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Pulmonary Ultrasound in Emergency Medicine and Critical Care

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Preface:

This educational resource is designed to provide clinicians with practical knowledge of pulmonary 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 practical physics and technical instrumentation. The second section focuses on the pulmonary ultrasound examination and some pathology visualised by ultrasound. 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.

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Principles of Pulmonary Ultrasound:

Ultrasound is named for the fact that this technology deals with waves traveling through a medium at frequencies above the threshold of human hearing. Within this publication the term “sound waves” are used which are more accurately described as pressure waves produced by the transducer that travel through a medium. The commercially available ultrasound machines available for bedside 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 our 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, large 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.

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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. Continuous wave Doppler has the ability to measure high velocities without aliasing. Aliasing occurs when the pulse repetition frequency is too low, and the high frequency measured "wraps" back around the scale and is visually misrepresented in the negative direction. Continuous wave Doppler is also highly sensitive to low flow states. It is the simplest form of Doppler and uses a dedicated probe that has 2 crystals within the transducer. Once crystal configuration transmits ultrasound waves 100% of the time, and the other receives Doppler information returning from tissues that reflected the ultrasound waves. The Continuous wave transducer must be held with an incidental angle of 0° or kept parallel with the interrogated structure. Due to the shape of the chest, this may limit the utility of Continuous wave Doppler for lung ultrasound. Additionally, continuous wave Doppler is displayed only as a waveform. In contrast, 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. B mode images are 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, as in a red and blue scale, or simply the presence of movement. Figure 3 demonstrates orange scale power Doppler as it detects pleural movement relative to the transducer surface.

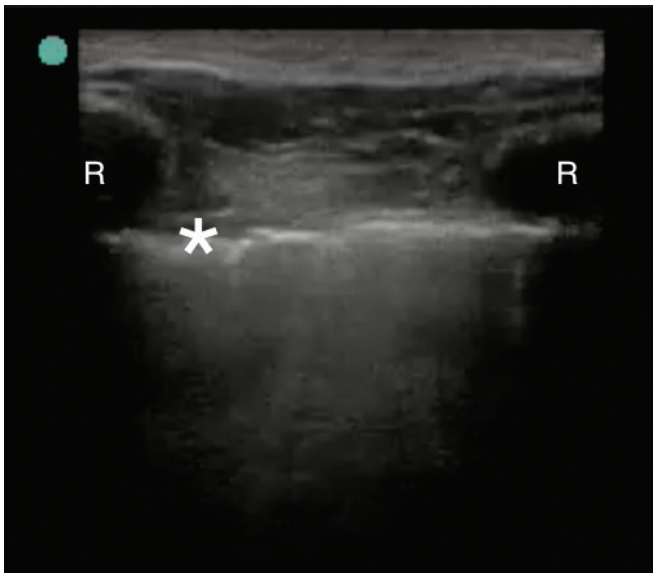

Figure 1: B mode imaging of normal lung. Acoustic shadowing of ribs (R) marks the pleural line (*) in this longitudinal view

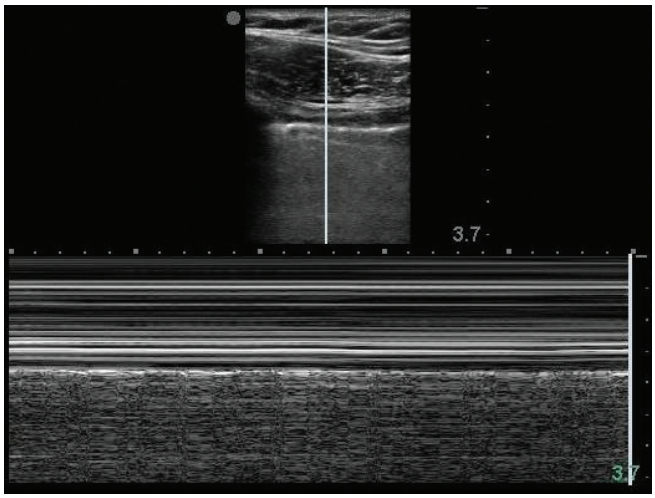

Figure 2: M mode imaging of normal lung

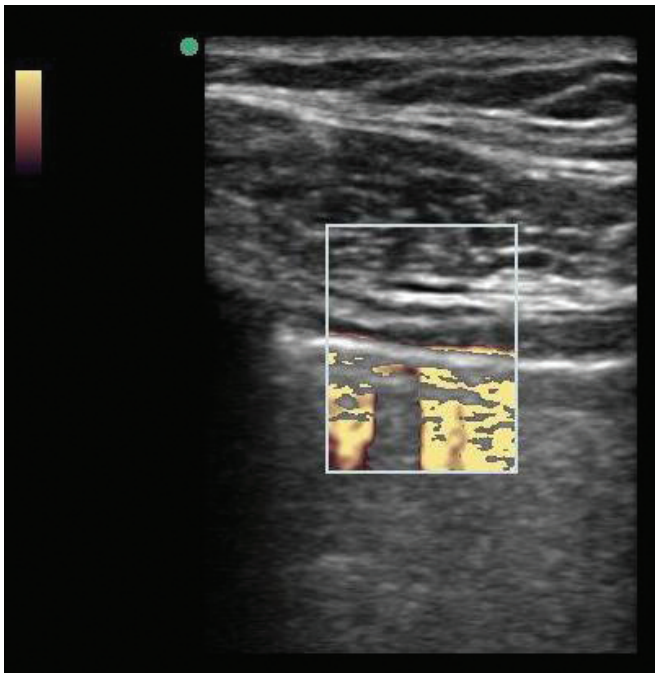

Figure 3: Power Doppler visualisation of normal lung

Pulmonary Ultrasound Examination and Pathology

Air is a poor medium for an ultrasound wave 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 is highly dependent on identification of 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 (*). Since bone reflects ultrasound waves, no signal is detected behind the cortex, creating the dark shadowing.

Normal pleural movement demonstrates a “shimmer sign” with B mode imaging. Poor respiratory effort, operator experience, operator fatigue, and other factors may make the identification of a “shimmer sign” difficult. M mode imaging is used with a high frequency probe to depict lung movement. A normal lung that is moving has a homogenous granular appearance under the brightly visualised pleura. Figure 2 depicts this “seashore sign”, with the homogenous granular appearing lung reminiscent of sand and approaching waves. The loss of granular appearing “sand” on the bottom half of the screen is indicative of pneumothorax. 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 map. A patient with a pneumothorax will not have lung sliding relative to the transduce surface, and no color will be detected in the sample selected (Figure 4).

The pleura surface itself creates an ultrasound artifact. A reverberation artifact is created when the ultrasound beam encounters a strong reflective surface and there is a difference in acoustic impedance between 2 tissues, such as the pleural line and the less dense lung. The ultrasound beam is transmitted back to the transducer several times, each time the signal is slightly weaker. This gives the appearance of the reflective surface being distal to, or in the far field from the actual structure. A lines are the reverberation artifact of the pleural line (Figure 5).

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). B lines move with lung sliding, whereas A lines are static. 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, 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 lung on 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. 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.(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 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.

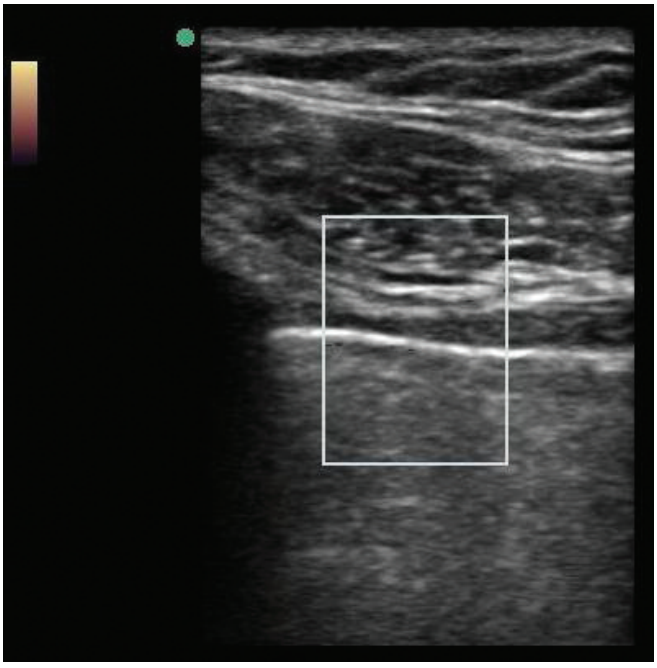

Figure 4: Power Doppler visualisation of pneumothorax

Several scanning protocols exist for pulmonary 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.(2) A 2 zone scanning protocol has been shown to perform similarly to an eight zone protocol.(7) 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.(8) 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 2.0cm 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%).(9) 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. (9,10) 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.

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.

Pleural effusion: EUS has been shown to have an accuracy similar to a CXR for evaluation of pleural effusion.(11) 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.(12) 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.(13-15) 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.(16) 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/

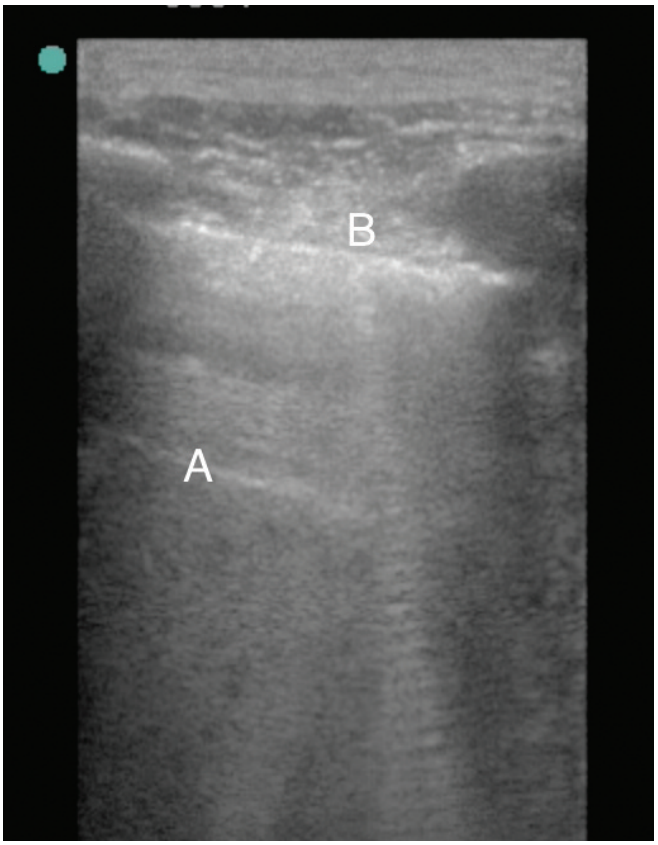

Figure 5: A line artifact (A) and B line or comet tail artifact (B)

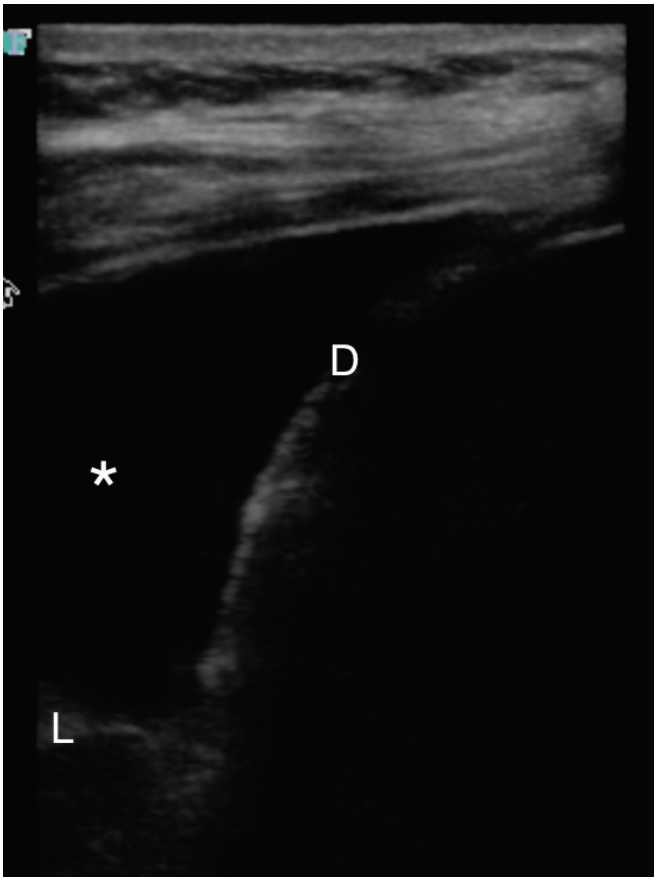

Figure 6: Large anechoic pleural effusion (*), diaphragm (D) and consolidated hyperechoic lung (L)

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