Thank you for viewing this presentation.

We would like to remind you that this material is the property of the author. It is provided to you by the ERS for your personal use only, as submitted by the author.

© 2016 by the author
Brief Overview of the Physics of Ultrasound

Dr Emma J Helm
Consultant Radiologist
University Hospitals Coventry and Warwickshire, UK
Disclosures

- I have no relevant disclosures
Basic Physics of Ultrasound

- What is ultrasound?
- How is ultrasound generated?
- Velocity of ultrasound in tissue
- Interaction of ultrasound with tissue
- Choice of probe
- Optimising the image
What is ultrasound?

- A longitudinal wave - particles move in the same direction as the wave.
- A succession of rarefactions and compressions transmitted due to elastic forces between adjacent particles.
What is ultrasound?

- Audible sound has frequency 20 Hz to 20 kHz
- Most diagnostic ultrasound has frequencies in range 2-20 MHz
Important equation!

- Frequency of oscillations is inversely proportional to wavelength

\[ f = \frac{c}{\lambda} \quad (c \approx 1540 \text{ m s}^{-1} \text{ in soft tissue}) \]

- Therefore for diagnostic ultrasound of 2-20MHz, frequency in tissue is approximately 1 - 0.1 mm in tissue
Generation of Ultrasound

- US generated by piezoelectric crystal
- Commonest material is lead zirconate titanate (PZT)
- When electric field applied crystal rings like a bell at a resonant frequency determined mainly by its thickness
- Same or similar crystal used as receiver to produce electrical signal when struck by the returning ultrasound wave.
Ultrasound Transducer

Converts electricity to sound and vice versa

- Plastic housing
- Co-axial cable
- Matching layer
- Piezoelectric crystal
- Acoustic insulator
- Backing block
Speed of ultrasound in tissue

- Speed of US in tissue depends on stiffness and density
- Stiffer material e.g. solid, transmits ultrasound faster

<table>
<thead>
<tr>
<th>Medium</th>
<th>Speed of sound (ms⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>331</td>
</tr>
<tr>
<td>Muscle</td>
<td>1,585</td>
</tr>
<tr>
<td>Fat</td>
<td>1,450</td>
</tr>
<tr>
<td>Soft Tissue (average)</td>
<td>1,540</td>
</tr>
</tbody>
</table>
Speed of ultrasound in tissue

- In clinical practice, speed of US in tissue is almost constant at $1540 \text{ ms}^{-1}$
Interaction of US with tissue

- Ultrasound which enters tissue may be transmitted, attenuated or reflected.

- Ultrasound needs to be transmitted far enough into the tissues in order to image them but must be reflected back to be received by the probe.

- Attenuation is a problem which needs to be addressed by the machine.
Attenuation – why does it happen?

• If particles in a tissue are small enough, they will move as a single entity and transmit sound in an orderly manner. Coherent vibration → sound

• If large molecules are present, chaotic vibration occurs → heat

• Loss of coherence is most important cause of loss of ultrasound energy
Absorption of ultrasound/Gain

- Absorption of ultrasound means that lower tissues return less ultrasound (some absorbed as heat, some reflected/refracted out of field of probe)

- To ensure a uniform picture (so deeper areas not darker), ultrasound uses Time Gain Compensation (TGC)

- TGC applies progressively increasing amplitude to later echoes in proportion to their depth i.e. differential amplification
TGC

- TGC can be varied by users. Can be used to compensate for artefactual increased brightness (when automatic TGC is excessive in certain situations).

- Beware previous user adjusting TGC controls and not resetting them before you start scanning!
• Absorption is proportional to ultrasound frequency
• Higher frequency probes have smaller depth penetration.
High vs. low frequency probes

- High frequency probes have good resolution (fine detail) but poor depth penetration
- Low frequency probes have poor resolution but good depth penetration
- Many US machines allow user to alter frequency up to maximum/minimum allowed
- Can be helpful in large patients/deep lesions
Pleura on 3.5 MHz curvilinear probe
Pleura on high resolution linear probe
Reflection

Importance of Reflection:

- allows generation of the ultrasound signal
- leads to loss of ultrasound signal
- helps determine appearance of tissue
- can cause artefacts
Reflection

- Whenever transmitted ultrasound crosses an interface between two tissues with different impedance, some ultrasound is reflected.
- Amount depends on difference in impedance.
- Ultrasound which is not reflected carries on and can be used to image deeper structures.
## Reflection

<table>
<thead>
<tr>
<th>Interface</th>
<th>Reflection coefficient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Tissue - Air</td>
<td>99</td>
</tr>
<tr>
<td>Soft Tissue - Bone</td>
<td>66</td>
</tr>
<tr>
<td>Fat - Muscle</td>
<td>1.08</td>
</tr>
<tr>
<td>Muscle - Liver</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Reflection - consequences

- Need coupling material between probe and patient skin
- Cannot see through aerated lung
- Cannot see through bone
Reflection - specular vs. scattering

- Specular reflection occurs when the surface is smooth compared with the wavelength i.e. flat for several mm

- Scattering occurs when irregularities in surface with irregularities are similar to wavelength. Important in generation of ultrasound image
Pulse Repetition Frequency

- Relatively slow speed of ultrasound in tissue limits rate at which ultrasound information can be acquired
- Need to wait for each pulse to fade away before second transmitted
- If send second pulse too early, last returning echoes from first pulse with overlap with first returning echoes from second pulse
Pulse Repetition Frequency

- The pulse repetition frequency (PRF) is set in order to allow time for the most distant echoes to return before sending next pulse.
- PRF will be slower if trying to image larger area or trying to use grey scale and doppler at same time.
- Reducing scan area can help increase PRF e.g. if trying to image fast moving structure.
Ultrasound tips

- Use highest frequency for necessary depth penetration
- Use tissue harmonics for larger patients
- Try moving patient into different positions eg to move ribs apart/move bowel gas out of way
- Use ‘optimise’ button
- Reduce size of sector for improved resolution
Ultrasound tips

- If all else fails........

MORE JELLY!
Any questions?

emma.helm@uhcw.nhs.uk