Point of care ultrasound in the acutely ill

The management of an acutely ill patient is often challenging and clinical signs are confusing or difficult to obtain. It is in these very patients however, that rapid and accurate diagnosis can be life-saving. It is here that bedside ultrasound can come to the rescue.

Ultrasound has evolved to become one of the most versatile modalities for diagnosing and guiding treatment of acutely ill patients. It consists of both cardiac (Echocardiography) and non-cardiac (lung, neuro, abdominal and vascular) ultrasound. Ultrasound is likely to be particularly useful in resource challenged areas as it is non-invasive, economical, repeatable and can be performed at the bedside.

In this series, we will try to cover the basic uses of ultrasound in acutely ill patients in a practical, handbook fashion. We will have to have a background knowledge of the physics of ultrasound before we start at the bedside. This will be covered here. All this information can also be seen at www.criticalecho.com

Table 1 – Uses of bedside ultrasound

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<th>Hemodynamics</th>
<th>Studies renal arterial resistivity indices as an indicator of renal blood flow</th>
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<td>Diagnosing urinary bladder distension and hydrenephrosis</td>
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Resuscitation

- Differentiating fine ventricular fibrillation from true asystole
- Diagnosing potentially reversible causes of PEA or asystole such as pericardial tamponade, myocardial infarction, severe hypovolemia, pulmonary embolism or tension pneumothorax - the Focused Echocardiographic Evaluation in Resuscitation (FEER)
- Assessing for cardiac standstill to help with prognostication during resuscitation

Neurology

- Detecting raised ICP using optic nerve sheath diameter
- Detecting midline shift
- Assessing adequacy of cerebral blood flow in patients with traumatic and non-traumatic brain injury
- Diagnosing cerebral circulatory arrest
- Assessing pupils in patients whose eyelids cannot be opened

Other diagnostic uses

- Detect fluid in pericardial, perisplenic, perihepatic and pelvic areas in trauma - the Focused Assessment with Sonography for Trauma (FAST)
Ultrasound is likely to be particularly useful in resource challenged areas as it is non-invasive, economical, repeatable and can be performed at the bedside.

Table 1 contd...
- Diagnosing sinusitis in intubated patients
- Therapeutic
  - Guided arterial and central vascular access
  - For guided thoracocentesis and abdominal paracentesis
  - Pericardiocentesis
  - Bedside Percutaneous nephrostomy
  - Guided drainage of collections

Fig. 1 – Ultrasound images

- Lung consolidation
- Deep vein thrombosis
- Pleural effusion
- Pericardial effusion
- Pneumoperitoneum
- Assessment of size and reaction of pupils
- Brain intraparenchymal hemorrhage
- Maxillary sinusitis
BASIC PHYSICS OF ULTRASOUND AND THE DOPPLER PHENOMENON

Medical ultrasound imaging consists of using high pitched sound bouncing off tissues to generate images of internal body structures.

Frequency

Frequency refers to the number of cycles of compressions and rarefactions in a sound wave per second, with one cycle per second being 1 hertz. While the term ultrasound generally refers to sound waves with frequencies above 20,000 Hz (the frequency range of audible sound is 20 to 20,000 Hz), diagnostic ultrasound uses frequencies in the range of 1-10 million (mega) hertz.

Wavelength

The wavelength is the distance travelled by sound in one cycle, or the distance between two identical points in the wave cycle i.e. the distance from a point of peak compression to the next point of peak compression. It is inversely proportional to the frequency. Wavelength is one of the main factors affecting axial resolution of an ultrasound image.

The smaller the wavelength (and therefore higher the frequency), the higher the resolution, but lesser the penetration. Therefore, higher frequency probes (5 to 10 MHz) provide better resolution but can be applied only for superficial structures and in children. Lower frequency probes (2 to 5MHz) provide better penetration albeit lower resolution and can be used to image deeper structures as used in adult cardiac and abdomen ultrasound.

Propagation velocity

The propagation velocity is the velocity at which sound travels through a particular medium and is dependent on the compressibility and density of the medium. Usually, the harder the tissue, the faster the propagation velocity. The average velocity of sound in soft tissues such as the chest wall and heart is 1540 metres/second.

ULTRASOUND TISSUE INTERACTIONS

The interaction of ultrasound waves with organs and tissues encountered along the ultrasound beam can be described in terms of attenuation, absorption, reflection, scattering, refraction and diffraction.

Attenuation

Sound energy is attenuated or weakened as it passes through tissue because parts of it are reflected, scattered, absorbed, refracted or diffracted.

Reflection

A reflection of the beam is called an echo and the production and detection of echoes forms the basis of ultrasound. A reflection occurs at the boundary between two materials provided that a certain property of the materials is different. This property is known as the acoustic impedance and is the product of the density and propagation speed. If two materials have the same acoustic impedance, their boundary will not produce an echo. If the difference in acoustic impedance is small, a weak echo will be produced, and most of the ultrasound will carry on through the second medium. If the difference in acoustic impedance is large, a strong echo will be produced. If the difference in acoustic impedance is very large, all the ultrasound will be totally reflected. Typically in soft tissues, the...
amplitude of an echo produced at a boundary is only a small percentage of the incident amplitudes, whereas areas containing bone or air can produce such large echoes that not enough ultrasound remains to image beyond the tissue interface.

**Figure 3: Production of an echo depending on relative acoustic impedances of the two media:** From: Aldrich: Crit Care Med, Volume 35(5) Suppl. May 2007. S131-S137

At a tissue–air interface, 99% of the beam is reflected, so none is available for further imaging. Transducers, therefore, must be directly coupled to the patient’s skin without an air gap. Coupling is accomplished by use of gel between the transducer and the patient.

**Scattering**
Not all echoes are reflected back to the probe. Some of it is scattered in all directions in a non-uniform manner. This is especially true for very small objects or rough surfaces. The part of the scattering that goes back to reach the transducer and generate images is called backscatter.

**Absorption**
Tissue absorption of sound energy contributes most to the attenuation of an ultrasound wave in tissues.

**Refraction**
The change in the direction of a sound wave on being incident upon a tissue interface at an oblique angle is refraction and is determined by Snell’s law.

**TRANSDUCERS**
Inside the core of the transducer are a number of peizo-electric crystals that have the ability to vibrate and produce sound of a particular frequency when electricity is passed through them. This is how ultrasound waves are formed. These transducers also act as receivers for the reflected echoes as they generate a small electric signal when a sound wave is incident upon it.

**Duty factor**
In most modes of ultrasound operation, only 1% of the time is spent in generating a pulse of ultrasound waves and 99% of the time is then spent listening for the echoes. This is called the duty factor…1% in such a case.

**Pulse repetition frequency (PRF)**
The PRF is the number of pulses (send and listen cycles) of ultrasound sent out by the transducer per second. It is dependent on the velocity of sound and on the depth of tissue being interrogated. The deeper the tissue being examined, the longer the transducer has to wait for echoes to come back, hence a lower PRF.

**Beam**
The ultrasound beam is focused by the transducer so as to be as close to a flat plane as possible. The beam is made up of tens to hundreds of scan lines.

**Orientation**
There is usually a dot, groove or light on one ends of the transducer to assist orientation. A corresponding marking is also displayed on the screen to help give an orientation to the images.

**Resolution**

  **Axial resolution:** The ability to resolve objects in the line of the ultrasound beam. Factors affecting axial resolution include Spatial Pulse Length (SPL) and frequency.

  **Lateral resolution:** Resolution at 90° to the direction of the beam. Factors affecting lateral resolution are width of the beam, distance from the transducer, frequency, side and grating lobe levels.

  **Temporal resolution:** Refers to the ability to detect moving objects in the field of view in their true sequence. The number of frames generated per second (frame rate) determines temporal resolution.

In the next episode of this article, we will look at knobology, probology, infection control and ergonomics of bedside ultrasound.