Point-of-Care Ultrasound for Shortness of Breath and Dehydration

www.rmgultrasound.com

RIVERSIDE

Author:

Virginia M Stewart, MD FACEP RDMS RDCS RDMSK
Dr Stewart is a practicing Emergency Physician in Eastern Virginia, USA. She is the Emergency Ultrasound Director and Emergency Ultrasound Fellowship Director for Riverside Medical Group.

Preface:

This educational resource is designed to provide clinicians with practical knowledge of point-of-care ultrasound that translates to rapid bedside evaluation of patients. Ultrasound has become an integral part of Emergency Medicine and Critical Care in the United States and across the world.

This e-book has 3 sections; The first section focuses on the pulmonary ultrasound examination and some pathology visualised by ultrasound. The second section focuses on the role of Inferior Vena Cava (IVC) measurement. The third section briefly addresses the BRIPPED scanning protocol.

Health care providers are challenged daily to rapidly diagnose and treat life threatening respiratory illness. Ultrasound is a non-invasive, rapid bedside tool that enables providers to quickly identify and treat undifferentiated shortness of breath. The BRIPPED project is a rapid, accurate approach to using ultrasound in the evaluation of shortness of breath in the Emergency Department. The development and evaluation of the BRIPPED protocol would not exist without the work and dedication of my colleagues: Hjalti Bjornsson, MD, Michelle Clinton, MD, Don Byars, MD RDMS RDCS RDMS RVT, David P Evans, MD RDMS RDCS, and Brian Campbell, MD.

- Virginia M Stewart, MD FACEP RDMS RDCS RDMSK

SECTION 1

Pulmonary Ultrasound Examination and Pathology

Air is a poor medium for ultrasound waves due to its low density and slow propagation velocity. Healthy lungs contain air, and are surrounded by the highly reflective bones of the ribs. Rather than visualising lungs directly, pulmonary ultrasound identifies various artifacts or detection of movement.

In a longitudinal view, the acoustic shadowing of the ribs marks the space where the pleural line may be identified. In Figure 1, the acoustic shadow of the ribs (R) is created by the strongly reflective bony cortex, and marks the pleural line (asterix). Since bone reflects ultrasound waves, no signal is detected behind the bony cortex, creating shadowing.

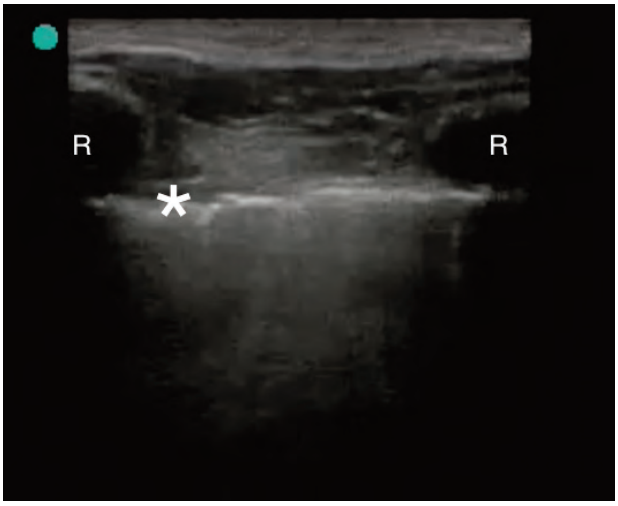

Figure 1: B mode imaging of a normal lung. Acoustic shadowing of ribs (R) marks the pleural line (*) in this longitudinal view

Normal pleural movement demonstrates a "shimmer sign" with B mode imaging. Poor respiratory effort, operator experience or fatigue, and other factors may complicate the identification of a "shimmer sign". M mode imaging uses a high frequency probe to depict lung movement. Using M mode, a normal lung that is moving has a homogenous granular appearance under the brightly visualised pleura. Figure 2 depicts this "seashore sign", with the normal lung reminiscent of sand and approaching waves. The loss of granular appearing "sand" on the bottom half of the screen is indicative of pneumothorax.

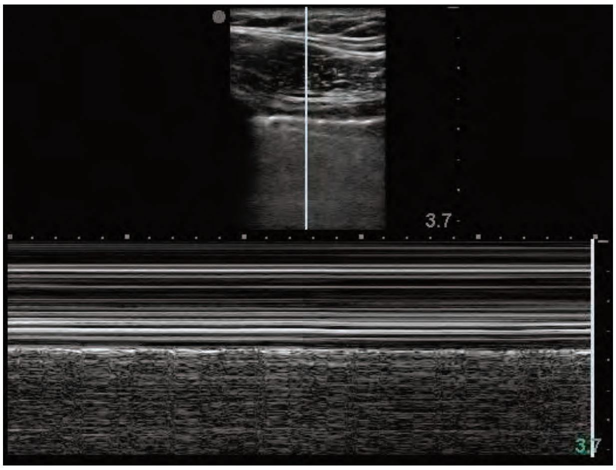

Figure 2: M mode imaging of a normal lung

Lung sliding is also detected by Doppler. Power Doppler (Figure 3) utilises an orange scale to detect movement relative to the transducer surface, which is more sensitive for movement as compared to the red blue Color Doppler. A patient with a pneumothorax will not have lung sliding relative to the transducer surface, and no color will be detected in the sample selected (Figure 4).

B lines, also known as "comet tail" artifacts, represent the common border between the interlobular septa and the alveolar wall.[1] B line artifacts start from the pleural line, and are hyperechoic, or brighter than the surrounding field. Figure 5 demonstrates the vertical B lines and horizontal A lines parallel to and below the pleural line. A lines are the reverberation artifact of the pleural line. B lines move with lung sliding during respiration. In a normal lung the B lines appear to "wipe" side to side over the stationary appearing A lines. The lack of B line movement also indicates pneumothorax.

B lines are key to the identification of interstitial lung disease due to pulmonary fibrosis, pulmonary

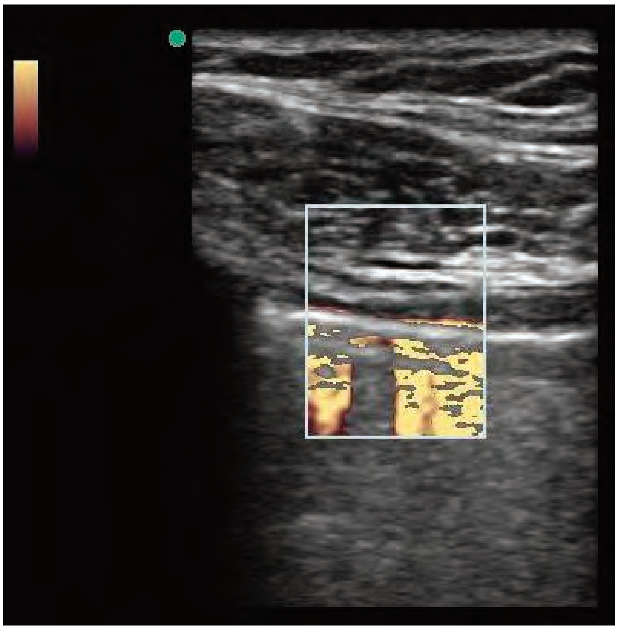

Figure 3: Power Doppler visualisation of a normal lung

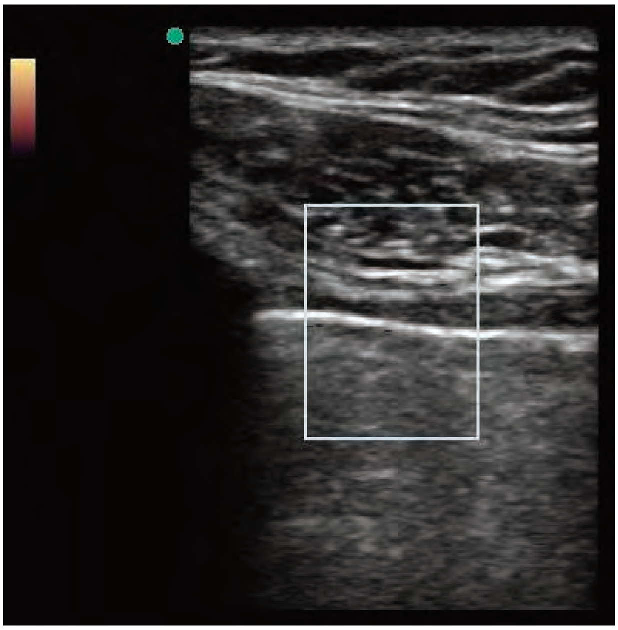

Figure 4: Power Doppler visualisation of pneumothorax

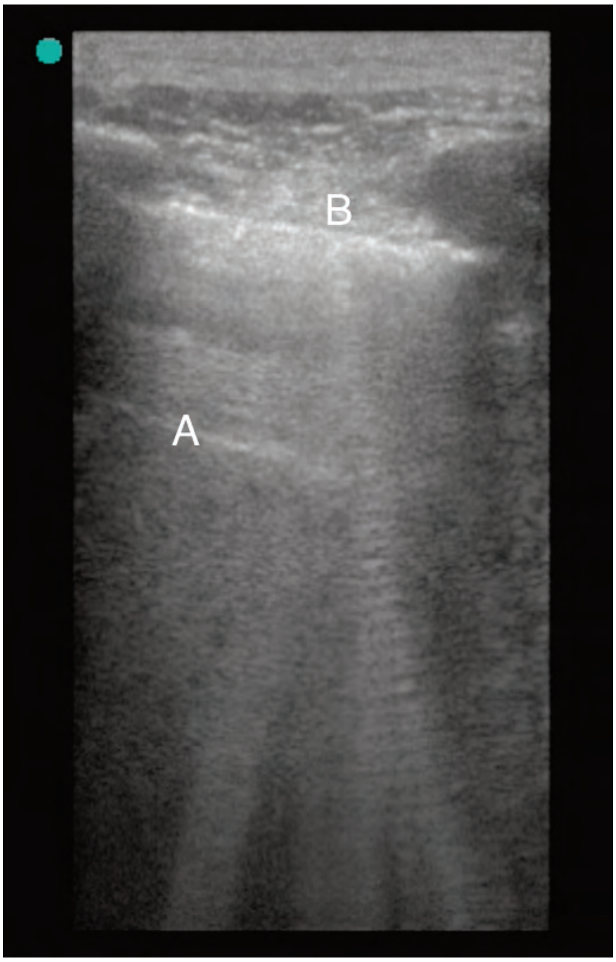

Figure 5: A line artifact (A) and B line or comet tail artifact (B)

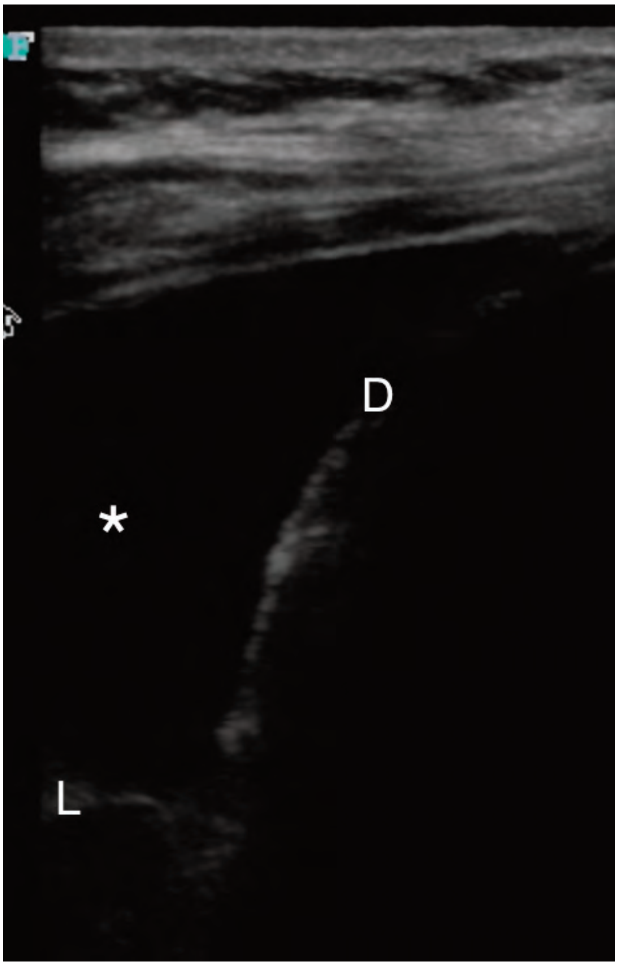

Figure 6: Large anechoic pleural effusion (*), diaphragm (D) and consolidated hyperechoic lung (L)

edema, acute respiratory distress syndrome, and other pathologies.[2] Due to the pleural traction created from underlying fibrotic lung and thickening of the interlobular septa, B lines appear at least 7mm apart in interstitial lung disease.[3] Ground glass appearing on a lung on a chest tomography appear on ultrasound as B lines that are at least 3mm apart.[4]

The lack of B lines is seen in pulmonary consolidation due to the replacement of the alveolar air with fluid or blood. A consolidated lung may appear homogenous or heterogenous. Doppler evaluation of the lung assists with the evaluation of a vascular blood supply indicating lung cancer rather than an infectious etiology of consolidation.[5]

A lung that is compressed from pleural effusion, tumor, bronchial obstruction, or other atelectasis appears wedge shaped and brighter, or more echogenic. Pleural effusions and hemothorax are typically anechoic, or black, on ultrasound. Dynamic evaluation of the compressed lung demonstrates lung floating in an anechoic effusion. Interpleural distance of greater than 50mm at the lung base represents a pleural effusion of at least 800mL.[6] Figure 6 demonstrates a pleural effusion with compressed floating lung.

Inferior Vena Cava Ultrasound and Shortness of Breath

Intravascular volume status is important to consider in a patient with shortness of breath due to congestive heart failure, since treatment may exacerbate hypovolemia and contribute to hemodynamic instability. Central venous pressure (CVP) is not a reliable indicator of volume depletion and does not accurately predict which patients will be “volume responders”. [8, 9]

The role of ultrasound for Inferior Vena Cava measurement (IVC) in patients with shortness of breath is often debated. Authors have disputed different modes and points of measurement and with varying probe placement.[10-14] Additionally, patient position, habitus, degree of respiratory distress, and the presence of mechanical ventilation can influence the size and collapsibility of the IVC. Common agreement may be found from a recent metanalysis, suggesting a moderate level of evidence supporting the IVC diameter is low in hypovolemic patients as compared with euvolemic patients.[15]

The caval index calculates the percentage collapse of the IVC: IVC expiratory diameter – IVC inspiratory diameter, divided by the IVC expiratory diameter x 100 = caval index (%). In the setting of shortness of breath, a caval index near 100% suggests complete collapse of the IVC and is indicative of volume depletion. The closer the number to 0% the more likely the patient has intravascular volume overload.[16] Additionally, cardiac tamponade from pericardial effusion should be considered with a non-collapsable IVC in patients with shortness of breath. The BRIPPED scan is a screening tool for patients with shortness of breath of unclear etiology. Among its components discussed below,

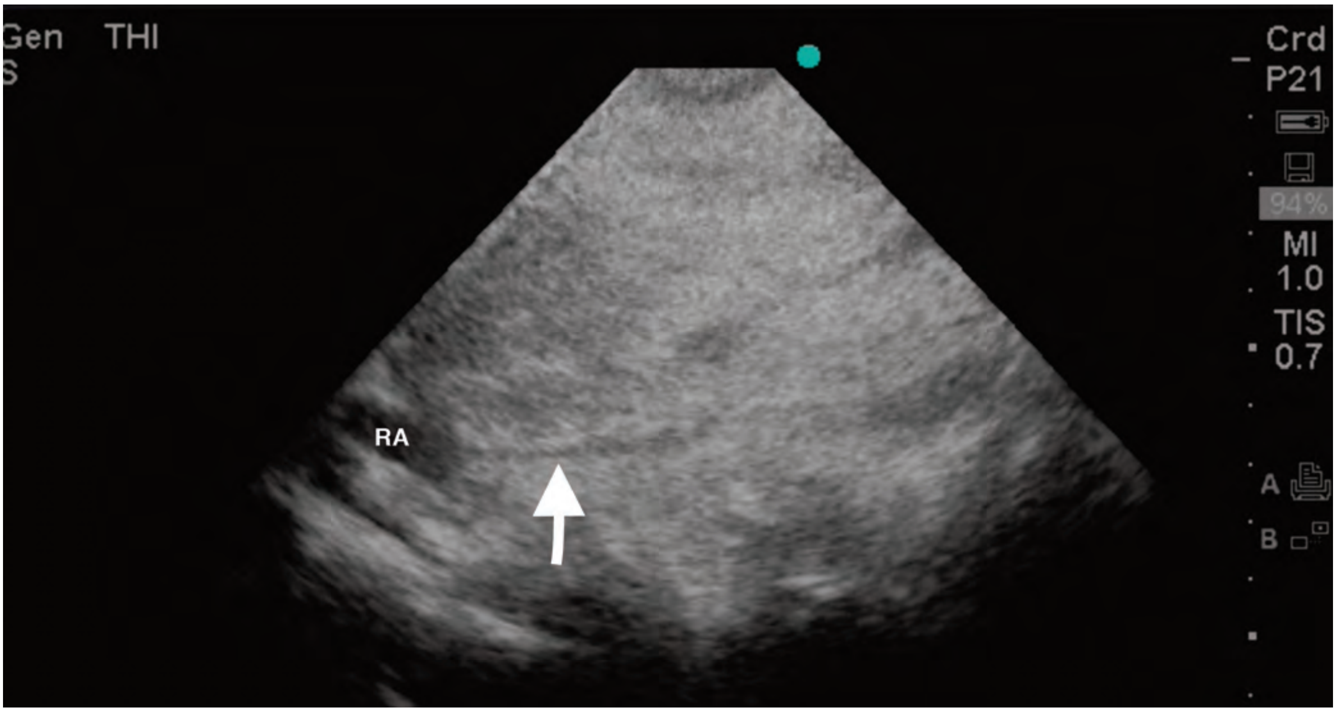

Figure 7: IVC (arrow) collapses with inspiration. RA = Right Atrium

the scan simplifies the caval index by qualitatively evaluating the collapse of the IVC. Figure 7 demonstrates a collapsed IVC in a patient admitted to the Emergency Department with shortness of breath due to congestive heart failure. This patient is intravascularly depleted and required intravenous fluids. Figure 8 demonstrates a dilated IVC in a patient with shortness of breath due to congestive heart failure with intravascular volume overload. Additionally BRIPPED screens patients for pericardial effusion and other etiologies of shortness of breath.

The IVC is visualised in the long axis plane in patients who are semi-recumbent or supine. The IVC should be visualised as it enters the right atrium, to differentiate it from the aorta that runs parallel to the IVC. With the BRIPPED protocol, the sonographer may image the IVC, and obtain cardiac windows using the same lower frequency phased array probe to evaluate ejection fraction and pericardial effusion. The probe is placed below the xiphoid bone, and the probe marker rotated towards the patient's head. Alternatively, the probe may be placed anterior to the mid axillary line, with the probe marker towards the head.

Figure 8: Dilated IVC with minimal respiratory variation. RA = Right Atrium

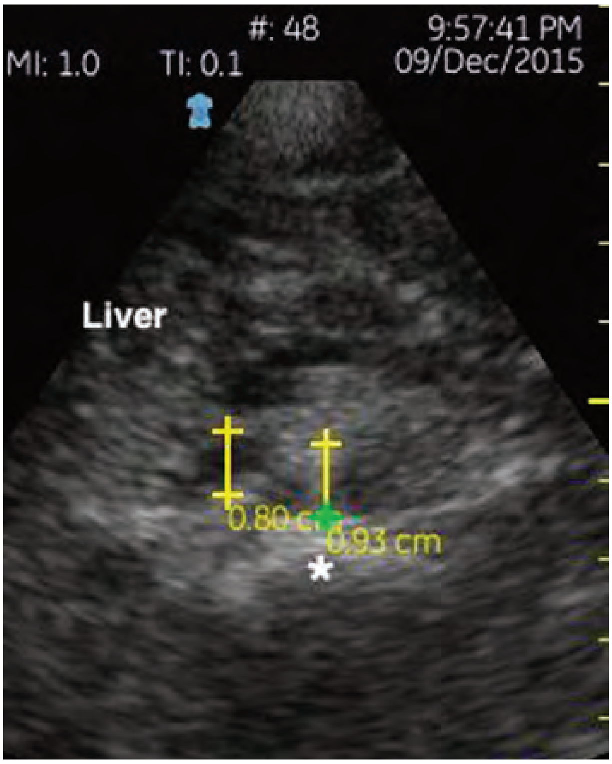

Figure 9: Infant IVC measuring 0.8cm and aorta measuring 0.93cm anterior to posterior transverse diameter. The IVC/aorta ratio is greater than 0.8 in this euvolemic infant. The aorta demonstrates pulsatile flow under color or power doppler (not pictured) and is located above the spine (*)

Additionally the role of IVC ultrasound in dehydration is debated in pediatric populations. In a prospective non-consecutive cohort study of children < 18 years old, the ratio of the IVC and Aortic diameters were found to be a modest predictor of significant dehydration in children.[17] Maximum short (transverse) axis anterior to posterior diameters for both the IVC and Aorta were measured during expiration for the IVC and systole for the aorta. Figure 9 demonstrates this measurement. A ratio cut off of 0.8 was used to identify children with significant dehydration.

SECTION 3

BRIPPED Protocol:
The BRIPPED scan is an effective screening tool for undifferentiated shortness of breath that evaluates pulmonary B-lines, Right ventricle size and strain, Inferior Vena Cava (IVC) collapsibility, Pleural and Pericardial Effusion, Pneumothorax, Ejection Fraction of the left ventricle, and lower extremity Deep Venous Thrombosis.

B-lines: Sonographic pulmonary B-lines have been shown to correlate with congestive heart failure.[18-21, 25, 26] A high frequency linear probe is used to evaluate at minimum 2 mid clavicular apical lung windows.

RV strain: Right ventricular (RV) enlargement can be caused by a Pulmonary Embolus (PE), acute RV infarct, Congestive Heart Failure (CHF), pulmonary valve stenosis or pulmonary hypertension, and is a risk factor for early mortality in PE.[27] A low frequency phased array probe is used to evaluate RV strain in an apical 4 chamber view.

IVC-size and collapsibility: Using an IVC size cutoff of 2.0 cm has been shown to have a sensitivity of 73% and specificity of 85% for a Right Atrial Pressure (RAP) above or below 10 mmHg. The collapsibility during forced inspiration of less than 40% has even greater accuracy for elevated RAP (sensitivity 91%, specificity 94%, NPV 97%).[28] A low frequency phased array or curvilinear probe is used to visualise the IVC long axis, and dynamic imaging is used to assess collapsibility as either complete or less than 40%.

Pneumothorax: Bedside ultrasound is more accurate than supine chest x-ray with diagnostic ability approaching that of CT. [29, 30] The same windows for B-lines are utilised for pneumothorax screening. Additionally any area of decreased breath sounds, or crepitus palpated along the chest wall is evaluated for pneumothorax with a high frequency linear probe.

Pleural effusion: EUS has been shown to have an accuracy similar to a CXR for evaluation of pleural effusion.[23, 24] A low frequency phased array or

curvilinear probe is used to evaluate each mid axillary line at the costophrenic angle in the sitting patient.

Pericardial effusion: EUS has a sensitivity of 96% and specificity of 98% compared to formal echocardiography.[31] A low frequency phased array probe is used to evaluate pericardial effusion from an apical 4 chamber view and a parasternal long axis view of the heart.

EF: The qualitative assessment of left ventricular ejection fraction by emergency physicians has been shown to correlate well with an assessment by a cardiologist.[32-34] The same low frequency probe and parasternal long axis used to evaluate pericardial effusion is used to evaluate ejection fraction. Dynamic qualitative assessment of ejection fraction is classified as normal, depressed, or severely depressed.

DVT in lower extremities: Ultrasound was performed by emergency physicians using a 2 point compression venous ultrasound on patients with suspected lower extremity DVT. This approach had a 100% sensitivity and 99% specificity in diagnosing DVT, compared to a reference venous ultrasound in radiology.[35] A high frequency linear probe evaluates compressibility of the common femoral and popliteal veins with dynamic scanning. If pretest probability is higher for DVT, then additional fields are included, starting below the inguinal ligament at the common femoral vein, and each segment of vessel is compressed every 2 cm to the trifurcation of the popliteal artery distally.

The BRIPPED protocol can be performed in its entirety from a head to toe approach, switching between transducers, or completing the exam with one transducer then switching to the next. An example of the latter would be to first use the low frequency probe to evaluate the parasternal long axis and apical 4 chamber, noting the presence or absence of pericardial effusion, ejection fraction, and RV strain. Then the long axis of the IVC is evaluated for dynamic collapsibility. Moving laterally, the costophrenic angles are evaluated bilaterally for pleural effusion. The probe is switched to the high frequency probe to evaluate each lung apex is evaluated in the mid clavicular line for the presence of pneumothorax and B lines. Lastly, the dynamic 2 point DVT screening is performed with compression ultrasound. The BRIPPED protocol and other bedside ultrasound resources can be viewed here:

http://www.anatomyguy.com/b-ripped-scan-for-evaluation-of-emergency-department-patients-with-shortness-of-breath/

References:

1. Kirkpatrick, A.W., et al., Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the Extended Focused Assessment with Sonography for Trauma (EFAST). J Trauma, 2004; 57(2): 288-95.
2. Jalli R, Sefidbakht S, Jafari SH. Value of ultrasound in diagnosis of pneumothorax: a prospective study. Emerg Radiol 2013; 20:131
3. Wilkerson RG, Stone MB. Sensitivity of bedside ultrasound and supine anteroposterior chest radiographs for the identification of pneumothorax after blunt trauma. Acad Emerg Med 2010; 17:11.
4. Raja AS, Jacobus CH. How accurate is ultrasonography for excluding pneumothorax? Ann Emerg Med 2013; 61:207.
5. Alrajhi K, Woo MY, Vaillancourt C. Test characteristics of ultrasonography for the detection of pneumothorax: a systematic review and meta-analysis. Chest 2012; 141:703.
6. Alrajab S, Yousset AM, Akkus NI, Caldito G. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. Crit Care 2013; 17:R208.
7. O'Connor AR, Morgan WE. Radiological review of pneumothorax. BMJ 2005; 330:1493.
8. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven mares. Chest 2008. 134(1):172-8.
9. Marik PE, Cavallazzi R. Does the central venous pressure predict fluid responsiveness? An updated meta-analysis and a plea for some common sense. Crit Care 2013. 41(7):1774-81.
10. Kircher B, Himelman R, Schiller N. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. AM J Cardiol 1990; 66: 493-6.
11. Akilli B, Bayir A et al. Inferior vena cava diameter as a marker of early hemorrhagic shock: a comparative study. Ulus Travma Acil Cerrahi Derg 2010;16(2):113-8.
12. Barbier C, Loubières Y, Schmit C, Hayon J, Ricôme JL, Jardin F, Vieillard-Baron A. Respiratory changes in inferior vena cava diameter are helpful in predicting fluid respon- siveness in ventilated septic patients. Intensive Care Med 2004; 30:1740–1746
13. Blehar DJ, Dickman E, Gaspari R. Identification of congestive heart failure via respiratory variation of inferior vena cava. Am J Em Med 2009;27:71–5.
14. Blehar et al. Inferior vena cava displacement during respirophasic ultrasound imaging. Critical Ultrasound Journal 2012, 4:18
15. Dipti A et al. Role of inferior vena cava diameter in assessment of volume status: a meta-analysis. AJEM 2012 (30). 1414 -19.
16. Nagdev AD, Merchant RC, Tirado-Gonzalez A, et al. Emergency department bedside ultrasonographic measurement of the caval index for noninvasive determination of low central venous pressure. Ann. Emerg. Med. 2010;55:290-5.
17. Jauregui et al. The BUDDY (Bedside Ultrasound to Detect Dehydration in Youth) study. Crit Ultrasound J 2014. 6(15).
18. Lichtenstein D, Meziere G, Biderman P, Gepner A, Barre O. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med. 1997; 156:1640–6.
19. Soldati G, Copetti R, Sher S. Sonographic Interstitial Syndrome The Sound of Lung Water. J Ultrasound Med 2009; 28:163-174.
20. Reibig A, Kroegel C. Trasnthoracic sonography of diffuse parenchymal lung disease: the role of comet tail artifacts. J Ultrasound Med. 2003;22:173-180.
21. Rumack CM, Wilson SR, Charboneau JW. Diagnostic Ultrasound. 3rd ed. St. Louis, MO: Mosby; 2004.
22. Copetti R, Cattarossi L, Macagno F, Violino M, Furlan R. Lung Ultrasound in respiratory distress syndrome: a useful tool for early diagnosis. Neonatology. 2008:94(1):52-9.
23. Wernecke K. Sonographic features of pleural disease. AJR AM J Roentgenol. 1997;168:1061-1066.
24. Vignon P, Chastagner C, Berkane V, et al. Quantitative assessment of pleural effusion in critically ill patients by means of ultrasonography. Crit Care Med. 2005;33:1757-1763.
25. Lichtenstein D, Meziere G. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest. 2008;134:117-125.
26. Liteplo, A.S., et al., Emergency thoracic ultrasound in the differentiation of the etiology of shortness of breath (ETUDES): sonographic B-lines and N-terminal pro-brain-type natriuretic peptide in diagnosing congestive heart failure. Acad Emerg Med, 2009; 16(3):201-10.
27. Kucher, N., et al., Prognostic role of echocardiography among patients with acute pulmonary embolism and a systolic arterial pressure of 90 mm Hg or higher. Arch Intern Med, 2005; 165(15):1777-81.
28. Brennan, J.M., et al., Reappraisal of the use of inferior vena cava for estimating right atrial pressure. J Am Soc Echocardiogr, 2007; 20(7):857-61.
29. Kirkpatrick, A.W., et al., Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the Extended Focused Assessment with Sonography for Trauma (EFAST). J Trauma, 2004; 57(2): 288-95.
30. Xirouchaki N, Magkanas E, Vaporiid K, et al., Lung ultrasound in critically ill patients: Comparison with bedside chest radiography. Intensive Care Med, 2011; 37(9):1488-1493.
31. Mandavia, D.P., et al., Bedside echocardiography by emergency physicians. Ann Emerg Med, 2001; 38(4):377-82.
32. Alexander, J.H., et al., Feasibility of point-of-care echocardiography by internal medicine house staff. Am Heart J, 2004; 147(3): 476-81.
33. Moore, C.L., et al., Determination of left ventricular function by emergency physician echocardiography of hypotensive patients. Acad Emerg Med, 2002; 9(3):186-93.
34. Randazzo, M.R., et al., Accuracy of emergency physician assessment of left ventricular ejection fraction and central venous pressure using echocardiography. Acad Emerg Med, 2003; 10(9): 973-7.
35. Crisp, J.G., L.M. Lovato, and T.B. Jang, Compression ultrasonography of the lower extremity with portable vascular ultrasonography can accurately detect deep venous thrombosis in the emergency department. Ann Emerg Med, 2010; 56(6): 601-10.

RIVERSIDE

Mailing Address:
500 J Clyde Morris Blvd
Department of Emergency Medicine
Newport News, VA 23601

t: (757) 594 2000
w: www.rmgultrasound.com