The Rapid Assessment of Dyspnea with Ultrasound: RADiUS

William Manson, MD*, Nadim Mike Hafez, MD

KEYWORDS

• Emergency • Ultrasound • Dyspnea • Critical care

This article reviews the focused bedside ultrasonography examination performed to evaluate the patient who presents with undifferentiated dyspnea. This 4-step ultrasonographic protocol combines cardiac and thoracic ultrasonography applications into 1 focused examination. The authors refer to this new ultrasonographic protocol as the rapid assessment of dyspnea with ultrasonography (RADiUS). This protocol involves multiple limited examinations, including echocardiography and evaluation of the thoracic cavity.

Many emergency and critical care physicians are already performing the components of this examination as a part of their daily practice through the use of both the FAST (focused assessment with sonography in trauma) examination[1] and RUSH (rapid ultrasonography in shock) protocol.[2,3] In the mid-90s, the FAST examination became an important tool in the rapid evaluation of the patient with trauma. This examination combined a limited evaluation for free intra-abdominal fluid with the assessment of pericardial effusion. Although it involved only 4 limited views, this clinician-performed ultrasonographic evaluation at the point of care revolutionized the care of the acutely injured patient, by identifying critical patients needing emergent laparotomy. The FAST examination has recently been expanded to the Extended FAST (E-FAST)[4] examination through the addition of pneumothorax evaluation. More recently, the RUSH protocol developed the concept of resuscitation ultrasonography with its 3-step protocol. This examination intends to provide the clinician with a more accurate initial diagnosis in patients presenting with undifferentiated hypotension. The RUSH protocol combines limited echocardiography, the EFAST, limited aorta, and focused inferior vena cava (IVC) evaluation.

The RADiUS examination involves 4 different components. These include (1) a focused cardiac examination, (2) a focused IVC evaluation, (3) evaluation of the thoracic cavity for pleural effusions, and (4) assessment of the pleural line. The physician may also choose to include a focused assessment of the lower extremities for deep venous thrombosis (DVT). However, this examination is time consuming and may not be required for all patients.

The cardiac portion of the examination is considered the most technically challenging because the examiner needs to image the cardiac structures from multiple different scan planes. The cardiac portion of the examination evaluates for presence of pericardial effusion, and it also assesses left ventricular function and right ventricular dilation indicating right ventricular strain. This portion also allows the sonologist to evaluate the patient's intravascular volume and response to fluid resuscitation. The sonographic evaluation for the presence of pleural effusions is easily performed and typically is straightforward. This assessment can be performed in a supine patient in a similar fashion to the hepatorenal and splenorenal views of the FAST examination. The pleural evaluation can assess for pneumothorax and presence of interstitial fluid.

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Department of Emergency Medicine, Emory University School of Medicine, 49 Jesse Hill Jr Drive, Atlanta, GA 30303, USA
* Corresponding author.
E-mail address: wmanson@emory.edu

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Similar to the timing of the FAST examination, which may occur at the end of the primary survey or during the secondary survey, there are no hard rules for when the physician should perform the RADiUS examination. The examination should complement, not replace, a focused history and physical examination. The RADiUS examination should never delay treatment of an emergent airway, but aids the physician in the subsequent management of the critically ill patient (**Fig. 1**).

CARDIAC ULTRASONOGRAPHIC EXAMINATION

The evaluation of the patient's heart can provide more information than any other aspect of the RADiUS examination, but is also the most challenging component of the evaluation. Comprehensive echocardiography, typically performed by sonographers and interpreted by dedicated cardiologists, is not routinely available in most emergency departments. A study by Moore and colleagues[5] in 2006 noted that 26% of emergency departments had no accesses to formal echocardiography and only 29% had 24-hour availability of echocardiography within their institution. Given this lack of immediate availability of echocardiology, it is not surprising that focused cardiac ultrasonography has now become a standard component of the emergent evaluation of patients with acute cardiopulmonary disease and of emergency medicine training.[6,7]

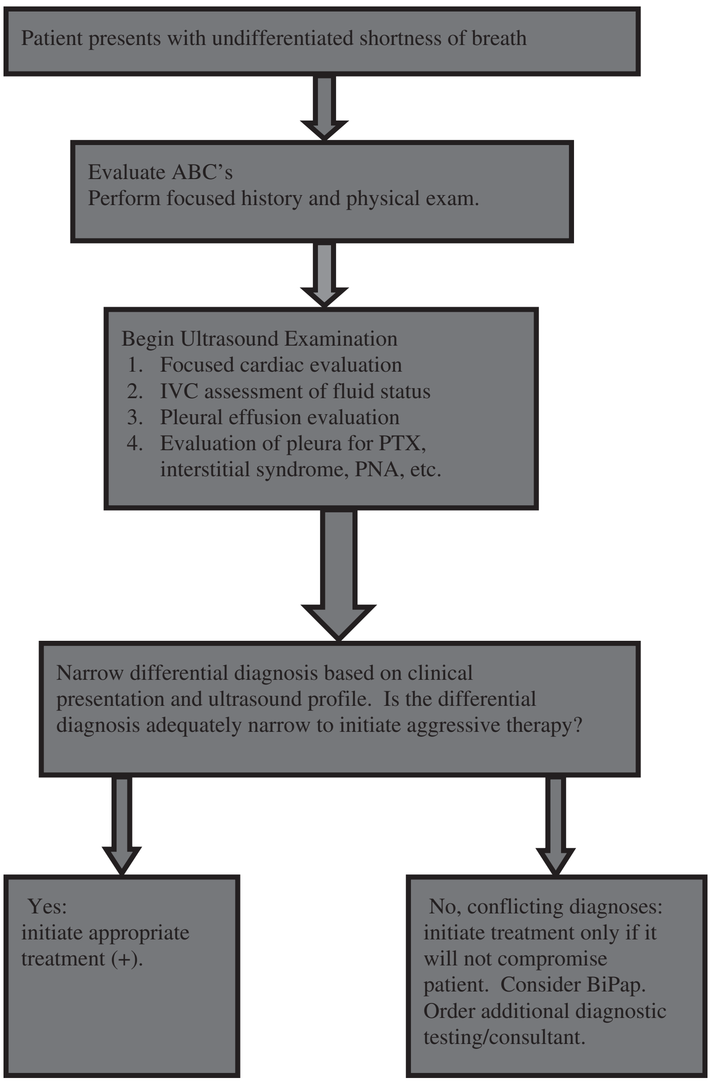

Fig. 1. Ultrasound evaluation of patient presenting with undifferentiated dyspnea. This flow diagram proposes an integration of the RADiUS examination into the clinical evaluation of a patient. ABCs, airway, breathing, and circulation; BiPAP, bilevel positive airway pressure; PNA, pneumonia; PTX, pneumothorax.

Box 1
High-risk populations for pericardial effusion

1. Unexplained dyspnea or hypotension
2. Cancer with chest pain or dyspnea
3. Congestive heart failure (CHF)/enlarged cardiac silhouette
4. Blunt chest injury
5. Penetrating chest injury
6. Uremia with chest pain or dyspnea
7. Pericarditis
8. Systemic lupus erythematosis with chest pain or dyspnea

Data from Mandavia D, Hoffner R, Mahaney K, et al. Bedside echocardiography by emergency physicians. Ann Emerg Med 2001;38(4):377–82.

The benefit of brief cardiac ultrasonography by the treating physician has been noted by several investigators. A study in 1989 by Hauser[8] noted the list of potential diseases that an emergency physician could diagnose with a brief ultrasonography of the heart, including cardiogenic shock, cardiac tamponade, pulmonary embolism (PE), and ischemia. Another study by Kimura and colleagues[9] in 2001 noted the potential benefit of performing a brief screening cardiac ultrasonography on patients in a chest pain center. This study compared brief cardiac ultrasonography of the parasternal long-axis view with a comprehensive formal echocardiographic examination. The examinations were performed by a cardiologist or an experienced cardiac sonographer, and later formally interpreted by a cardiologist. In a small subset of patients, nonphysician personnel from the emergency department also performed screening ultrasonography. The study noted a clear benefit to identifying significant cardiac disease, even if the sensitivity of the screening examination did not match that of the comprehensive echocardiogram. More recently, the American College of Emergency Physicians and the American Society of Echocardiography have written a joint paper highlighting the benefits of focused bedside echocardiography.[10]

Pericardial Effusion

Several studies have shown that noncardiologist physicians are capable of accurately identifying pericardial effusions with focused cardiac sonography. In 2001, Mandavia and colleagues[11] published one of the first studies assessing the accuracy of trained emergency physicians in correctly diagnosing pericardial effusions. Trained emergency physicians performed a focused cardiac ultrasonographic examination on 515 patients deemed at high risk for pericardial effusion based on their medical history and presenting symptoms (**Box 1**). Review of the scans by a cardiologist with expertise in echocardiography noted sensitivity of 96% and a specificity of 98% for the diagnosis of a pericardial effusion, with 93% of the 515 patients examined having technically adequate scans. The positive predictive value (PPV) was 92.5% and the negative predictive value (NPV) was 98.8%. In addition, Tayal and Kline[12] published a small study in 2003 reporting that goal-directed emergency physician echocardiography performed on patients with pulseless electrical activity allowed for the identification of underlying life-threatening pathologies as well as the rapid initiation of correcting treatments.

When identifying pericardial effusion, emergency physicians and surgeons are typically comfortable with the subcostal view (**Fig. 2**), which is a routine part of the FAST examination.[1]

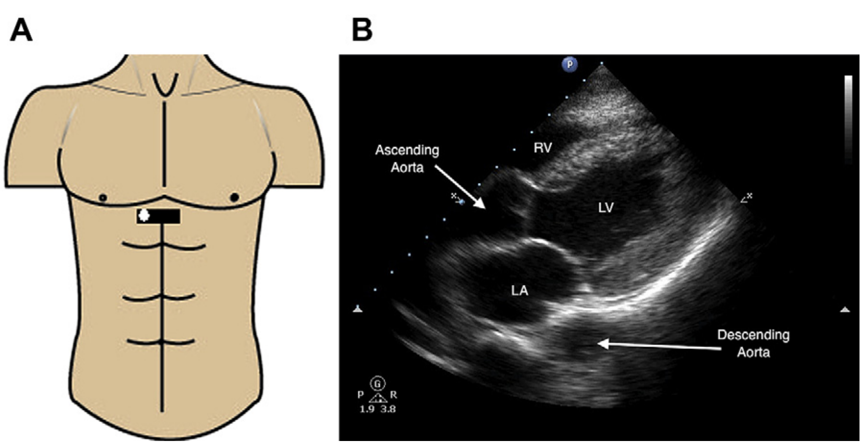

Fig. 2. (*A*) Subxiphoid view probe position. (*B*) Normal subxiphoid view. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

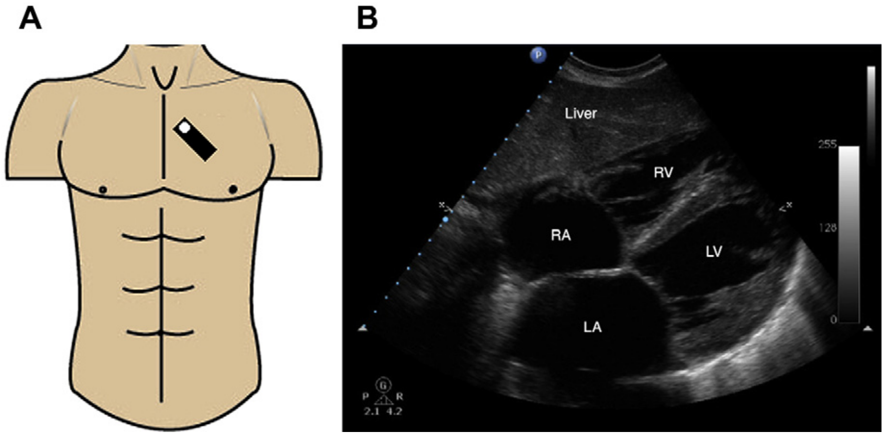

Fig. 3. (*A*) Parasternal long view probe position. (*B*) Normal parasternal long axis. LA, left atrium; LV, left ventricle; RV, right ventricle.

However, almost any cardiac view is capable of identifying large pericardial effusions. The parasternal long-axis view (see **Fig. 3**) is particularly helpful in differentiating pericardial effusion from pleural effusion. In this view, a pericardial effusion appears as an anechoic space in the far field of the image. It is located posterior to the left ventricle/ left atrium, but anterior to the descending aorta (**Fig. 4**).[13] In contrast, a pleural effusion is seen as an anechoic area tracking posterior to the aorta (**Fig. 5**).

Quantifying pericardial effusion can also be performed at the bedside. Small effusions exist when separation between the heart and parietal pericardium is less than 0.5 cm. Moderate effusions are 0.5 cm to 2 cm, and large effusion are greater than 2 cm.[13] However, other studies have reported different values. A 2001 study by Blaivas[14] using subcostal and parasternal views defined large effusions as greater than 15 mm and small effusions as less than 10 mm.

Cardiac Tamponade

Although the size of pericardial effusion does not predict tamponade physiology, the rate of accumulation of the effusion often determines whether a patient develops tamponade. Some patients with tamponade physiology can be identified by Beck's triad of hypotension, jugular venous distension, and distant, muffled heart sounds on physical examination. However, these signs are frequently absent in all patients with significant pericardial effusions and tamponade.[15] As pericardial pressure rises in tamponade, the right ventricle may begin to collapse during diastole, suggesting

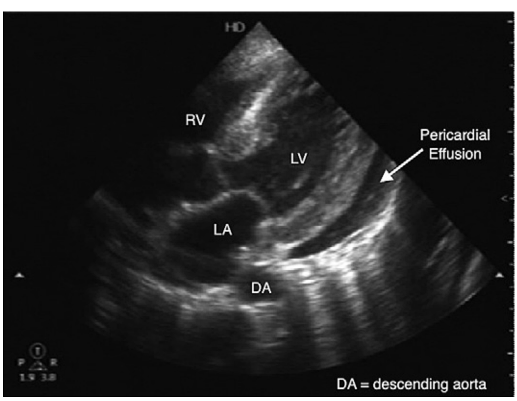

Fig. 4. Parasternal long-axis view showing a pericardial effusion. Notice how the pericardial effusion separates the heart from the descending aorta. DA, descending aorta; LA, left atrium; LV, left ventricle; RV, right ventricle.

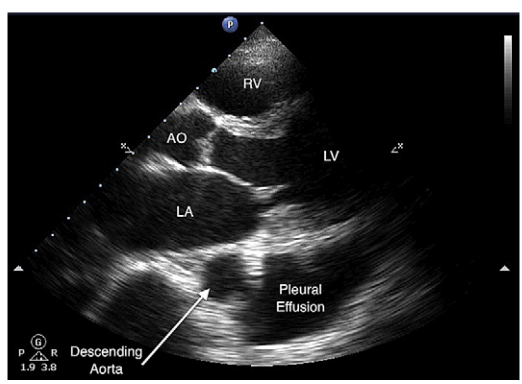

Fig. 5. Parasternal long-axis view showing a pleural effusion. Notice how the pleural effusion is located distal to the descending aorta. AO, ascending aorta; LA, left atrium; LV, left ventricle; RV, right ventricle.

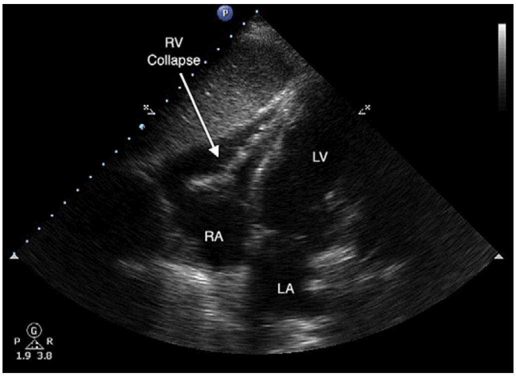

Fig. 6. Subxiphoid view showing a pericardial effusion between the liver and right ventricle (RV). The collapse of the RV during diastole indicates tamponade physiology. LA, left atrium; LV, left ventricle; RA, right atrium.

pericardial tamponade (**Box 9**, **Fig. 6**). In addition, the thin-walled right atrium may begin to collapse during systole (**Fig. 7**).[13]

Left Ventricular Function

Although precise quantification of left ventricular dysfunction is clearly better suited to cardiologists, assessment of the quality of left ventricular function can often be assessed on focused cardiac sonography. In 2002, Moore and colleagues[16] noted that appropriately trained emergency physicians using only visual qualitative estimation of left ventricular function could accurately assess the degree of left ventricular dysfunction when compared with formal echocardiographic calculations. The interobserver variability between the primary cardiologist and the emergency physicians (Pearson correlation coefficient $R = 0.86$) determination of left ventricular function compared favorably with the interobserver variability between cardiologists ($R = 0.84$). Previous studies evaluating cardiologists' visual estimation of ejection fraction have shown similar levels of correlation ($R = 0.77$–0.90).[17,18]

Other studies have shown similar results. Randazzo and colleagues[19] in 2003 also reported that emergency physicians and cardiologists agree with regards to qualitative assessment of left ventricular function. Their study, which enrolled more than 100 patients, noted excellent agreement (86%) between cardiologists and emergency physicians. In 2009, Melamed and colleagues[20] reported that intensivists with minimal goal-directed training had similar success.

PE

Although the sensitivity of echocardiography to detect patients with acute PE ranges from 40% to 70%,[13] the examination has been shown to have a high specificity for PE when right ventricular hypokinesis with apical sparing is noted.[21] On sonographic examination the right ventricle shows significantly decreased function, but the apex of the right ventricle shows motion similar to a normal heart (**Box 2**, **Fig. 8**). This sign, first described by McConnell in 1996 and now know as the McConnell sign, has 94% specificity and an NPV of 96%. A recent case study by Bomann and Moore[22] showed the value of this finding when it led emergency physicians to diagnose and save an unstable patient through thrombolytic therapy.

Some investigators have attempted to combine clinical findings with echocardiographic data to diagnose PE. A European study in 1996 attempted to combine clinical findings (hepatojugular reflux, signs of DVT, and S1-Q3 on EKG) and echocardiographic parameters from patients with a suspected PE.[23] This combination resulted in a sensitivity of 96% and specificity of 83% for the presence of a PE. However, this study was limited by broad exclusion criteria, incomplete patient data, and a small sample size. Grifoni and colleagues[24] in

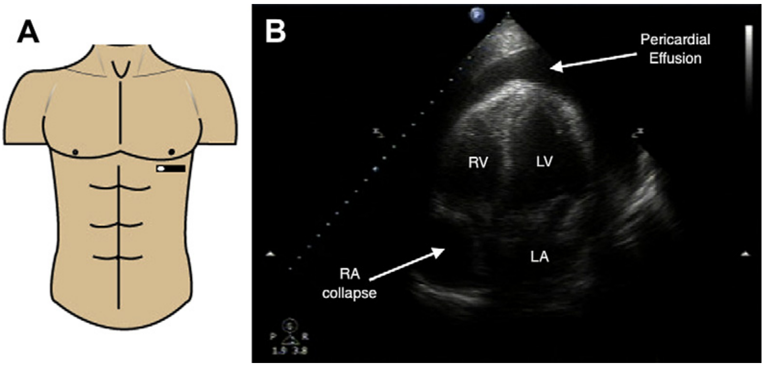

Fig. 7. (*A*) Apical 4-chamber view probe position. (*B*) Apical 4-chamber view showing a large pericardial effusion and collapse of the right atrium (RA) during systole, indicating tamponade physiology. The right atrium is scalloped inward in a concave arc, opposed to the normal convex shape of the right atrium. LA, left atrium; LV, left ventricle; RV, right ventricle.

Box 2
Case 1

- Clinical History
  - A 39-year-old woman with past medical history of chronic obstructive pulmonary disease (COPD) and hypertension complained of constant diffuse bilateral chest pain, chills, cough, wheezing, and shortness of breath for 1 week after operative repair of a femur fracture. She was tachycardic and tachypneic with a borderline temperature.
- Findings
  - The electrocardiogram (EKG) showed sinus tachycardia with nonspecific T-wave changes. The RADiUS examination revealed the following information: parasternal long view showing enlarged right ventricle; apical 4-chamber showing right ventricle hypokinesis with apical sparing (see Fig. 8); the IVC was dilated with minimal respiratory variation; pleural examination showed bilateral A-lines only.
- Diagnosis
  - The RADiUS examination confirmed the suspicion of a submassive PE showing right heart strain. Initiation of anticoagulation was indicated. Thrombolytics may be indicated if the patient experiences hemodynamic compromise.

1998 combined echocardiography, clinical features, and a lower extremity duplex ultrasonography to identify patients with PE. These investigators reported a sensitivity of only 89% and specificity of 74%. A more recent study by

Box 3
Well's criteria

- Clinical signs and symptoms of DVT
- Alternative diagnosis less likely than PE
- Heart rate greater than 100 beats per minute (bpm)
- Immobilization for at least 3 days
- Surgery in previous 4 weeks
- Hemoptysis
- Malignancy with treatment within the past 6 months.

Mansencal and colleagues[25] in 2008 combined echocardiography and DVT evaluation in patients with a positive D-dimer screening test. In their high-risk population, they generated only 87% combined sensitivity and 69% specificity. However, this concept may prove valuable in the future, because no one has studied the effect of using the Well's criteria Box 3 or the PE rule-out criteria Box 4 in combination with bedside echocardiography to exclude PE.[26,27]

ULTRASOUND EXAMINATION OF THE IVC

Evaluation of intravascular fluid status is a necessary but challenging component of treating patients with dyspnea or hypotension. Vital signs and physical examination findings too often fail to reliably assess the patient's volume status. More invasive means of obtaining these data are available but require extensive procedures and specialized equipment not readily available to all physicians. Ultrasound examination of the IVC is a noninvasive, reliable, and repeatable alternative that can be used to differentiate between a physiologic state of fluid overload or

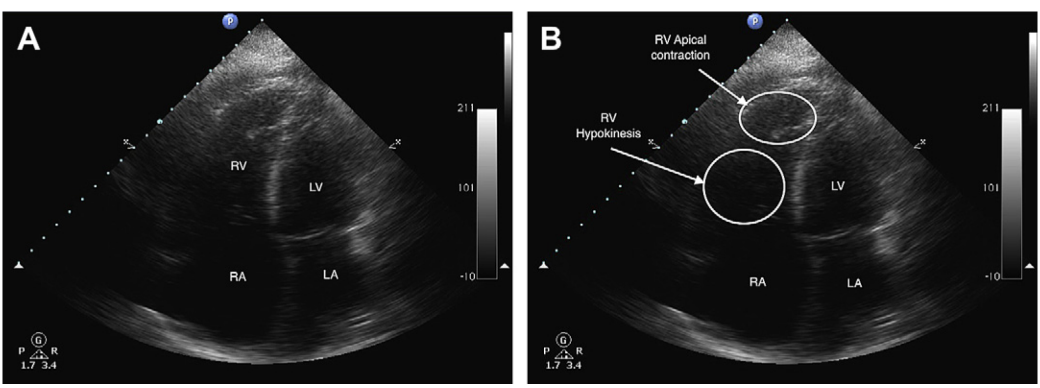

Fig. 8. (*A*, *B*) Apical 4-chamber view showing a positive McConnell sign. In this view we see right ventricular dilation (RV/LV ratio >1:1) and hypokinesis. However, the apex of the right ventricle shows normal function. This sign has a 94% specificity for pulmonary embolus and an NPV of 96%.[20] LA, left atrium; LV, left ventricle; RA, right atrium.

Box 4
PE rule-out criteria

- Age less than 50 years
- Heart rate less than 100 bpm
- Oxygen saturation on room air greater than 94%
- No previous DVT/PE
- No recent trauma or surgery
- No hemoptysis
- No exogenous estrogen
- No clinical signs suggesting DVT

Table 1
Estimation of right atrial pressure (RAP)

IVC Diameter (cm)	% Change with Respiration	Estimated RAP
<1.2	Spontaneous collapse	Volume depletion
<1.7	>50%	0–5 mm Hg
>1.7	>50%	5–10 mm Hg
>1.7	<50%	10–15 mm Hg
>1.7	No change	15–20 mm Hg
Dilated with dilated hepatic veins	No change	>20 mm Hg

one of intravascular fluid depletion. Earlier work by cardiologists has focused on an assessment of the diameter of the IVC in conjunction with its variation throughout spontaneous respiration to estimate right atrial pressure.[28,29] **Table 1** summarizes these findings from the American Society of Echocardiography. A study by Randazzo and colleagues[15] showed that assessment of the central venous pressure by point-of-care physicians correlated 83.3% of the time with the formal assessment of the same ultrasonographic images by a staff cardiologist.

Collapsibility of the IVC is an excellent predictor of a patient's volume status. Greater than 50% collapse of the IVC with spontaneous respiration **Fig. 18** correlates best with intravascular volume depletion.[29,30] Some investigators advocate the use of M-mode to help determine the size variations of the vessels with respiration, but this may result in inaccurate measurements secondary to caudal displacement of the IVC during spontaneous respirations.[31] Many attempts have been made to identify alternative ultrasonographic markers of intravascular volume status. Dilation of the IVC diameter in short axis greater than 10 mm has been proposed as the cutoff for identifying fluid overload.[32] Given the variation in estimations of measurements/volumes among the various studies, Wallace and colleagues[31] attempted to standardize the location to measure the IVC to ensure reproducibility between patients and physicians. These investigators concluded that the most consistent locations for measuring IVC collapse are (1) the IVC in transverse view at the level of the left renal vein and (2) the longitudinal view of the IVC through the liver, 2 cm caudal to the hepatic vein inlet. In addition, some researchers have gone beyond traditional methods and have used peripheral venous-compression ultrasonography as well as an ultrasonographic evaluation of the internal jugular vein to evaluate the intravascular volume status. However, these techniques require additional research before they are validated.[33,34]

Although only a binary examination, the evaluation of IVC collapsibility can rapidly narrow the differential diagnosis. Right ventricular dilation in the presence of a plethoric IVC (**Fig. 9**) may indicate right heart failure, PE, or pulmonary hypertension. A dilated IVC may also be present in cardiac tamponade or long-standing left ventricular dysfunction. Patients in sepsis may present with intravascular volume depletion and hyperdynamic cardiac activity. For patients with presumed COPD

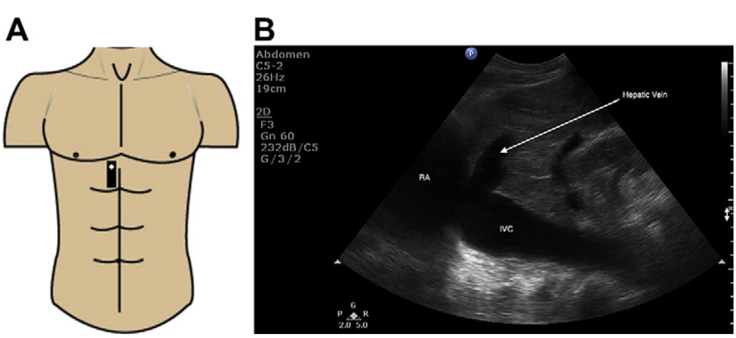

Fig. 9. (*A*) IVC view probe position. (*B*) IVC as it enters the right atrium (RA). The hepatic vein is also visible and can be seen communicating with the IVC. Both the IVC as well as the hepatic vein are fully dilated. A plethoric IVC may be consistent with increases in intravascular volume or increased right heart pressures.

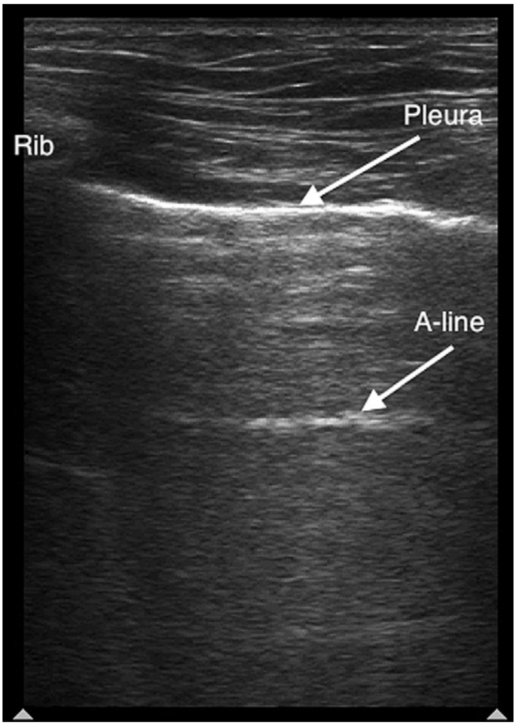

Fig. 10. Patient's pleura using a linear probe showing an A-line artifact. A-lines are a type of reverberation artifact that is the result of ultrasound beams reflecting off the pleura. These lines appear at equal distances, distal from the original signal of the pleura. When A-lines are present in the absence of B-lines they suggest that interstitial edema is not present.

exacerbation, IVC volume status may vary, and its effects on the patients' symptoms have to be interpreted in light of the presence or absence of various comorbidities.

ULTRASOUND EXAMINATION OF THE LUNGS AND PLEURA

The ultrasonographic assessment of the lungs in a patient with undifferentiated shortness of breath can yield a significant amount of information regarding a wide variety of clinical conditions. These results should be interpreted in context of the previous examinations of both the heart and the IVC when making clinical decisions. Ultrasound of the pleura is capable of identifying a pneumothorax, interstitial edema, acute respiratory distress syndrome (ARDS), noncardiogenic pulmonary edema, and consolidation. Imaging the thoracic cavity above the diaphragm allows for the identification of a pleural effusion or hemothorax that is not visible on chest radiograph.

Ultrasound is more sensitive and specific than chest radiography for detection of pneumothorax in all patients.[35] Normal lung tissue on ultrasonography is characterized by the presence of a hyperechoic pleural line with pleural movement (lung sliding) and multiple reverberation artifacts know as A-lines. These artifacts are hyperechoic lines that are present distal to the pleural line, arising at equal distances. The reverberation artifact is created by high difference in tissue density around the pleural line caused by subpleural air (**Fig. 10**). A pneumothorax can be diagnosed on sonography by showing the absence of lung sliding, the absence of the comet-tail artifact, and/or the presence of a lung point.[36–38] Traditional examination of the lung to detect pneumothorax is performed in B-mode or M-mode (**Fig. 11**) but some investigators have advocated the use of power Doppler.[4] This technology detects movements at low velocities and can highlight the subtle

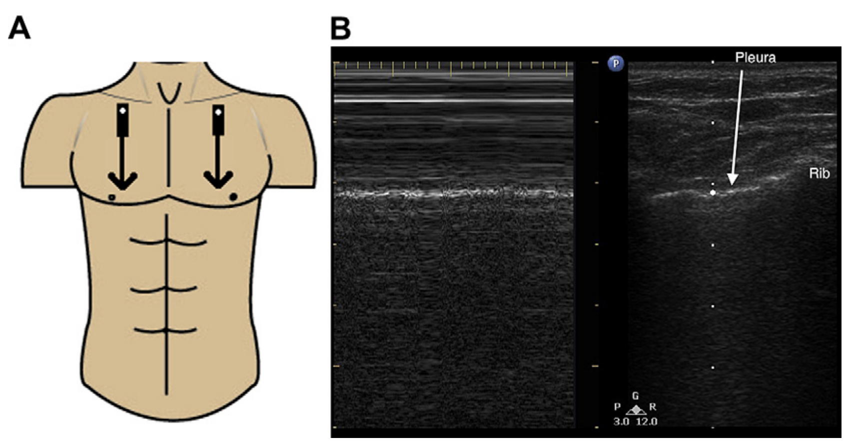

Fig. 11. (*A*) Probe position for pleural evaluation. (*B*) Split-screen image of the pleura, showing B-mode and M-mode simultaneously. The right side shows the hyperechoic pleura and the adjacent rib with its corresponding shadow in B mode. The left side shows the corresponding M-mode image with the classic seashore sign, which indicates normal lung motion and hence the absence of a pneumothorax.

movements of the pleura. In the setting of a pneumothorax the power Doppler signal highlighting the pleural movement is absent. Other investigators have cautioned about sole reliance on the absence of lung sliding, as the sole objective for diagnosing lung collapse, because this finding can be common in right main stem intubations, lung consolidations, and any other process that separates the visceral and parietal pleura.[39] The specificity of lung sliding ranges from 91% to 100%. The sensitivity of lung sliding to detect pneumothorax ranges from 95% to 100%.[35,40–42] These numbers vary largely depending on the number of lung fields examined. The sensitivity of finding a small pneumothorax increases with the number of lung fields examined.

Several other sonographic findings other than lung sliding may aid in the diagnosis of pneumothorax (**Box 5**; **Fig. 12**). Comet-tail artifacts, another type of reverberation artifact, originating at the pleural line, are usually present in normal lung tissue. Comet-tail artifacts differ from A-lines in that they arise from the pleural line as a hyperechoic tail, directed perpendicularly away from the pleural line (**Fig. 13**). Although comet-tail artifacts are absent in almost all cases of pneumothorax, they are only 60% specific for the diagnosis of pneumothorax. A combination of absent lung sliding and absent comet-tail artifacts

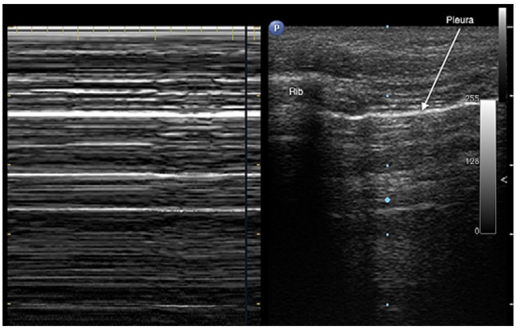

Fig. 12. Split-screen image of B-mode on the right and M-mode on the left. This image shows the pleural line in the B-mode image, with a rib and its shadow at the edge of the image. The M-mode tracing lacks the sandy appearance distal to the pleural line. Instead, horizontal hyperechoic lines extend beyond the pleural line. This image shows the stratosphere sign, indicating a pneumothorax. Contrast this image with **Fig. 11** (seashore sign).

Box 5
Case 3

- Clinical History
  - An 18-year-old female patient presented with pleuritic right chest, shoulder pain, and shortness of breath for 12 hours. She denied any family history of PE, coronary artery disease (CAD), or coagulopathy. She denied taking any medications including oral contraceptive pills. She was currently on her menstrual period. She was tachypneic, tachycardic, and her pulse oximetry was 94% on room air, but had an otherwise unremarkable clinical examination.
- Findings
  - The RADiUS examination revealed the following information: parasternal long and apical 4-chamber views show no normal left ventricular function; the IVC was normal in size and varied less than 50% with spontaneous respiration; examination of the right pleura showed stratosphere sign on M-mode (see **Fig. 12**); examination for effusion on the right side showed loss of mirror-image artifact.
- Diagnosis
  - The RADiUS examination confirmed the diagnosis of catamenial pneumothorax.

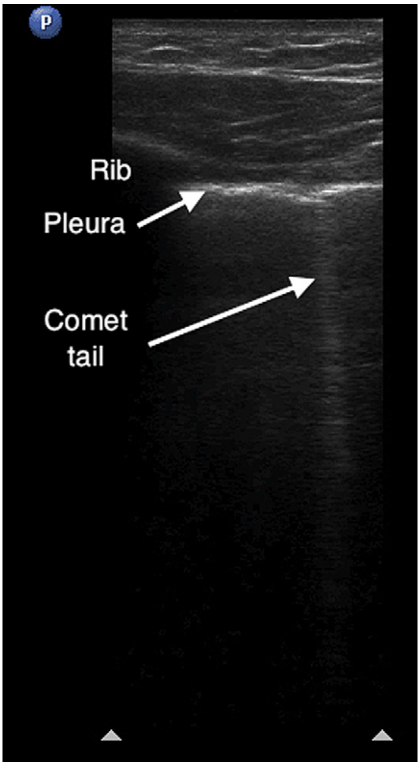

Fig. 13. Patient's pleura showing the comet-tail artifact arising from the pleural line. Comet-tails are a type of reverberation artifact that are seen coming from the pleura line in normal individuals.

improves diagnostic accuracy and has been shown to have 100% sensitivity and 96.5% specificity.[37] Lichtenstein and colleagues[38] introduced the concept of a lung point to describe the transition point in the thorax between the normal pleura and pneumothorax. These investigators identified the point where the visceral and parietal pleura separated, indicating the beginning of the pneumothorax. The presence of a lung point was found to be 66% sensitive and 100% specific. Lichtenstein and Meziere[43] combined these findings to yield a sensitivity of 88% and a specificity of 100% with a PPV of 100% and an NPV of 99%.

Evaluation of the pleural line artifacts can differentiate between some of the most common conditions encountered in critical patients.[43,44] A-lines are a reverberation artifact of the pleural line; they are present in normal lungs and are often more prominent in patients with COPD and asthma (see **Fig. 10**). B-lines are a type of comet-tail artifact arising from the pleural line; they are hyperechoic reverberations that move with lung sliding and extend the length of the viewing screen (**Fig. 14**). More specific definitions have been proposed by various investigators, including the requirement that B-lines obscure A-lines on real-time imaging, but these findings have not been validated.[43] B-lines represent extravascular lung fluid or any process that increases the normal size of the interlobular pulmonary septae, including fibrosis or infection.[45,46] Both the distribution and number of B-lines help to differentiate various disease processes. Unilateral B-lines are believed to be consistent with an inflammatory process such as pneumonia. B-lines associated with a pulmonary contusion carry a sensitivity of 94.6% and specificity of 96.1%.[47] When assessing patients with dyspnea in the intensive care unit (ICU), the predominance of B-lines on one side of the chest with the predominance of A-lines on the contralateral side showed 100% specificity for pneumonia.[43] However, even when associated with artifacts signifying a possible concomitant consolidation their sensitivity is only as high as 14%.[43] Dynamic air bronchograms, defined as linear hyperechoic artifacts within the consolidation with greater than 1 mm centrifugal movement with inspiration, help to differentiate pneumonia from atelectasis.[48] The presence of bilateral B-lines defines the alveolar-interstitial syndrome: a collection of disease processes encompassing pulmonary edema, ARDS, noncardiogenic pulmonary edema (**Boxes 6–8**, **Fig. 15**), and diffuse interstitial lung disease.[49] Bilateral anterior B-lines showed a sensitivity of 97% and a specificity of 95% as well as a PPV of 87% and NPV of 99% for the diagnosis of CHF.[43] The resolution of B-lines may also be used to monitor therapy.[46] Lung findings in patients with COPD distinguish

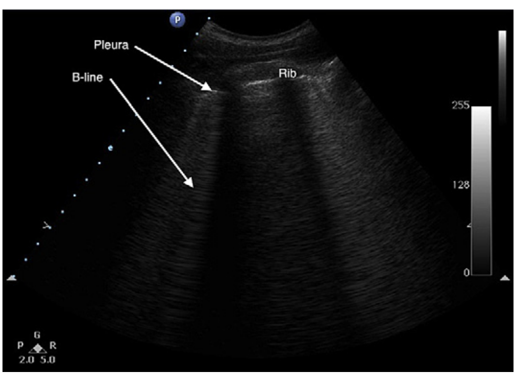

Fig. 14. B-lines. The hyperechoic line near the footprint of the image represents the pleural line. The rib interrupts this line and produces a distal shadow. Multiple hyperechoic reverberation artifacts can be seen originating from the pleural line, extending to the far field of the image, representing B-lines. Multiple bilateral B-lines are consistent with pulmonary edema.

Box 6
Case 2

- Clinical History
  - A 52-year-old man with past medical history of COPD, CHF, CAD, and gout complained of progressive dyspnea and increased sputum for 3 days. He was tachypneic and mildly tachycardic. He had chronic bilateral lower extremity edema, bibasilar rales, and a slight expiratory wheeze.
- Findings
  - The RADiUS examination revealed the following information: parasternal long view showed severely reduced left ventricular function; apical 4-chamber showed dilated left ventricle; the IVC was plethoric with minimal respiratory variation; bilateral small pulmonary effusions were also noted along with diffuse bilateral B-lines (see **Fig. 15**).
- Diagnosis
  - The RADiUS examination confirmed pulmonary edema caused by an acute exacerbation of heart failure. Successful treatment with preload and afterload reduction resulted in improvement of rales, wheezing, and oxygen saturation.

Box 7
Case 4

- Clinical History
  - A 28-year-old G2P2 postpartum female presents with shortness of breath, right sided pleuritic chest pain, mild bilateral lower extremity edema, and a productive cough with blood streaked sputum after recent vaginal delivery. The differential diagnosis includes peripartum caridomyopathy, hemodynamically significant pulmonary embolism, and hospital-acquired pneumonia with sepsis.
- Findings
  - The RADiUS exam reveals the following information: parasternal long view shows no reduction in left ventricular function. The apical four-chamber view shows normal right ventricular size. Examination of the IVC shows greater than 50% collapse with spontaneous respiration (see Fig. 18). Ultrasound of the pleura shows B lines in the right anterior lung fields (see Fig. 14) and A lines on the left (see Fig. 10).
- Diagnosis
  - Based on the RADiUS exam this patient most likely has pneumonia with sepsis and requires initiation of early goal directed therapy with fluids and antibiotics.

Box 8
Case 5

- Clinical History
  - A 38-year-old business executive was brought directly from the airport to the local emergency department in Florida after a 5-day skiing vacation in Colorado, complaining of dyspnea on exertion. In addition he complained of nonproductive cough, fatigue, nausea, headache, and bilateral lower extremity muscle cramps. Family history was significant for thromboembolism. The physical examination showed decreased breath sounds bilaterally, tachypnea, tachycardia, bilateral positive Homans sign, and pulse oximetry of 92% on room air.
- Findings
  - The RADiUS examination revealed the following information: parasternal long and apical 4-chamber views showed normal left ventricular function. The IVC collapsed greater than 50% with spontaneous respiration. Examination of the pleura showed diffuse bilateral B-lines (see Fig. 15).
- Diagnosis
  - As a result of sleeping at 3657 m (12,000 ft) for 4 nights, this patient had developed high-altitude pulmonary edema. The bilateral B-lines, as well as normal cardiac and IVC views, were consistent with noncardiogenic pulmonary edema.

themselves from the disease processes mentioned earlier by a lack of diffuse B-lines.[43,50]

Research does not support sonographic assessment of the lungs or pleura for PE. A study in 2005 by Mathis and colleagues[51] used thoracic ultrasonography to search for triangular or rounded pleural-based lesions as well as unilateral pleural effusion, which may indicate pulmonary emboli. However, this single study of 352 patients had poor sensitivity. Using ultrasonography to diagnose PE has not replaced either computed tomography angiography or ventilation-perfusion scintigraphy. Ultrasound is not sufficiently sensitive to rule out PE. As noted earlier the cardiac examination may help to provide insight into the presence of a hemodynamically significant PE.

Some dyspnea protocols include lower extremity venous ultrasonography to rule out DVT. Several studies have reported that emergency physicians and other clinicians can be accurate and fast in their diagnosis of DVT.[52–55] The inclusion of a DVT evaluation significantly increases time spent performing the ultrasonographic assessment of dyspnea. This examination can be selectively added in cases of suspected PE/DVT.

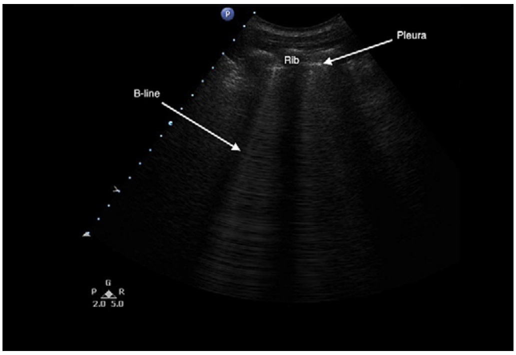

Fig. 15. B-lines. The hyperechoic line near the footprint of the image represents the pleural line. The rib interrupts this line and produces a distal shadow. Multiple hyperechoic reverberation artifacts can be seen originating from the pleural line, extending to the far field of the image, representing B-lines. Multiple bilateral B-lines are consistent with a patient with the alveolar-interstitial syndrome: CHF exacerbation, ARDS, diffuse interstitial lung disease, or noncardiogenic pulmonary edema.

Box 9
Case 6

- Clinical History
  - A 46-year-old man on hemodialysis complained of dyspnea and a cough after missing dialysis. He was diaphoretic, anxious, and moderately distressed, with mild crackles at the bases bilaterally, tachycardic with 3/6 systolic ejection murmur, and jugular venous distention.
- Findings
  - The RADiUS examination revealed the following information: subxiphoid and apical 4-chamber views showed pericardial effusion with right ventricular collapse during diastole; the IVC was dilated and did not collapse with respiration, and the pericardial effusion was visible (see Fig. 16); evaluation of the pleura showed scattered B-lines.
- Diagnosis
  - The RADiUS examination confirmed that cardiac tamponade was present with increased pressure in the pericardial effusion. There was collapse of the right ventricle in diastole and the right atrium in systole. The IVC was plethoric and did not change significantly with respiration.

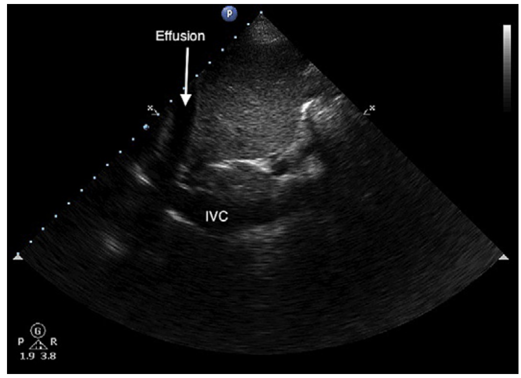

Fig. 16. IVC viewed with a phased-array probe in the sagittal plane. Notice the anechoic space between the liver and epicardium, representing a pericardial effusion.

Pleural Effusion

Ultrasound is an excellent tool to identify pleural effusions. These images are easy to obtain for most physicians, because they require only a modification of the hepatorenal and splenorenal views currently used for the FAST examination (Figs. 17 and 19). Not only can the presence or absence of an effusion be identified by bedside sonography, but ultrasonography can also aid in identifying the extent of the effusion and help simplify any associated procedures.[43,56] The evaluation of pleural effusion should be interpreted within the context of the previously performed cardiac and pulmonary examination as well as the clinical presentation of the patient. Unilateral effusions are commonly associated with pneumonia, PE, aortic dissection, and traumatic hemothorax. Bilateral effusions are associated with volume overload, noncardiogenic pulmonary edema, and CHF.[43]

Ultrasound was also capable of accurately predicting the size of pleural effusions (Box 10; Fig. 19), which can be helpful when considering a thoracentesis on a mechanically ventilated

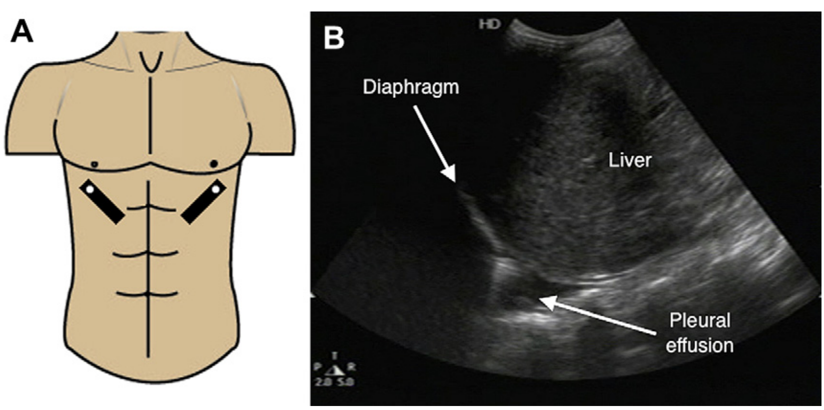

Fig. 17. (*A*) Probe position for evaluation of pleural effusion. (*B*) Pleural effusion, which is noted to be present secondary to the lack of mirror-image artifact. As seen in this image there is no mirror image artifact superior to the diaphragm. A small anechoic triangle of fluid can be seen superior to the diaphragm, suggesting a small pleural effusion.

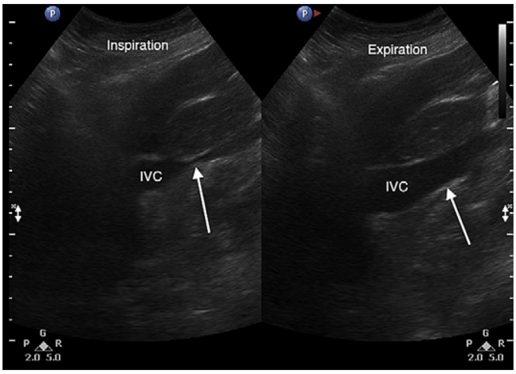

Fig. 18. Split-screen image showing collapse of the IVC during normal respiration. The arrow is directed to an area approximately 2 cm caudal to the junction of the hepatic vein and IVC. Notice that the IVC experiences almost complete collapse during normal respiration, which suggests that the patient will likely respond to the administration of fluids.

patient. Vignon and colleagues[57] showed a significant correlation between the expiratory interpleural distance at the thoracic base and the presence of significant pleural effusion. In their study a interpleural distance of more than 45 mm (right) or more than 50 mm (left) was predictive of a pleural effusion volume greater then or equal to 800 mL, with a sensitivity of 94% and 100% and a specificity of 76% and 67%, respectively. Balik and colleagues[58] conducted a study on 81 ventilator-dependent patients in an ICU and showed that the volume (mL) of pleural effusion could be accurately estimated by the formula SP (maximum distance, measured in mm, between the visceral and parietal pleura at end expiration) $\times$ 20. However, the mean prediction error for this study was 158.4 $\pm$ 160.6 mL. A more recent article by Pneumatikos and colleagues[59] suggests using a cutoff of more than 50 mm between the posterior chest wall and the lung on ultrasonography as highly predictive for the presence of an effusion that contains greater than 500 mL of free fluid. In these studies thoracentesis performed under ultrasonographic guidance led to a reduced complication rate.

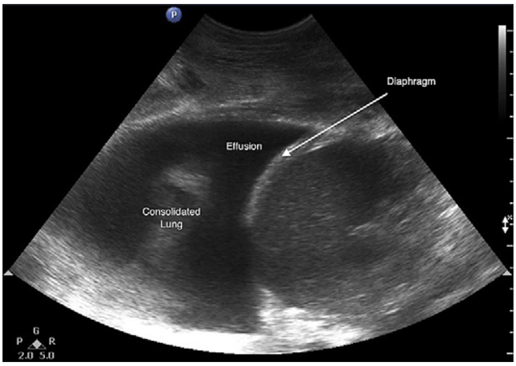

Fig. 19. Large pleural effusion viewed with the curvilinear probe in the coronal plane. Notice the large anechoic space superior to the diaphragm. When large pleural effusions are present, it is not unusual to see consolidated lung tissue floating in the effusion.

Box 10
Case 7

- Clinical History
  - A 66-year-old woman with a past medical history of COPD and right-sided breast cancer and mastectomy several years previously presented with progressive dyspnea and cough with occasional blood-streaked sputum. Her physical examination was remarkable for tachycardia, tachypnea, pulse oximetry 93% on room air, and decreased breath sounds on the right side. The EKG noted a narrow complex sinus tachycardia.
- Findings
  - The RADiUS examination revealed the following information: parasternal long and apical 4-chamber views showed normal left ventricular function; the IVC was normal in size and varied less than 50% with spontaneous respiration.
- Diagnosis
  - Examination of the right thorax revealed a large pleural effusion (see Fig. 19). Given the patient's clinical status, an ultrasound-guided thoracentesis was indicated.

SUMMARY

The RADiUS examination has the ability to change clinical practice by rapidly narrowing the differential diagnosis and allowing the clinician to administer definitive therapy. This real-time bedside sonographic examination combines research from cardiology, radiology, critical care, and emergency medicine. Although its ability to diagnose some important conditions such as PE may be limited, the RADiUS examination is specific for multiple disease processes. Future research may show that the outcomes and lengths of stay of patients can be improved by this focused examination.

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