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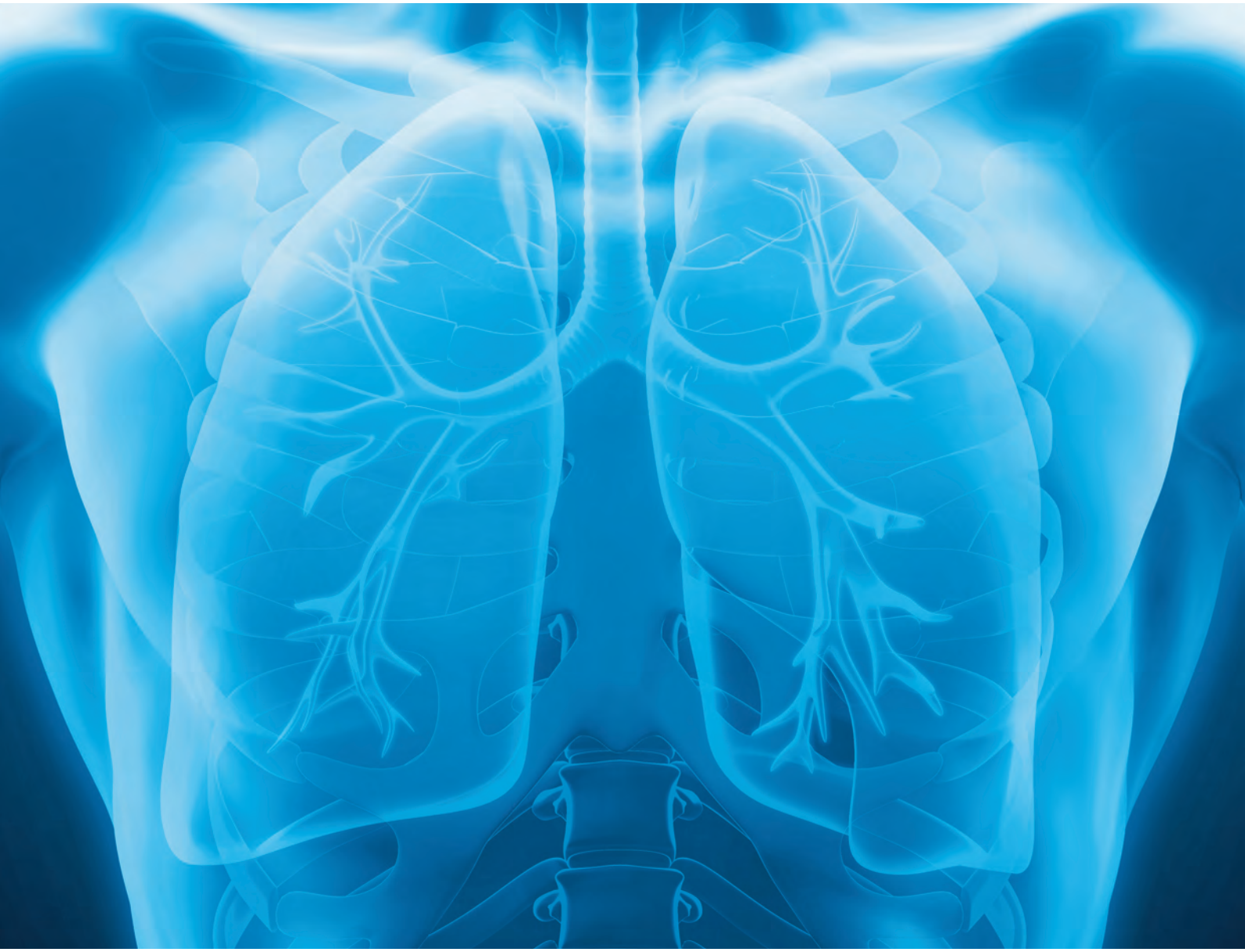

POINT-OF-CARE ULTRASOUND IN SHORTNESS OF BREATH AND INTRAVENOUS ACCESS IN EMERGENCY DEPARTMENT PATIENTS

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Preface: This educational resource is designed to provide clinicians with practical knowledge of pulmonary and procedural 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 2 sections; the first section focuses on practical physics and technical instrumentation, the pulmonary ultrasound examination and pathologies, and briefly addresses the BRIPPED scanning protocol. The second section discusses ultrasound guided intravenous access.

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.

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Point-of-Care Ultrasound in Shortness of Breath and Intravenous Access in Emergency Department Patients

Principles of Pulmonary Ultrasound:

Ultrasound deals with waves traveling through a medium at frequencies above the threshold of human hearing. More accurately, these waves are pressure waves produced by the ultrasound transducer that travel through a tissue medium. Typically, bedside ultrasound machines used for emergency department and critical care applications utilise frequencies between 2 to 14 megaHertz. Several probes are often available for selection, depending on the application or procedure performed. Two important properties of the ultrasound wave important to probe selection are frequency and wavelength. Wavelength is the distance between successive crests of the sound wave. Frequency is the number of occurrences of a repeating event (for ultrasound purposes, the sound wave crest) over a unit of time. Frequency and wavelength are inversely related. The longer the wavelength, or greater the distance between the wave crests, the less frequent the crests occur over a unit of time. In other words, long wavelengths have low frequencies. Lungs are relatively superficial compared to intracavitary organs, so less distance is required to visualise the pleura. A higher frequency probe (5-14 MHz), with a shorter wavelength is required. In addition to ultrasound wave properties, the ultrasound transducer surface is also considered in probe selection for pulmonary ultrasound. Flat footprints of varying length and square or rectangular shape are available.

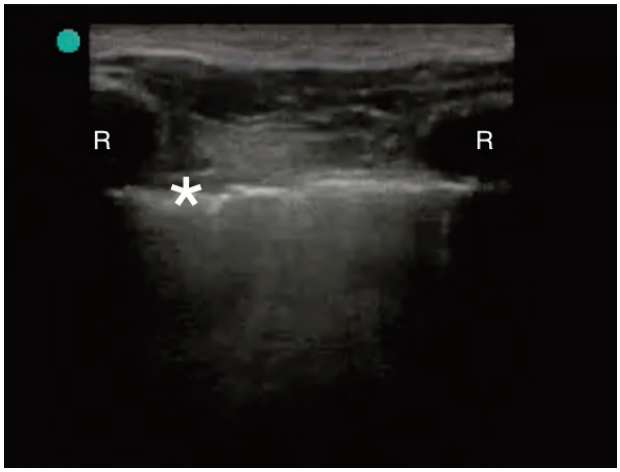

Figure 1: B mode imaging of normal lung. Acoustic shadowing of ribs (R) marks the pleural line (*) in this longitudinal view.

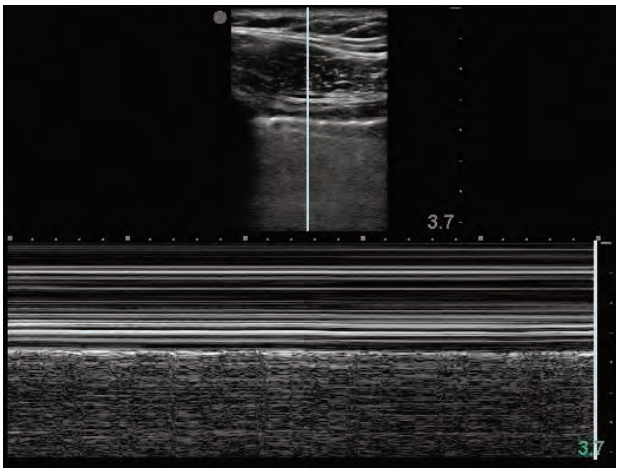

Figure 2: M mode imaging of normal lung.

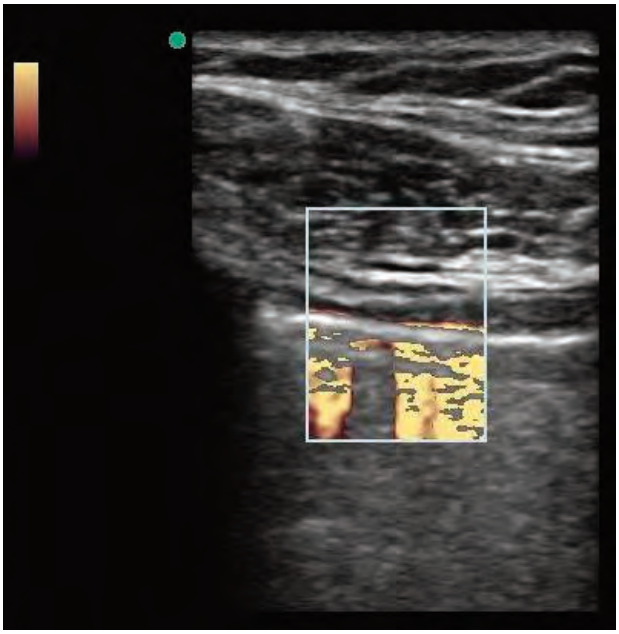

Figure 3: Power Doppler visualisation of normal lung.

Various modes are utilised to visualise intrathoracic structures, including B mode, M mode, and Doppler assessment. B-mode stands for "brightness" mode and presents a 2 dimensional display in varying shades of gray (Figure 1). M-mode stands for "motion" mode, and selects an "ice pick" single dimension sample from pixels of the B mode image (Figure 2). The horizontal axis represents time and the vertical axis represents the motion of reflecting echoes. Many machines simultaneously display B and M mode imaging. Doppler assessment is obtained either through continuous, pulse wave, or color flow mapping. Pulse wave Doppler uses a single crystal that transmits the ultrasound wave, then "listens" to receive the returning Doppler information. The returning pulse is a snapshot of the position of the reflecting surface position within the sample. A B mode image is displayed along with information about pleural movement in relation to the transducer surface. Pulse wave Doppler information is displayed acoustically or is converted into color. A color map indicates flow direction with a red and blue scale, or simply the presence of movement, which is depicted as an orange scale. Figure 3 demonstrates power Doppler as it detects pleural movement (orange) relative to the transducer surface.

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.

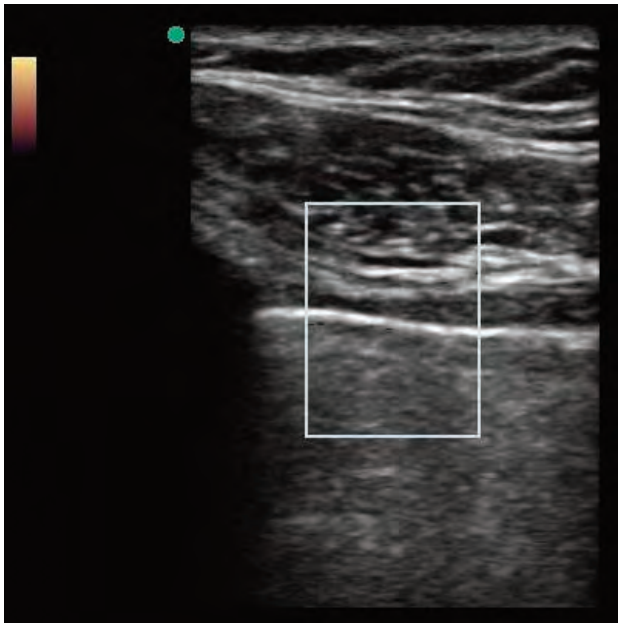

Figure 4: Power Doppler visualisation of pneumothorax.

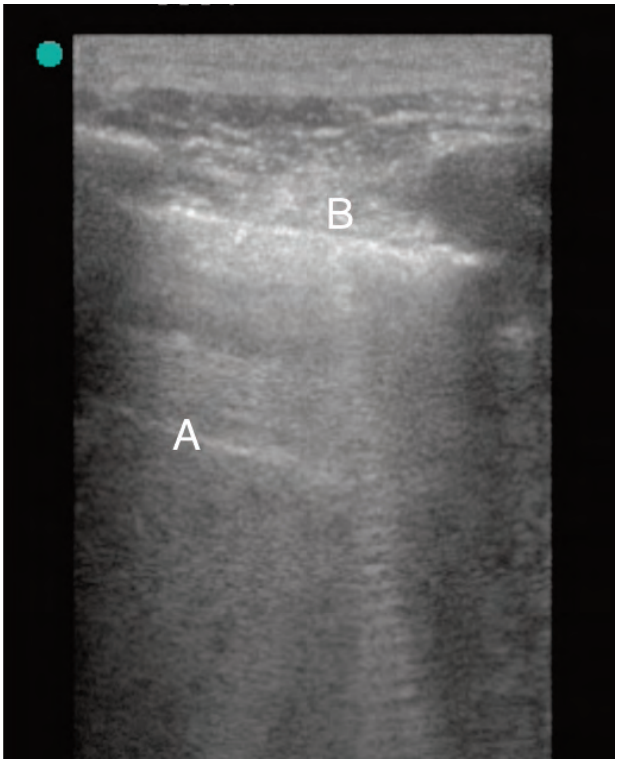

Figure 5: A line artifact (A) and B line or comet tail artifact (B).

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, 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. Bedside ultrasound is more accurate than supine chest x-ray for detecting pneumothorax, with diagnostic ability approaching that of CT.[1-6]

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.[7] 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 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 identification of interstitial lung disease due to pulmonary fibrosis, pulmonary edema (cardiogenic and noncardiogenic), adult and neonatal respiratory distress syndrome, and other pathologies.[8] Several authors have identified different anatomic and causal mechanisms for the sonographic appearance of B lines. In 2009, Soldati et al conducted a 3 part study that included a retrospective analysis of pulmonary ultrasound images in patients with interstitial syndrome, a literature analysis, and an experimental model of artificially made lung tissue. This study concluded

that reverberation artifact creating "ring-down" phenomenon is responsible for the appearance of B lines and this acoustic phenomenon is likely created by proximity of air bubbles with a critical radius.[9]

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.[10] Ground glass appearing lung on chest tomography appear on ultrasound as B lines that are at least 3mm apart.[11]

Acute Respiratory Distress Syndrome (ARDS) demonstrates rib spaces with multiple B lines, few B lines or no B lines. ARDS, while a diffuse lung disease, on CT imaging demonstrates areas of normal appearing lung interspaced with focal areas of edema. These "skip lesions" create the presence of varying numbers of B lines per rib space in a patient with ARDS.

In contrast to ARDS, respiratory distress syndrome (RDS) of the neonate lacks areas of normal lung. RDS is identified by a high density of B lines, also described as "white lung", pleural line abnormalities, and the absence of "spared areas".[12]

The lack of B lines is seen in pulmonary consolidation due to the replacement of the alveolar air with fluid or blood. Consolidated lung may appear homogenous or heterogenous. Doppler evaluation of lung assists with evaluation of a vascular blood supply indicating lung cancer rather than an infectious etiology of consolidation.[13]

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. An inter-pleural distance of greater than 50mm at the lung base represents a pleural effusion of at least 800mL.[14] Figure 6 demonstrates a pleural effusion with compressed floating lung.

Several scanning protocols exist for pulmonary

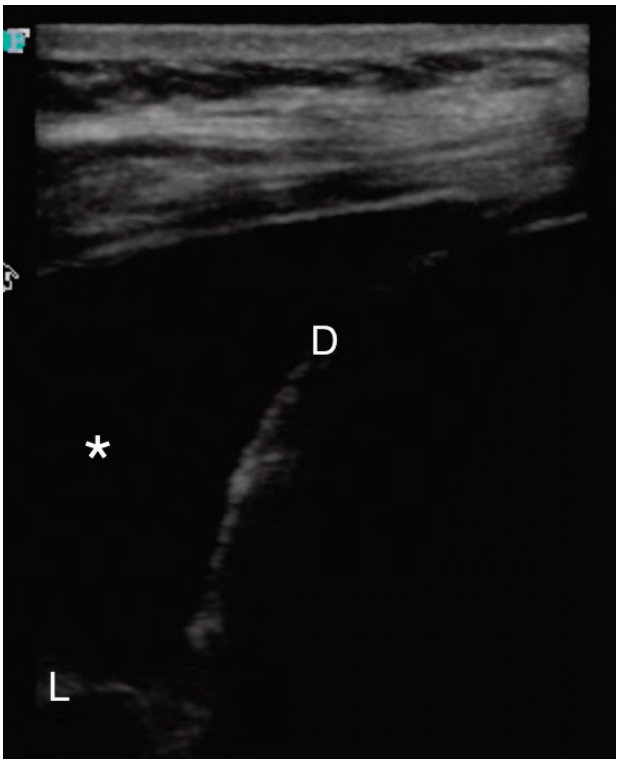

Figure 6: Large anechoic pleural effusion (*), diaphragm (D) and consolidated hyperechoic lung (L).

ultrasound. As a general rule of thumb, it is recommended to visualise more than one lung field, and over any area where there is clinical suspicion for pathology. The BRIPPED protocol is a screening tool for undifferentiated shortness of breath that may be performed with the patient in any position, and utilises high and lower frequency probes using a portable bedside ultrasound machine.

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.[8-11,15,16] 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.[17] 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%).[18] 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. [19,20] 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.[13,14] 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.[21] 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.[22-24] 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 two 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.[25] 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/

Intravenous Access

Patients presenting to the Emergency Department (ED) with shortness of breath may have characteristics that impede intravenous (IV) access. Such characteristics may include hypotension, dialysis dependence, morbid obesity, or histories of diabetes, sickle cell disease, or IV drug use. One prospective observational study identified nearly one in every 9 to 10 adults presenting to an urban ED had difficult venous access requiring 3 or more IV attempts.[26] If peripheral IVs are not established, patients may need a central venous catheter placed for life saving medications administered. In addition to requiring physician skill, central venous catheter insertion carries a risk of complications including infection, arterial puncture or aneurysm, and pneumothorax. Ultrasound-guidance for peripheral IV placement (UGPIV) has prevented the need for central venous catheter placement in 85% of patients with difficult IV access.[27] UGPIV has been performed by Emergency Medical Technicians (EMTs) in prehospital settings, as well as nurses and physicians. Patients who have been identified as having difficult acces, have higher patient satisfaction scores when ultrasound is used in peripheral IV access attempts.[28]

Frequently, the large veins of the antecubital fossa are sufficient to place large bore peripheral IVs needed for resuscitation. The brachial and basilic veins are easy to locate. The brachial artery is generally flanked by 2 smaller veins and the median nerve. Anatomically, these structuers are medial to the insertion of the medial biceps tendon. This tendon is palpable in the antecubital fossa as the patient flexes then extends the elbow. The basilic vein is located medial to the brachial vessels. Generally, it is more superficial, larger, and does not have an accompanying artery or nerve at the level of the antecubital fossa. As you move proximally up the arm (towards the head) the basilic vein dives deeper toward the humerus, and longer angiocatheters may be required for cannulation.

When considering vascular access, there are 2 views, a short and long axis view. Cannulation from the short axis is considered "out of plane" since the needle is perpendicular to the probe. A short axis approach "looks" at a cross section of the vessel. Long axis uses and "in plane" approach with the needle entering from the probe marker end, and "looks" along the length of the vessel. Figure 7 identifies a vessel using color Doppler in the short axis view. Figure 8 demonstrates a long axis view with a hyperechoic angiocatheter. Figure 9 is a the same vessel in long axis with the angiocatheter placed. While both approaches may be used for UGPIV placement, the benefit for the short axis is the ability to identify target veins as well as accompanying non-target (arteries and nerve) structures.

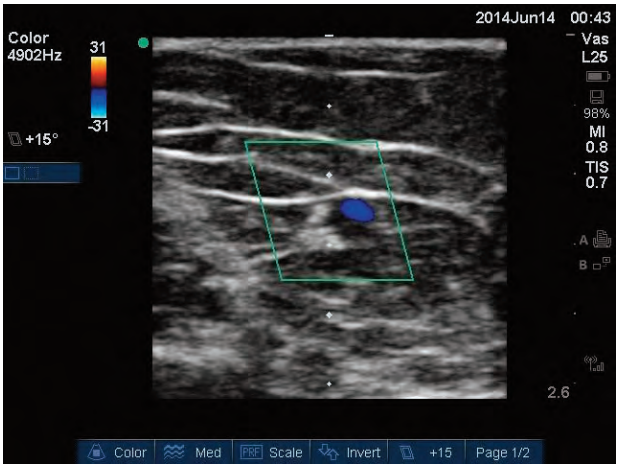

Figure 7: Short axis view of a peripheral vessel visualised with Color Doppler (blue). The scale on the right of the screen demonstrates a total depth of 2.6 cm. A guide (white dots) in the center of the screen marks each 0.5cm of depth. Therefore the depth of the vessel is between 1-1.5cm deep to the skin surface.

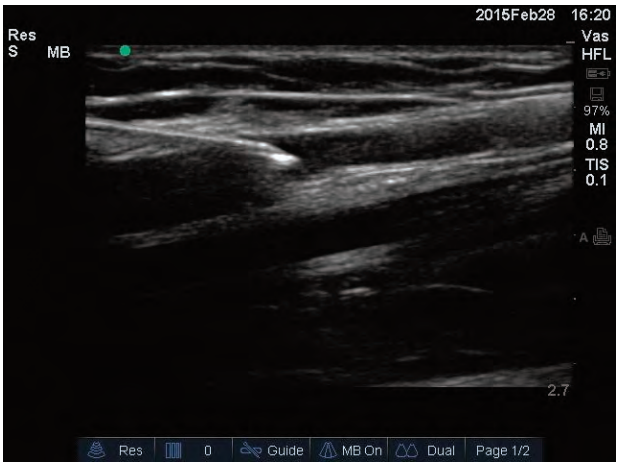

Figure 8: Long axis view of a peripheral vessel. The hyperechoic needle is visualised approaching from the top left of the screen into the vessel lumen.

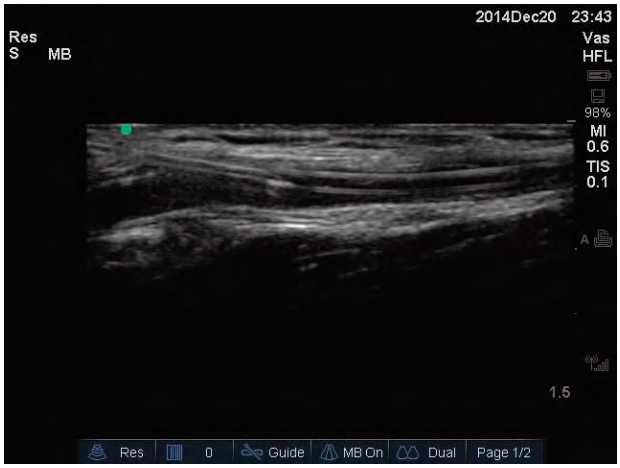

Figure 9: In this long axis view of a peripheral vessel the catheter has been threaded and is seen within the lumen of the vessel.

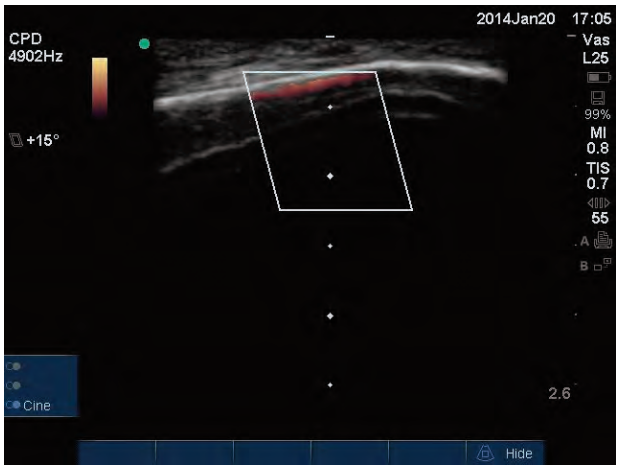

Figure 10: Power Doppler (orange) confirms placement of an intraosseus line within the distal tibia. The bright white line of the tibia cortex (in long axis view) is visualised at the top of the screen, with flow confirmation from a 10cc saline flush immediately distal (below) to the hyperechoic cortex.

Identify the Vein: Remember the C's

The two Cís to remember for UGPIV access or for central venous cannulation are Compression and Color (or Power) Doppler. Veins are thinner-walled and more easily compressed than arteries. This author advocates for finding a vessel first in the short plane, and compressing the vessel to ensure it is indeed a vein, rather than a less or non-compressible artery. Color or Power Doppler may be utilised to determine if pulsatile flow is consistent with an artery or vein. Color Doppler uses red and blue to determine flow towards or away from the probe respectively. Power Doppler detects flow without concern for direction. Color should not be relied on alone to determine arterial or venous flow due to the color scale setting can be flipped or reversed, or aliasing can occur. Arterial flow is more pulsatile than venous. Venous flow may require distal augmentation (by squeezing the forearm distal to the probe) to appreciate the blush of color.

Once the target vein is identified, the depth from the skin surface should be noted. A common mistake is to use an angiocatheter that is too long or too short. A general rule of thumb is to use a catheter length that is more than twice the depth of the vessel to ensure at least half the catheter lies within the vein. Sterile ultrasound gel should be used, with a covered probe to prevent infection. To prevent the risk of multiple punctures, this author advocates for first bouncing the needle on the skin over the point of entry. The tissue should deform at the top of the screen, and confirm the needle is over the target vessel. One the skin is punctured, the needle tip is kept in view by angling the ultrasound probe until the target vessel is punctured.

To confirm placement, either a "bubble study" with agitated saline may be performed or Color (or Power) Doppler utilised to visualise saline flow through the cannulated vessel. A vessel that is not properly cannulated will demonstrate extravasation of saline around the vessel into the tissue before the tissue swells to a degree which is palpable on the surface of the skin. Figure 10 demonstrates confirmation of intraosseous (IO) lines utilise Power Doppler. A 10cc saline flush is rapidly pushed through the line, and flow is demonstrated beneath the bony cortex in this adult tibia. If the line is improperly placed, the blush of color using Doppler would appear in the soft tissues.

For further information about UGPIV placement, visit: http://rmgultrasound.com/piv-access/

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