interstitium and pleural space, both of which reach the pleural surface and result in detectable pathologic sonographic findings. COPD is usually diagnosed by clinical symptoms and compelling history; sonographically, COPD is distinguished from CHF by the absence of pathologic ultrasound findings.

Aerated or hyperaerated lungs are seen in patients with normal lungs, asthma, or COPD and are sonographically pictured as A lines. A lines are hyperechoic, horizontal lines visualized parallel to the pleural line and are caused by reverberation artifact between the probe and pleural line. **(See Figures 6 and 11.)**

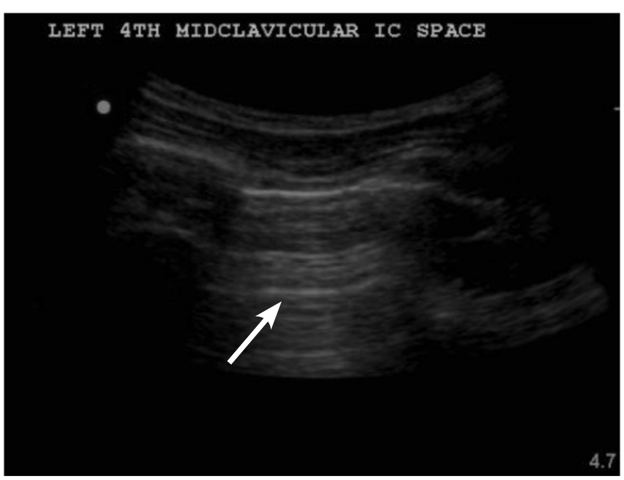
Thickened interstitial or fluid-filled alveoli are seen as vertical artifacts (B lines) and are seen most commonly in patients with extravascular lung water or pulmonary edema, as seen in CHF. B lines are generated as continuous back-and-forth reflections of the ultrasound beam trapped between air- and water-rich pulmonary structures. **(See Figures 12 and 13.)** The defining features of the B lines of pulmonary edema are: (1) they are vertical beams, (2) they arise from the pleural line, (3) they spread all the way to the edge of the screen without fading, (4) they are synchronous with lung sliding, (5) there are at least 3 B lines seen on the screen using a microconvex probe, and (6) they are distanced from each other by no more than 7 mm.[11,13] **(See Table 2.)** Visualization of isolated B lines or visualization of multiple B lines with a distance between each greater than 7 mm are considered nonpathologic findings and are not representative of the thickened interlobular septa that generate the artifacts of B lines. B lines that are isolated to one or both posterolateral lung zones should raise suspicion for alveolar consolidation in the appropriate clinical context or may actually be a normal finding.[11]

Decompensated CHF may be accompanied by pleural effusions.[35] Transudative effusions, as may be found in CHF, should be anechoic and homogenous. If there are particles or septa visible, this is suggestive of an exudate or hemothorax and may suggest an alternate diagnosis.[36] Transudative effusions are characterized by their borders and dynamic nature. The effusion will be outlined on the screen by the pleural line superiorly and the visceral line inferiorly, with rib shadows on each vertical side of the effusion. The diaphragm, liver/spleen, and lung will be seen as surrounding echoic structures as well. When M-mode is used, the pleural effusion will reveal a sinusoid pattern formed by the respiratory variation of the effusion between the visceral and parietal pleura.[37] **(See Figures 14 and 15.)**

Focused echocardiography can also be used to grossly quantify the patient's LV function with excellent correlation with expert interpretation, but an in-depth discussion is beyond the scope of this article. As discussed earlier, emergency physicians have been shown to adequately and reliably assess global LV systolic function by visually estimating the left ventricle's contractility in video imaging.[32] This skill, like most diagnostic imaging modalities, requires previous knowledge of the appearance of a normally contracting LV in order to recognize the hypokinetic LV. More thorough echocardiographic evaluation (eg, of segmental wall motion abnormalities, diastolic dysfunction, and valvular pathology) requires advanced training and is not routinely undertaken by point-of-care sonographers in the ED.

IVC diameter and respiratory variation can provide additional clues to CVP and right-sided filling pressures, which are often elevated in patients with decompensated CHF. This technique is fully discussed in the **Pulmonary Embolism** section of this article.

Figure 11. "A line" Created By Reverberation Artifact



Caveats: Both ultrasonography and CT imaging can be imprecise in determining the etiology of thickened interlobular septae, or B lines, as it is a relatively nonspecific sign. The differential includes cardiogenic versus noncardiogenic causes of pulmonary edema (eg, acute respiratory distress syndrome [ARDS]).

Patient #2: Emergency Department Approach To The Acutely Dyspneic Patient

Cardiac Tamponade

Defining Features

Pericardial tamponade is defined as an abnormal collection of fluid within the pericardium that causes compression of the heart. The adverse hemodynamic

Figure 12. "B Lines" Arising From Pleural Line

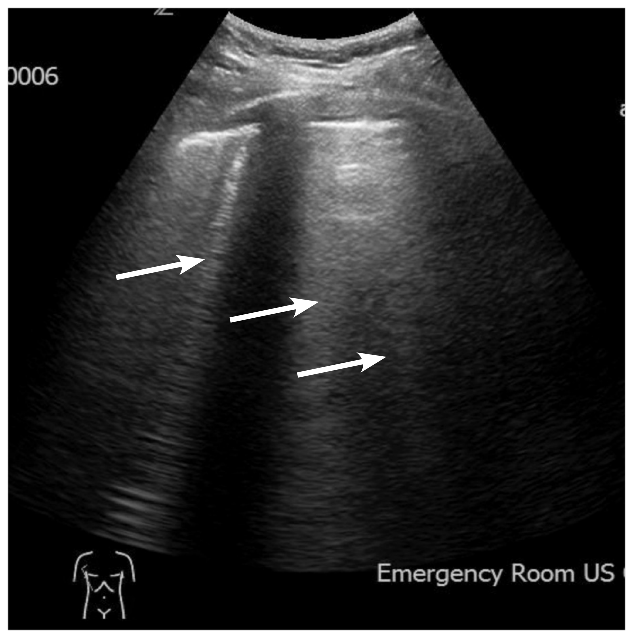
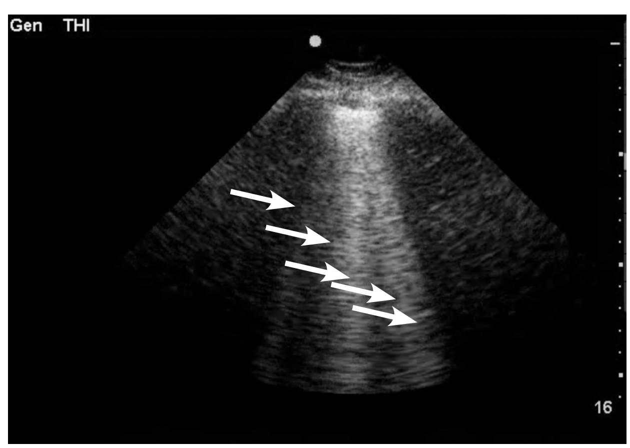


Figure 13. Diffuse "B Lines"



effects of tamponade depend on the rate at which fluid collects as well as the amount of fluid present. A slowly progressive effusion may initially be asymptomatic, while a rapidly accumulating effusion may cause tamponade physiology with much smaller volumes of fluid. Once tamponade is present, there is reduced ventricular filling and decreased cardiac output with eventual hemodynamic collapse if undetected or untreated. Rapid recognition of symptoms, diagnosis, and treatment is essential to minimize mortality. The diagnosis may be detected readily using point-of-care echocardiography.[38]

Presentation

The variable symptoms of cardiac tamponade may include dyspnea, palpitations, tachypnea, and mottled extremities secondary to distal hypoperfusion. The classic physical examination findings of tamponade include tachycardia and Beck's Triad (distant heart sounds, increased JVD, and hypotension) are insensitive and should not be relied upon for diagnosis.[39] Pulsus paradoxus is an abnormally large decrease in blood pressure during inspiration, defined as a drop > 10 mm Hg. Electrical alternans may be present on electrocardiography or telemetry. This alternating voltage pattern results from the heart "swinging" in a fluid-filled pericardial sac. **(See Figure 16.)** The utility of pulsus paradoxus and electrical alternans in the diagnosis of pericardial tamponade is limited by the low sensitivity of both findings.[40,41]

Chest radiography, similarly, lacks diagnostic performance to routinely rule in or rule out the diagnosis.[42] Point-of-care echocardiography, in properly trained hands, allows for much greater diagnostic accuracy than history, physical examination findings, or plain radiography of the chest. An additional advantage of point-of-care ultrasound in unstable patients is the ability to confirm the diagnosis at the patient's bedside.

Figure 14. Left-Sided Pleural Effusion

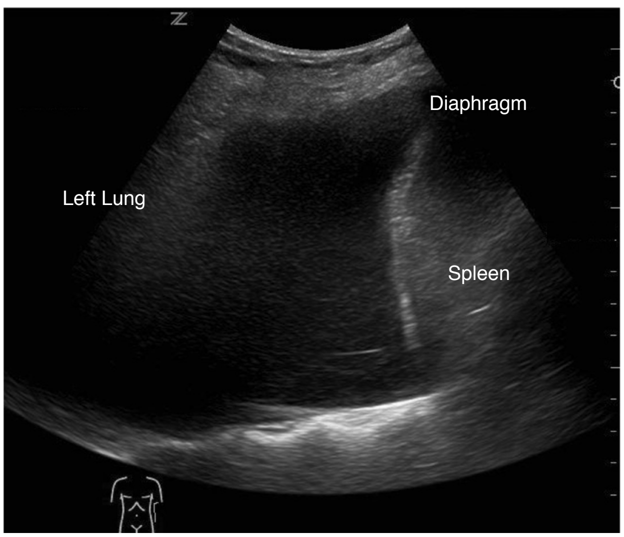
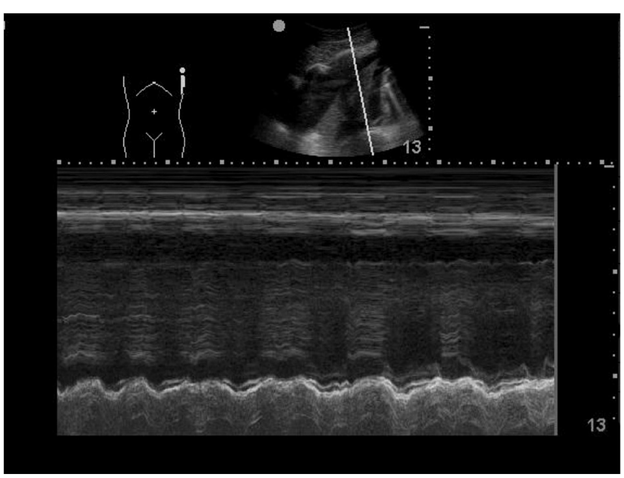


Figure 15. Sinusoid Sign

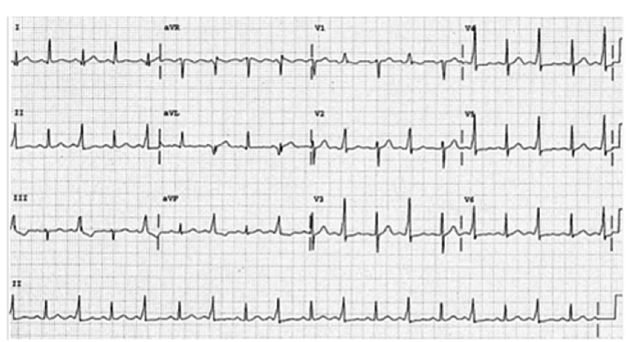


Point-of-Care Ultrasound

Evidence: Significant research in the past 2 decades has shown that emergency physicians are able to reliably detect pericardial effusions using point-of-care ultrasound.[38, 43-46] Emergency physician-performed echocardiography for effusion has a sensitivity of 96%, specificity of 98%, and overall accuracy of 97.5%.[43] A small prospective study has also shown the ability of ultrasound to identify cardiac tamponade in patients with impending cardiac arrest,[47] occasionally leading to life-saving changes in decision making. **(See Table 3.)**

Probe Selection And Positioning: Emergency echocardiography is performed with low frequency (2-4 MHz) curvilinear or phased array transducers. Transducer selection is important to maximize image quality. In this examination, optimal imaging of the heart requires greater depth of ultrasound wave penetration. Recall that depth is inversely related to transducer frequency, so increased depth requires a

Figure 16. Electrical Alternans In A Patient With Pericardial Tamponade



lower frequency transducer. Because the parasternal and apical views require an intercostal approach, rib shadowing can be minimized by selection of a small footprint probe (such as the phased array probe, **Figure 5D).**

There are 4 conventional views that are commonly obtained as part of a thorough point-of-care cardiac ultrasound: (1) parasternal long axis view, (2) parasternal short axis view, (3) apical 4 chamber view, and (4) subxiphoid view. Although there are additional views that provide useful information, they are beyond the scope of this article to discuss. The classic orientation for transthoracic echocardiography, as developed by cardiac sonographers, teaches alignment of the probe indicator or "marker dot" with the right shoulder in the parasternal long axis view or to the left shoulder in the parasternal short axis view. The marker dot on the transducer demarcates the leading edge of the sonographic beam.

Parasternal Long Axis: The parasternal long axis view can be obtained by placing the probe in the third or fourth intercostal space of the left chest with orientation of the marker dot toward the patient's right shoulder, which is equivalent to 10 o'clock when considering the chest as the clock face. Look for the landmark mitral valve and rotate the probe to image the aortic and mitral valve in the same long axis plane. **(See Figures 17A and 18A.)**

Parasternal Short Axis: The parasternal short axis view is achieved by rotating the probe ninety degrees from the long axis view; the probe indicator will now be aligned with the patient's left shoulder at approximately 2 o'clock. Adjust the probe angle to obtain a circular short axis or cross sectional view of the left ventricle at the level of the papillary muscles. With small adjustments in the probe angle in the cephalad direction, the sonographer will be able to view the mitral valve and then the aortic valve in cross section, surrounded by the left atrium and right ventricle. With caudal adjustments in the probe angle, the apex of the left ventricle can be seen. When assessing global LV function in a focused study, the papillary muscle cut is most commonly endorsed. **(See Figures 17B and 18B.)**

Table 3. Test Characteristics Of Emergency Echocardiography

Reference	Population Studied and Methods	Results	Conclusion
Tayal 2003[47]	20 patients were enrolled in this prospective observational study evaluating bedside echocardiography performance by emergency physicians in PEA and near-PEA states	All pericardial effusions detected were confirmed by formal echocardiography, and 3 patients with tamponade physiology underwent immediate pericardiocentesis or surgery	Echocardiography performed by emergency physicians in PEA or near-PEA states can detect pericardial effusions/ tamponade with correct treatment rendered
Jones 2003[45]	21 emergency medicine residents enrolled in this prospective study with evaluation before and after a focused 6-hour echocardiography training course	There was significant improvement in emergency medicine resident ability to evaluate for pericardial effusion, chamber size, and LV function after the training	A 6-hour training course allows for improved emergency medicine resident performance in point-of-care ultrasound
Blaivas 2001[46]	103 patients with unexplained dyspnea were enrolled for this prospective observational study in the ED where ultrasound was performed to evaluate for the presence of pericardial effusion	13.6% of patients had a pericardial effusion detected by ultrasound	Pericardial effusion may be more prevalent in the unexplained dyspneic patient that previously thought; however, the extent to which it is contributing to the dyspnea was not explored
Mandavia 2001[38]	515 patients were enrolled in this prospective study with ultrasound performed by emergency physicians and compared to cardiologist interpretation	Sensitivity 96% Specificity 98% Overall accuracy 97.5%	Emergency physicians are skilled in performing point-of-care ultrasound evaluation of pericardial effusion
Rozycki 1999[43]	261 patients with penetrating truncal wounds enrolled in this prospective study of pericardial ultrasound performed by surgeons and cardiologists as compared to operative findings	Sensitivity 100% Specificity 96.9% Accuracy 97.3%	Accurate positive ultrasound examinations allow immediate bedside decision making to pursue operative intervention
Rozycki 1998[44]	1540 patients with blunt and penetrating truncal injuries were enrolled in this prospective study of surgeon-performed FAST (inclusive of evaluation for pericardial effusion)	Sensitivity 83.3% Specificity 99.7%	Surgeons trained to perform FAST examinations, inclusive of a pericardial window, are successful at interpretation of their findings

Abbreviations: ED, emergency department; FAST, focused assessment with sonography for trauma; LV, left ventricular; PEA, pulseless electrical activity.

Apical 4 Chamber: The apical 4-chamber view is obtained by placing the probe lateral to the left nipple line (typically at the point of maximal impact) and aiming cephalad. The marker dot on the transducer will generally point towards the patient's left shoulder, at 2 o'clock. The apical 4-chamber view displays the ventricular septum in the middle of the image, with the right heart displayed on the left side of the screen and the larger left heart on the right side of the screen. **(See Figures 17C and 18C.)**

Subxiphoid: The subxiphoid (or "subcostal") view differs from the parasternal views because it uses the left lobe of the liver as the acoustic window. Rib shadowing is no longer a concern, as the image is obtained by placing the transducer in the subxiphoid space parallel with the patient's skin, with the marker dot pointing to the patient's left side, at 3 o'clock. A 4-chamber view will be visible, with the right ventricle adjacent to the liver, both ventricles in the near field, and the atria in the far field. **(See Figures 17D and 18D.)**

Sonographic Findings: Sonographers may use any of the 4 conventional views of point-of-care transthoracic echocardiography to visualize a pericardial effusion. **(See Figures 18A-D and 19A-C.)** The parasternal long axis and subxiphoid views are often the easiest images to obtain. Diastolic collapse of the right ventricle and right atrium with distension and decreased respiratory variation of the IVC are identifiable features of pericardial tamponade and may be present prior to the development of severe hemodynamic instability.[48-51]

Diastolic collapse of the right ventricle and atria are the most frequently cited findings of tamponade. RV collapse may be visualized during ventricular

Figure 17A. Normal Transthoracic Echocardiography

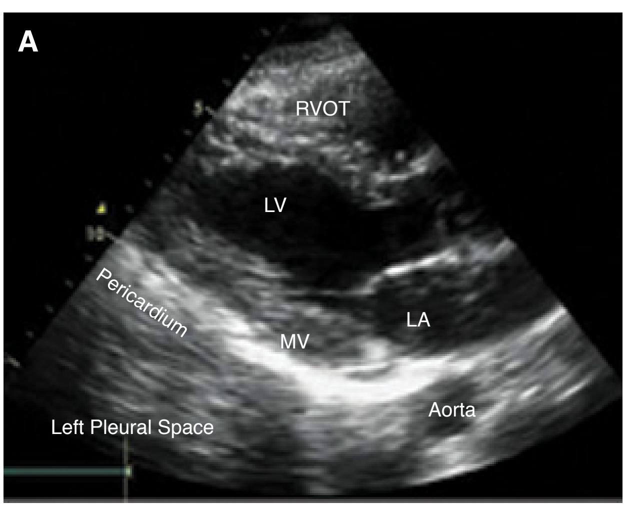
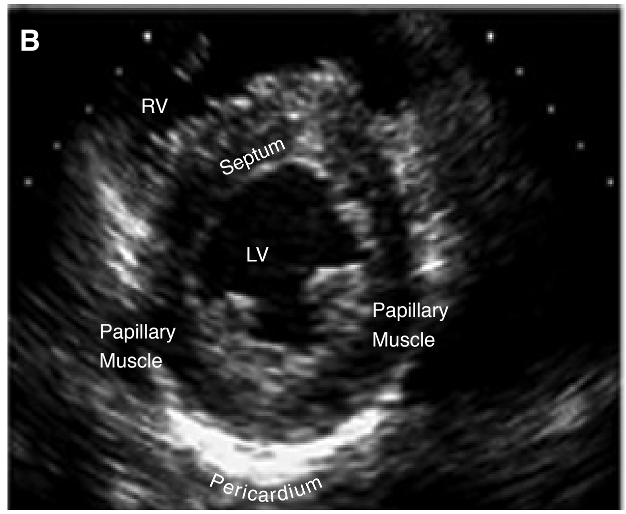
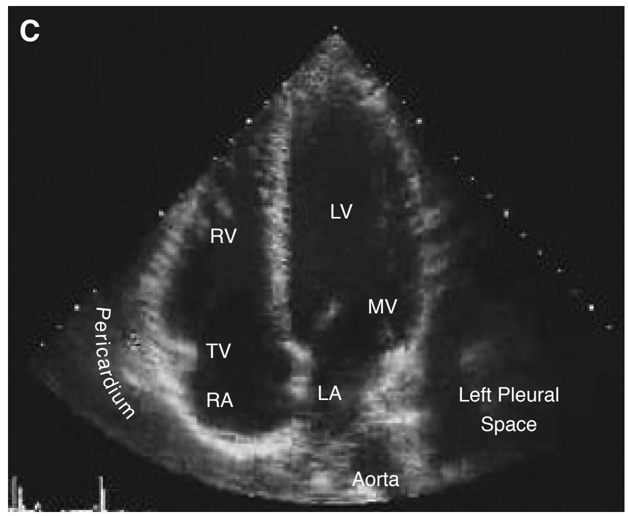
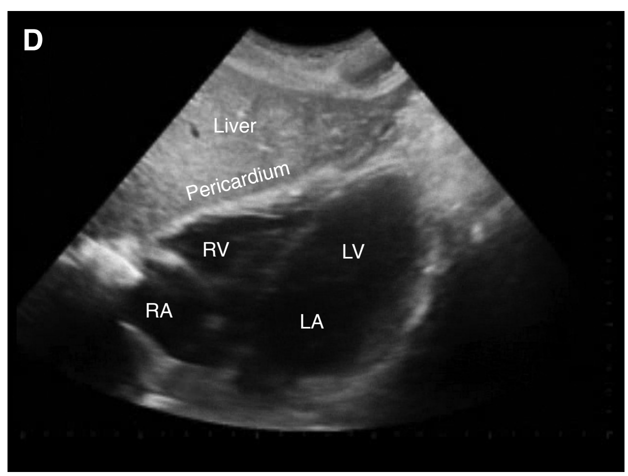


Figure 17B-D. Normal Transthoracic Echocardiography







A. Parasternal long axis view; B. parasternal short axis view; C. apical 4-chamber view; D. subxiphoid view.

Abbreviations: LA, left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium; RV, right ventricle; RVOT, right ventricular outflow tract; TV, tricuspid valve.

diastole as the intrapericardial pressure exceeds the lower right-sided chamber pressure. It is important to distinguish between collapse of the right ventricle and atria during systole (physiologic) or diastole (always pathologic). This distinction is difficult, especially in the tachycardic patient. The advanced sonographer can use M-mode to verify diastolic collapse, but this technique is beyond the scope of this article.[51] Ultimately, tamponade is a clinical diagnosis, and the pursuit of these echocardiography findings should not delay definitive management and/or consultation in an unstable patient.

IVC distention and decreased respiratory variation (plethora) are indicative of elevated right heart pressure. In spontaneously breathing patients, intrathoracic pressure typically varies with respiration and is decreased with inspiration (small IVC) and increased with expiration (large IVC). It should be noted that the exact inverse relationship is true in patients with positive pressure ventilation, as IVC diameter is maximal on inspiration and minimal on expiration. This is reflected sonographically by a change in the diameter of the IVC during the respiratory cycle. In cases of cardiac tamponade, the increased right-sided heart pressure translates to decreased respiratory variation in the IVC.[49] **(See Figure 20.)**

A technically adequate point-of-care echocardiography with no evidence of pericardial fluid excludes the diagnosis of cardiac tamponade. Alternatively, in unstable patients with tamponade, pericardiocentesis can be performed at the bedside with ultrasound guidance. Ultrasound-guided pericardiocentesis has been associated with fewer complications and has higher success rates than the traditional landmarks approach.[52,53]

Caveats: The sonographic findings of RV collapse and IVC distention may be present in pathologic states other than pericardial tamponade as they are sensitive but nonspecific findings. RV collapse can

Figure 18A. Parasternal Long Axis

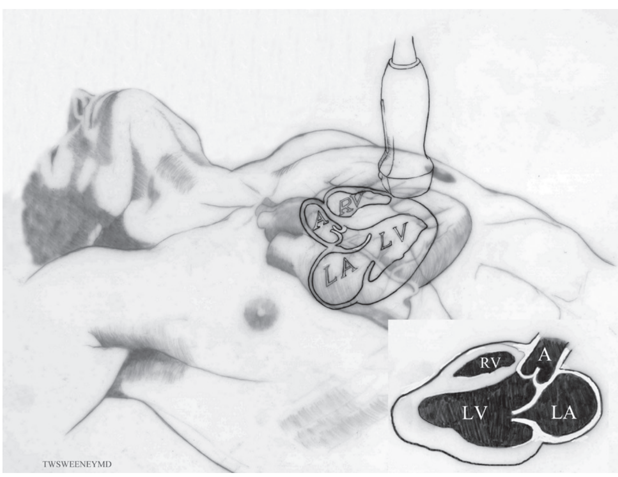


Figure 18B. Parasternal Short Axis

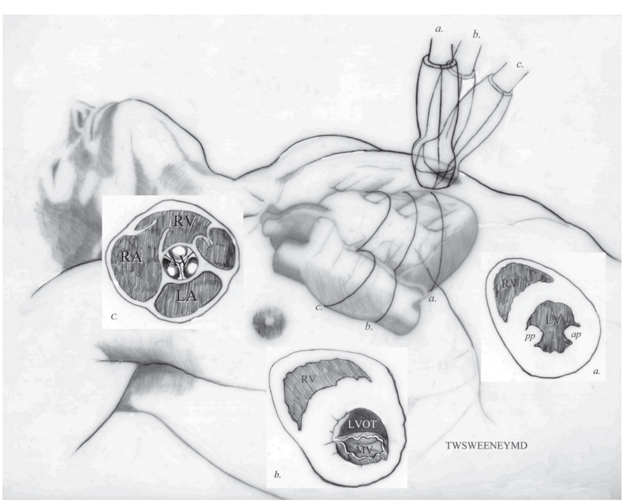


Figure 18C. Apical 4-Chamber

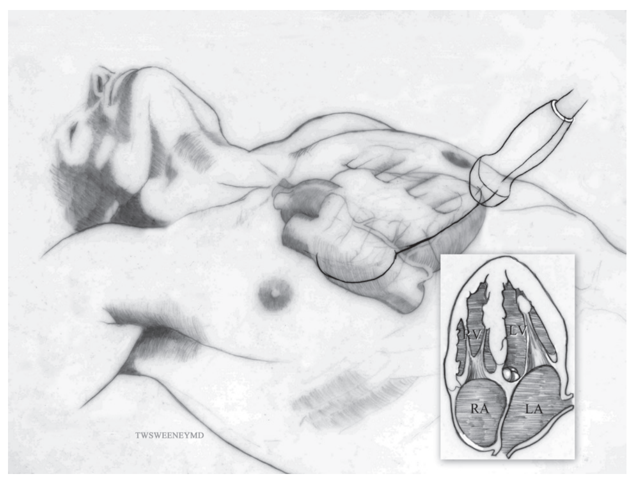
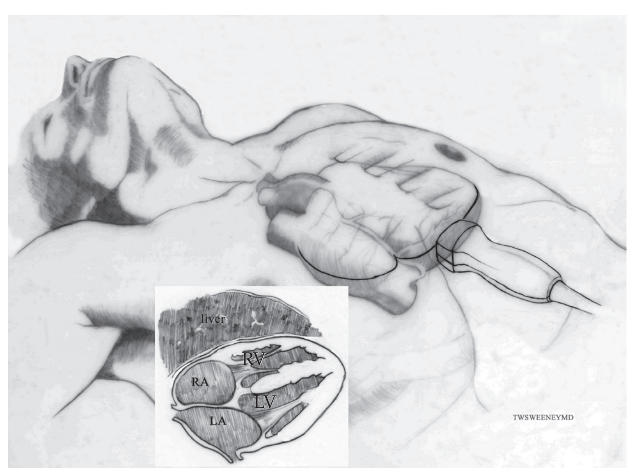


Figure 18D. Subxiphoid



occur in association with large pleural effusions or in patients with severe hypovolemia. PE, right-sided heart failure, and volume overload can also cause distension of the IVC. Fortunately, these findings typically do not exist in isolation, and clinical presentation should be used to guide decision making.

Pulmonary Embolism

Defining Features

PE is a crucial consideration in the differential diagnosis of acute dyspnea and hypotension. Patients with PE may present to the ED with the classic symptoms of subjective dyspnea, pleuritic chest pain, and risk factors for thromboembolic disease. Diagnosis can be elusive in hemodynamically stable patients given the frequent overlap of presenting symptoms with other disease processes. Once respiratory distress and hypotension are present, the clinician should strive to make the diagnosis expeditiously, as mortality in patients with massive PE can be as high as 25%.[54]

Presentation

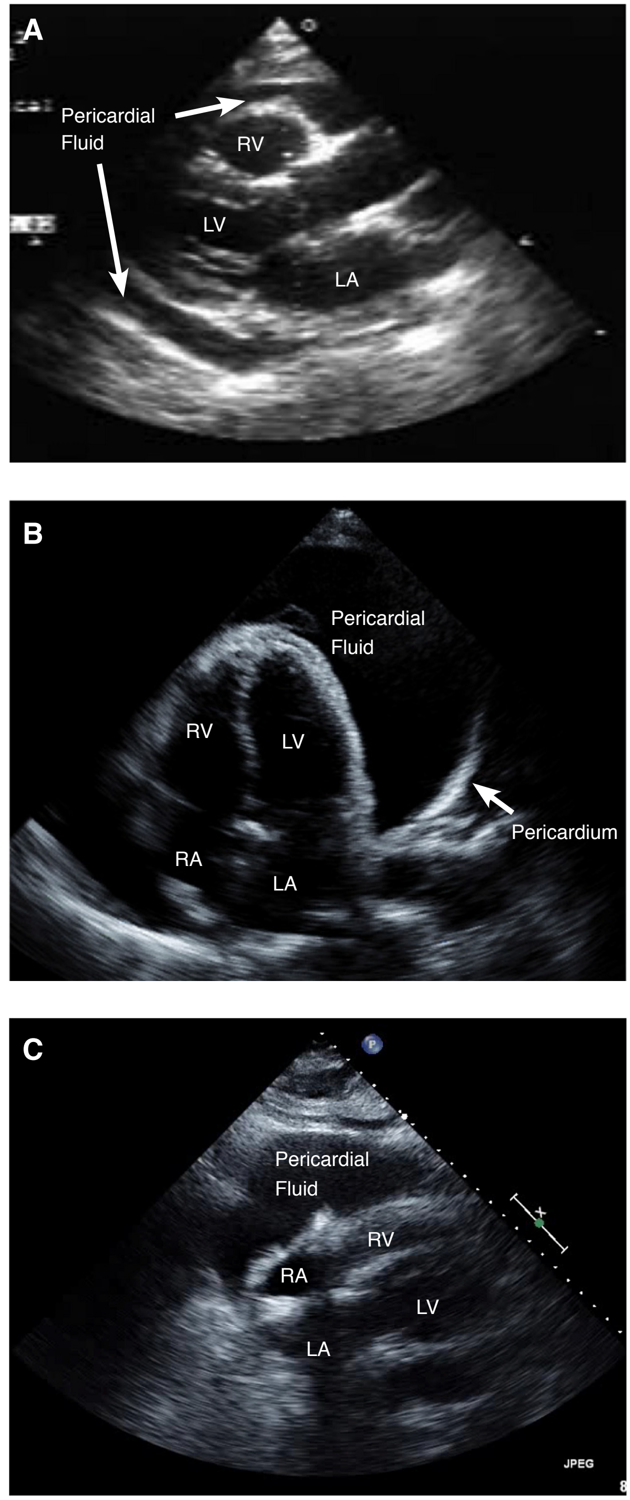
Signs and symptoms of PE consist classically of acute pleuritic chest pain, dyspnea, hypoxia, and hemoptysis. However, many symptoms of PE are nonspecific, and the clinician needs to maintain a high index of suspicion, particularly when a patient has risk factors for thromboembolic disease. The diagnosis of PE should be actively pursued in patients with respiratory symptoms unexplained by an alternate diagnosis.

Point-of-Care Ultrasound

Evidence: Multiple prospective studies reveal a low sensitivity (41%-70%) of bedside echocardiography for specifically identifying PE.[55-59] With such limited sensitivity, point-of-care ultrasound is not the appropriate diagnostic modality for PE. Alternatively, bedside echocardiography is very sensitive for the diagnosis of RV dysfunction in patients with suspected PE. Recognition of RV dysfunction is critical since it may be the most important determinant of mortality in patients with PE and shock and thus may influence a clinician's acute management and disposition decisions.[60] Current recommendations are for administration of thrombolytic therapy in patients with massive PE (hemodynamic instability or pulseless electrical activity [PEA] arrest); administration of thrombolytics in patients with submassive PE (hemodynamically stable with RV dysfunction) has failed to show any improvement in outcomes.[61]

Probe Selection And Positioning: It is important to note that the apical 4-chamber view may be especially useful in assessment of the patient with confirmed or suspected PE. By capturing the

Figure 19. Transthoracic Echocardiography Demonstrating Pericardial Effusions



Pericardial effusion as seen from the parasternal long axis view (A), apical 4-chamber view (B), and subxiphoid view (C).

Abbreviations: LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

left ventricle and right ventricle adjacent to one another, this view lends itself well to determination of abnormal RV size or function (these findings are reviewed later in this article). Images of the IVC should be obtained at this time as well. The IVC is measured with the same low frequency phased array or curvilinear transducer (used for cardiac views) and is positioned in the subxiphoid space. Instead of orienting the probe transversely, as would be expected for a subxiphoid cardiac image, the transducer is rotated into the long axis to demonstrate the IVC as it drains into the right atrium. Measurements of the IVC diameter may be obtained in M-mode, as noted 2-3 cm proximal to the entry of the IVC into the right atrium. If able, the patient is asked to inspire sharply ("the sniff test"), and the difference between end-inspiratory and end-expiratory IVC are noted. **(See Figure 20.)**

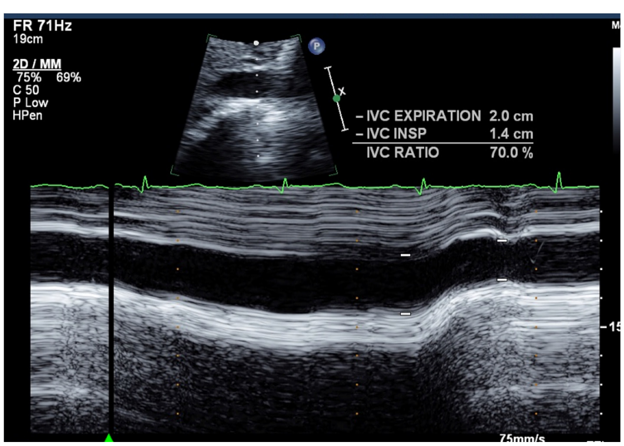
Sonographic Findings: In order to anticipate echocardiographic evidence of massive PE, the physiologic consequences of significant pulmonary clot burden need to be reviewed. Massive PE leads to acute cor pulmonale through multiple physiologic insults to the pulmonary vasculature and right heart. RV dysfunction results from elevated pulmonary artery pressures, which causes increased RV afterload and wall tension and subsequently leads to RV dilatation. **(See Figure 21.)** There is associated compression of the interventricular septum, leading to a shift of the septum into the left ventricle. Due to RV failure, underfilling of the left ventricle ensues, with corresponding drops in cardiac output and systemic perfusion.

These physiologic changes are reflected by a number of sonographic features in patients with right heart strain. The normal ratio of RV:LV diameter is less than 0.6:1. As the right ventricle dilates, this ratio changes. Should the right ventricle grow larger than the left ventricle (a ratio greater than 1:1), this implies severe RV disease.[62] Flattening of the interventricular septum may be noted in the parasternal short axis as the left ventricle takes on a "D" shape instead of its typical oval appearance. **(See Figure 22.)** As RV function declines, the advanced sonographer may note regional wall motion abnormalities between the stiff RV free wall and apex (known as "McConnell's Sign").[63] Tricuspid regurgitation may also be noted.

For further insight into elevated right-sided circulatory pressures, the sonographer can examine the IVC for dilatation and/or collapse with inspiration as a surrogate of CVP. According to the latest American Society of Echocardiography guidelines, IVC diameter < 2.1 cm with > 50% inspiratory collapse suggests CVP of 0 to 5 mm Hg; IVC diameter > 2.1 cm with < 50% collapse suggests CVP of 10 to 20 mm Hg.[64] **(See Figure 20.)** This data may serve as an adjunct to additional historical and physical examination data to support or refute clinical suspicion of right-sided heart failure, cardiac tamponade, or PE in the appropriate patient population.

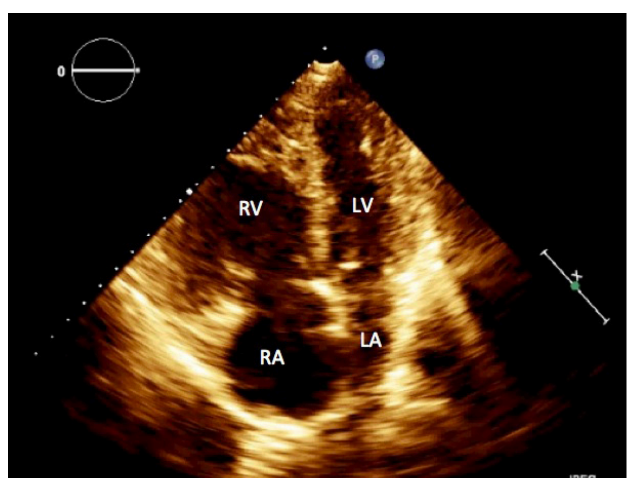
Although beyond the scope of this article, emergency physicians may also use 2-point compression ultrasound of the lower extremities to evaluate for thrombus. In the hemodynamically unstable patient with hypoxia and RV dysfunction, identification of lower extremity venous thrombosis can serve as further evidence of massive PE in the ED.[65,66]

Figure 20. Variation Of Inferior Vena Cava During Respiratory Cycle, Measured At Expiration And Inspiration



Respiratory variation as seen in an M-Mode image from a patient with pericardial effusion. Variability with respiration seen here does not support tamponade physiology.

Figure 21. Right Ventricular Dilation



Apical 4-chamber view shows significant right ventricular dilation, with an RV:LV ratio greater than 1.

Abbreviations: LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

Caveats: RV abnormalities may exist in patients with COPD, obstructive sleep apnea, pulmonary hypertension, and right-sided myocardial infarction, and an increased RV:LV ratio can be present in all of these pathologic states. RV free-wall thickness greater than 5 mm suggests chronically increased right heart pressures and can be an indicator of pre-existing RV pathology.[64] Clinicians need to rely on historical features, physical examination findings, risk factors, and available diagnostics (including point-of-care ultrasound findings) to guide final diagnosis and treatment plans.

Tension Pneumothorax

Defining Features

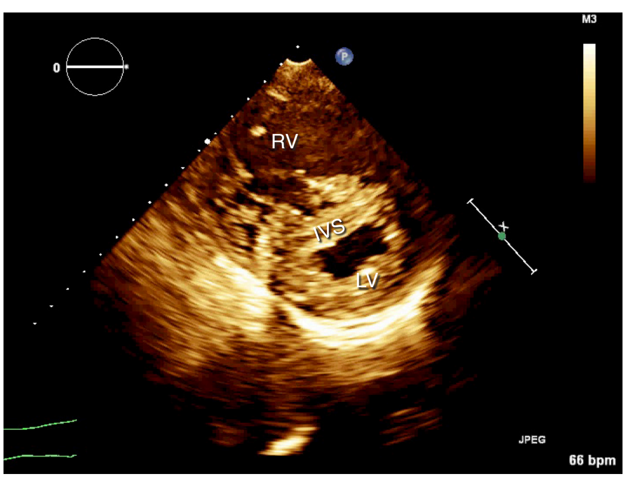
Pneumothorax can often be well tolerated; however, any condition that creates a pneumothorax can progress to tension physiology. Tension physiology occurs when, through a one-way valve effect, the pressure from the trapped intrapleural air exceeds the pressure in the rest of the thorax. As intrathoracic pressure rises on the affected side, it eventually creates a mass effect on adjacent mediastinal structures and the contralateral lung. Lung expansion is significantly reduced, and hypotension develops from impaired preload.

Presentation

The most common symptoms associated with pneumothorax are dyspnea and unilateral pleuritic chest pain. Pneumothorax size and pre-existing pulmonary reserve dictate the degree of respiratory and circulatory impairment. Once a simple pneumothorax progresses to a tension pneumothorax, vital sign derangements are common and include tachycardia, hypotension, and hypoxia. Note the overlap of these symptoms with those of cardiac tamponade. Physical examination findings such as decreased breath sounds may be difficult to appreciate in the ED setting due to significant ambient noise. Tracheal deviation (due to shift of mediastinal structures) and JVD are late findings of tension pneumothorax.

Diagnosis of tension pneumothorax should be made clinically at the patient's bedside, given the rapid progression of symptoms from respiratory distress to hypotension and ultimately PEA arrest. Patients with true tension physiology are never stable enough for plain chest radiographs, and thoracic ultrasound may be used to confirm the diagnosis and to evaluate response to decompression.[67]

Figure 22. D-Shaped Left Ventricle



D-shaped left ventricle, as seen in the parasternal short axis view. The flattening of the IVS caused by overwhelming right ventricular pressures is responsible for the change in appearance of the normally circular LV seen in this view.

Abbreviations: IVS, interventricular septum; LV, left ventricle; RV, right ventricle.

Point-Of-Care Ultrasound

Evidence: Prospective studies **(Table 4)** have described the favorable sensitivity of ultrasound for diagnosis of pneumothorax. Comet tails and lung sliding are 2 normal lung artifacts that are not present in patients with pneumothorax (and are described in full detail in the following sections). The absence of lung sliding has a sensitivity of 95% and specificity of 91% to 100% for the diagnosis of pneumothorax, and the absence of comet tails has a sensitivity of 100% and specificity of 60% for diagnosis of pneumothorax. When considered together, the absence of both signs gives point-of-care ultrasound a sensitivity of 95% to 100% and specificity of 96.5% in the diagnosis of pneumothorax.[68-75]

Alternatively, the sensitivity of supine chest x-ray for detection of pneumothorax is reported as 36% to 75.5% in the literature.[75,76] This sensitivity can be improved with upright films or inspiratory and expiratory views, although these are rarely performed in routine evaluations. The poor sensitivity of plain films for pneumothorax creates a potential delay in diagnosis until upright films or chest CT are completed. Identifying pneumothorax via point-of-care ultrasound has important clinical implications, particularly when the patient requires urgent intubation and positive pressure ventilation or is rapidly deteriorating from a suspected large or tension pneumothorax where the time required for chest x-ray is unacceptable. Thoracic ultrasound is highly sensitive, may be performed at the bedside in less than 1 minute, and is interpreted immediately.[74] In fact, thoracic ultrasound's test characteristics are so favorable that it has become an additional component of the standard FAST examination (sometimes referred to as the extended FAST) to evaluate for pneumothorax in blunt and penetrating trauma patients.[77]

Probe Selection And Positioning: The scanning technique requires longitudinal evaluation of the anterior chest wall while the patient is supine, thus allowing for air to collect within the anterior nondependent portions of the pleural space. Ideally, a high frequency (5.0-10.0 MHz) linear transducer is selected. Begin with the probe in the mid-clavicular line in the second to fourth intercostal space. Confirm findings of present or absent lung sliding and/or comet tails after 4 to 5 respiratory cycles on both sides of the chest. If comet tails and lung sliding are absent in the appropriate clinical context, pneumothorax is likely. The sonographer may also note the transition point from normal lung to pneumothorax (lung point sign - described below). **(See Figure 23.)**

Sonographic Findings: The presence of pneumothorax on ultrasound is defined by the absence of 2 sonographic findings typically seen in normal subjects: lung sliding and comet-tail artifact. Between each rib lies the pleura, identified as a hyperechoic line, deep to which artifacts created by the lung-chest wall interface are present. Lung sliding is defined as a to-and-fro movement of the visceral pleura with respect to the parietal pleura during respirations. The comet-tail artifact is a hyperechoic reverberation artifact arising from the pleural line and spreading toward the lower edge of the screen in the vertical orientation.[71,72,78,79]

Lung sliding and comet tails are absent in patients with pneumothorax because air separates the parietal and visceral pleura and inhibits propagation of sound waves necessary to form the comet-tail artifact and lung sliding. The sonographer does not see air on ultrasound; recall that air is an unfavorable medium for sound wave propagation due to significant scatter of sound waves at tissue/air interfaces. Using M-mode, the sonographer is able to represent in still images lung sliding motion at the

Table 4. Test Characteristics Of Emergency Ultrasound For Pneumothorax

Reference	Population Studied and Methods	Results	Conclusions
Lichtenstein 2005[68]	200 ICU patients enrolled in this prospective study evaluating ultrasound findings of lung sliding and "lung point" in "occult pneumothoraces" missed on x-ray and identified on CT	Lung sliding: sensitivity 100%; specificity 78% Lung point: sensitivity 79%; specificity 100%	Additional data for lung sliding and lung point
Knudtson 2004[70]	328 consecutive trauma patients underwent ultrasound imaging by surgeons to evaluate for lung sliding and comet tails as indicators of pneumothorax as compared to x-ray	Specificity 99.7% Negative predictive value 99.7% Accuracy 99.4%	Surgeons are able to replicate good results in the use of ultrasound to diagnose pneumothorax
Rowan 2002[75]	27 patients enrolled in this prospective study of ultrasound findings of lung sliding and comet tails to diagnose pneumothorax compared to CT	Sensitivity 100% Specificity 94% Negative predictive value 100%	Additional study adding power to previous similar prospective studies
Kirkpatrick 2001[74]	36 patients in the ED enrolled in this prospective study of ultrasound findings of lung sliding and comet tails to diagnose pneumothorax compared to CT	Sensitivity 94% Specificity 100%	Emergency physicians are capable of good results using ultrasound to detect pneumothorax
Dulchavsky 2001[69]	382 patients enrolled in this prospective study of ultrasound findings of lung sliding and comet tails in the diagnosis of pneumothorax compared to x-ray	Sensitivity 95% Specificity 100% Negative predictive value 100%	Improved sensitivity and specificity when ultrasound is compared directly to x-ray
Lichtenstein 2000[73]	299 ICU patients enrolled in this prospective operator-blinded study evaluating ultrasound findings of lung sliding, comet tails, and the "lung point" in the diagnosis of pneumothorax as compared to the gold standard of CT	Lung point: sensitivity 66%; specificity 100%	Combined results of lung sliding, comet tails, and lung point greatly increase specificity in pneumothorax detection
Lichtenstein 1999[72]	114 ICU patients enrolled in this prospective study evaluating ultrasound findings of comet tail to diagnose pneumothorax versus the gold standard of CT	Sensitivity 100% Specificity 60% Negative predictive value 100%	Comet tails on thoracic ultrasound are more sensitive but less specific than lung sliding in the diagnosis of pneumothorax
Lichtenstein 1995[71]	111 ICU patients enrolled in this prospective study evaluating ultrasound findings of lung sliding to diagnose pneumothorax versus gold standard of CT	Sensitivity 95.3% Specificity 91.1% Negative predictive value 100%	Lung sliding on thoracic ultrasound is an accurate indicator of pneumothorax

Abbreviations: CT, computed tomography; ED, emergency department; ICU, intensive care unit.

interface of the parietal and visceral pleura. With M-mode, the sonographer may note 2 distinct patterns: the "seashore sign" or the "stratosphere sign" (also known as the "barcode sign"). The seashore sign is an irregular tracing along the x axis at the depth of the pleura due to normal motion from lung sliding. The stratosphere sign is a smooth motionless baseline on the x axis due to the absence of lung sliding. **(See Figures 24 and 25.)**

Lichtenstein et al also described the "lung point" sign in the diagnosis of pneumothorax. The lung point is characterized by the fleeting appearance of normal lung pattern (lung sliding present) replacing a pneumothorax pattern (lung sliding absent) in a particular location along the chest wall.[68,73] The finding of a lung point represents the transition point from normal lung to pneumothorax and is pathognomonic for pneumothorax, with specificity greater than 99%.[80] The lung point, specific as it is, is not required for the diagnosis of pneumothorax and may not be readily visualized in patients with a large pneumothorax.

Caveats: Potential causes of false positive examinations (loss of lung sliding for reasons other than pneumothorax) include bullous emphysema, pulmonary fibrosis, ARDS, and right main stem intubation. All of these conditions may fail to produce lung sliding by preventing the movement of the visceral pleura relative to the parietal pleura. Subcutaneous emphysema can generate a different type of comet-tail artifact, which arises above the pleural line and confounds image interpretation.

Cutting Edge

Focused ultrasound has evolved into a critical skill for the emergency physician and has been utilized in a myriad of clinical situations.[81,82] The initial report on bedside echocardiography use by emergency physicians was published in 1988 and initiated a period of intensive research and skills refinement, which continues to the present day.[83] The addition of bedside echocardiography has been shown to significantly improve diagnostic accuracy in patients with undifferentiated hypotension.[84] More recently, investigators have suggested that additional sonographic examinations should be included in the evaluation of patients with undifferentiated hypotension, but a universal protocol is yet to be prospectively validated. Such a protocol could unify several complementary ultrasound examinations into a comprehensive bedside survey of critically ill patients. Although this article has specifically focused on causes of acute respiratory distress, there is considerable overlap among patients with undifferentiated hypotension. To be thorough, 2 of the more well-known ultrasound protocols in undifferentiated

Figure 23. Pneumothorax And B Lines

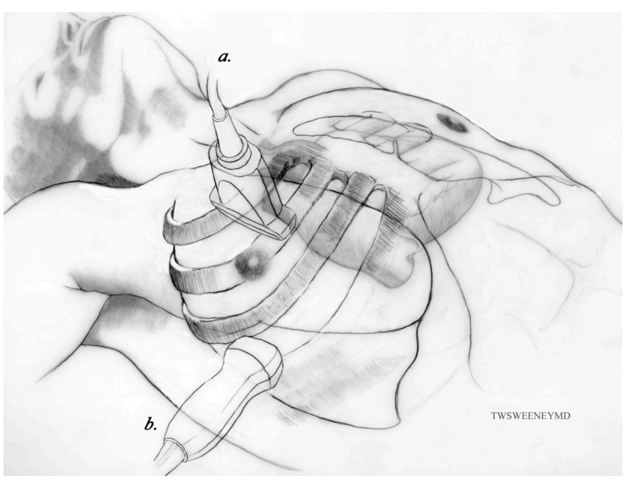


Figure 24. Seashore Sign

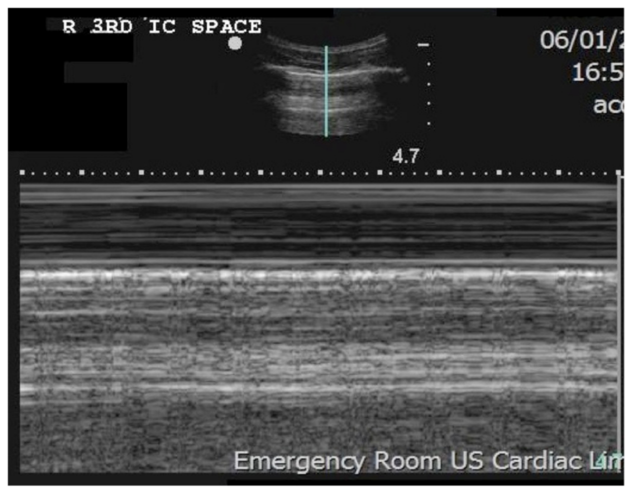
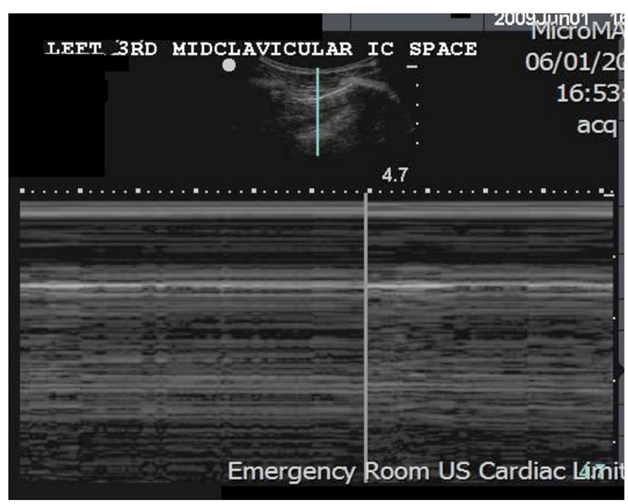


Figure 25. Stratosphere Sign



hypotension are briefly discussed below.

The Abdominal and Cardiac Evaluation with Sonography in Shock (ACES) examination is a 6-view protocol proposed to assist with diagnosis and goal-directed therapy in patients with nontraumatic undifferentiated hypotension. A complete study includes views of the heart (subxiphoid or parasternal long axis), IVC, abdominal aorta, right upper quadrant, left upper quadrant, and pelvis. Critical information may be obtained including assessment of LV function, volume status, presence or absence of pericardial fluid, abdominal aortic aneurysm, and peritoneal or pleural fluid.[85] The additional information may aid in the classification of shock into categories such as obstructive, septic, cardiogenic, or hypovolemic. The ACES protocol is limited by the lack of current data available on clinically significant outcomes (such as impact on accurate diagnosis and mortality reduction) and should be addressed in future investigations.

The Rapid Ultrasound for Shock and Hypotension (RUSH) protocol is a "3-part bedside physiologic assessment of the pump, the tank, and the pipes" that was developed by Perera et al.[86] Evaluation of the heart (pump) includes assessment for pericardial effusion, overall LV function, and relative size of the right and left ventricle. Evaluation of the tank includes assessment of the IVC, peritoneum, and lung; findings of hypovolemia, peritoneal fluid, and pulmonary edema have important indications in overall status of intravascular volume. The third part of the RUSH protocol involves investigation of the pipes, specifically looking for abdominal aortic aneurysm or evidence of femoral or popliteal thrombosis.[86]

The ACES and RUSH protocols mark a new shift in emergency ultrasound. While they both contain various elements of available point-of-care ultrasound examinations, they are united by a singular goal, which is to improve diagnosis and targeted therapy in patients with undifferentiated nontraumatic hypotension. Although the individual components (such as FAST, echocardiography, and pneumothorax) of each protocol have been extensively studied and validated, more rigorous outcome-oriented research has not yet been done to measure the actual influence of a combined protocol on patient care.

Essentials For The Community Physician

The literature is replete with evidence that emergency ultrasound is a readily learned skill that can be acquired by novice sonographers after a limited training period of high-frequency scanning. Novice sonographers have been shown to develop accurate interpretative skills for the FAST examination within 18 months of training.[44,80] Emergency physicians with varied prior experience in point-of-care ultrasound have demonstrated accuracy in determination of LV function with limited additional training.[32,34] The generally accepted number of scans required to

Risk-Management Pitfalls For Point-Of-Care Ultrasound In Hypoxic Patients

1. **Ruling out pericardial tamponade because the patient has a positive effusion but no signs of diastolic RV collapse.**
   While transthoracic echocardiography has a high sensitivity and specificity for the diagnosis of pericardial effusion, there are pre-existing conditions that can lead to the absence of additional ultrasound findings of tamponade. Cor pulmonale with RV hypertrophy can inhibit diastolic RV collapse due to elevated baseline right heart pressures. It should be recognized that pericardial tamponade is a clinical diagnosis based on the presence of a pericardial effusion in patients with hemodynamic instability.

2. **Ruling out PE because there are no signs of right heart strain on point-of-care ultrasound.**
   In patients with PE, right heart strain is an advanced finding in disease progression and severity, and it reflects critically elevated pulmonary pressures that are transmitted to the right side of the heart. Right heart dilatation typically results from the development of acute pulmonary hypertension and may be suggestive of massive PE when identified in the appropriate high-risk patient with signs of thromboembolic disease. The absence of right heart strain should not be used to rule out PE.

3. **Diagnosing pneumothorax in patients with known ARDS, pulmonary fibrosis, or subcutaneous emphysema.**
   All 3 findings (ARDS, pulmonary fibrosis, and subcutaneous emphysema) may be associated with absent lung sliding and comet tails on point-of-care ultrasound and can lead to a false diagnosis of pneumothorax. Patients with suspected pneumothorax and ARDS, pulmonary fibrosis, or subcutaneous emphysema should have an alternate form of chest imaging to make the diagnosis.

achieve competency is approximately 25 to 50. However, this number may vary depending on the type of examination and technical difficulties associated with image acquisition.

Of primary importance for community physicians interested in achieving competence in ultrasound is the availability of training pathways, since many community hospitals do not have an emergency ultrasound program or ultrasound director. In 2003, a 10-question survey was distributed to all 122 United States emergency medicine residency programs inquiring as to the current state of emergency ultrasound. The survey observed that half of responding programs had a defined credentialing pathway for novice sonographers.[87] Clearly, this has significant implications for practicing community physicians, who are even less likely than academic institutions to have an ultrasound director to assist with training and credentialing.

This opportunity gap was addressed in the 2008 ACEP Ultrasound Guidelines, which contained specific recommendations regarding educational pathways for those who were not residency trained in ultrasound.[6] Once an introductory course and appropriate number of examinations have been completed within each indication and image quality and interpretation have been reviewed, physicians should be eligible for credentialing in emergency ultrasound according to their institutional guidelines. Currently, there are numerous regional and national groups that offer introductory courses in emergency ultrasound. Many groups are also choosing to invest in the education and training of a single ultrasound director, who in turn assumes responsibility for the remaining physicians' ultrasound education.

Summary

Rapid identification and management of respiratory failure is essential in emergency medicine. Early diagnosis and accurate therapeutic interventions reduce mortality in patients with acute respiratory failure. Emergency ultrasound in dyspneic patients can rapidly exclude or rule in life-threatening causes of hypoxia and hypotension, including decompensated heart failure, pericardial tamponade, and pneumothorax. While emergency ultrasound does not definitively diagnose PE, it can accurately identify physiologic consequences of the disease (such as acute right heart strain) that are suggestive of its presence and, if present, guide prognosis and treatment decisions. As experience with emergency ultrasound in critical illness grows, clinicians will be expected to fully understand and exploit the power of point-of-care ultrasound to meet evolving standards of care in emergency medicine.

Case Conclusions

Patient #1: *You performed a thorough thoracic ultrasound of patient #1. You noted lung sliding and comet tails bilaterally. In the anterior zones of the chest, you noted diffuse B lines. There were small pleural effusions bilaterally as well. You recommended NIV and initiated a nitroglycerin drip, lasix IV, and an angiotensin converting enzyme inhibitor. You were thankful that you were able to initiate a therapeutic intervention quickly, as your second patient arrived in extremis. Forty minutes later, you reevaluated the progress of patient #1. She was weaning from bi-level NIV with a normalized blood pressure and heart rate. She felt much improved, was speaking in full sentences, and was ready for admission.*

Patient #2: *Given the decline in mental status and worsening hypoxia, the patient was emergently intubated. You reached for your portable ultrasound and considered the differential diagnosis. Given the patient's history of lupus, with severe hypotension and hypoxia, PE, cardiac tamponade, and post-viral cardiomyopathy with cardiogenic shock are at the top of your list. A focused point-of-care echocardiogram was notable for RV enlargement, hypokinesis, and absence of pericardial fluid. There was associated septal bowing into the left ventricle. Evaluation of the IVC was suggestive of RAP > 15 mm Hg. Ultrasound of the lower extremities revealed right-sided femoral vein thrombosis, effectively clinching the diagnosis of PE. You ordered systemic thrombolytics for presumed PE. Your patient was admitted to the ICU where she was transitioned to heparin after lytic infusion was completed. You were notified the following day that a CTA of the chest demonstrated extensive bilateral PE, and her condition continued to improve.*

Editors' Note

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References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study, will be included in bold type following the reference, where available. In addition, the most informative references cited in this paper, as determined by the authors, will be noted by an asterisk (*) next to the number of the reference.

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CME Questions

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1. **Examples of artifact include all of the following EXCEPT:**
   a. Reverberation
   b. Mirror image
   c. Attenuation
   d. Shadowing

2. **The B lines of pulmonary edema originate at the pleural line, spread without extinction to the far edge of the screen, and are horizontally directed.**
   a. True
   b. False

3. **Which of the following is NOT one of the 4 typical views in a thorough point-of-care cardiac ultrasound?**
   a. Parasternal short axis
   b. Parasternal long axis
   c. Suprasternal
   d. Apical 4 chamber
   e. Subxiphoid

4. **While an increased RV:LV ratio may raise a clinician's suspicion of significant PE, it can be seen in a variety of disease processes, including all of the following EXCEPT:**
   a. COPD
   b. Obstructive sleep apnea
   c. Pulmonary hypertension
   d. Left-sided myocardial infarction

5. **When using ultrasound to evaluate for pneumothorax, potential causes of false positive examinations include:**
   a. Bullous emphysema
   b. Right main stem intubation
   c. Pulmonary fibrosis
   d. ARDS
   e. All of the above

Upcoming *EMCC* Topics

- Severe Sepsis And Septic Shock
- Massive GI Bleeding
- Managing Coagulopathy In ICH
- Air Transport Of The Critically Ill Patient
- Cardiocerebral Resuscitation
- Severe TBI
- Burn Support
- High-Risk Scenarios In Penetrating Trauma

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EB Medicine
1-800-249-5770 or 1-678-366-7933
Fax: 1-770-500-1316
5550 Triangle Parkway, Suite 150, Norcross, GA 30092
E-mail: **ebm@ebmedicine.net**
Website: **www.ebmedicine.net**
To write a letter to the editor, please email: arntfieldmd@ebmedicine.net

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