ISUOG Basic Training
Physical Principles of Ultrasound including Safety
Learning objectives

At the end of the lecture you will be able to:

• Explain how an ultrasound image is generated
• Describe the different ultrasound modes used for imaging
• Describe the current international safety standards relating to the thermal index (TI) and the mechanical index (MI)
Key questions

1. What is ultrasound?
2. How is a B-mode real time image produced?
3. How should the ALARA principle be applied?
Sound/Ultrasound

- Longitudinal mechanical wave
- Transmitted through medium by local displacement of particles within medium – compression & rarefaction
- Frequency (Hertz) = cycles/sec
- Human audible range = 20Hz – 20,000Hz (20kHz)
- Ultrasound = frequencies above audible range
Sound

- Compressional wave
- Gas, liquid or solid medium
- Speed of sound depends on medium and temperature
  - Air \( 343 \text{ m/s} \)
  - Water \( 1482 \text{ m/s} \)
  - Steel \( 5960 \text{ m/s} \)
  - Average in biological tissue \( 1540 \text{ m/s} \)
Physics of sound

- Medical US ~ 1 – 20 MHz
From US to image

- Piezoelectric effect—ability to generate (transduce) electrical charge in response to applied mechanical stress, & vice versa
- Piezoelectric crystal - quartz, zirconium titanate, modern ceramics
Pulse transmission

A-mode
Pulse receiving

Display on monitor
Ultrasound transducer (probe)

- Lens
- ‘Matching’ layer
- Grounding-electrode
- Crystal elements
- Electrodes
Distance of reflector is calculated (time window send-receive)

\[ D = \frac{1}{2} \text{Time of flight} \times \text{velocity} \]

B-mode (Imaging)
From US to image
From US to image

Large angle / width takes time!
Large number of sectors takes time!
From US to image

Depth takes time!
The variations in a single line of echoes are recorded against time

M-Mode (Motion)
Frequency, resolution & penetration

- **Low frequency:**
  - Less resolution
  - More penetration

- **High frequency:**
  - High resolution
  - Less penetration

<table>
<thead>
<tr>
<th>Frequency (mHz)</th>
<th>Penetration (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>10-20</td>
</tr>
<tr>
<td>5.0</td>
<td>5-10</td>
</tr>
<tr>
<td>7.5</td>
<td>2-5</td>
</tr>
<tr>
<td>10.0</td>
<td>1-4</td>
</tr>
</tbody>
</table>

Both 21 weeks!
Image - resolution

- Lateral resolution
- Axial resolution
- Temporal resolution
Image enhancement

Tissue harmonic imaging
- $2f$, $3f$, $4f$: laws of physics
- Probe also able to receive harmonic frequencies

Less penetration
Increased axial resolution
Artefacts

An ultrasound image which does not match actual anatomy
Artefacts
Drop out/ acoustic shadowing

- Dark area posterior to dense reflector
- Most marked along US beam

Reduce/remove by adjusting angle of insonation
Artefacts

Posterior enhancement/amplification

- Area of increased brightness immediately posterior to cystic structure
- Caused by lack in sound attenuation through a structure with few interfaces

Confirm by changing angle of insonation
Artefacts
Reverberation

- Occurs when US beam encounters 2 strong parallel reflectors
- Multiple parallel echoes result from back-and-forth travel of US between 2 reflecting surfaces

Change angle of insonation
Artefacts
Reverberation

- Probe face & subcutaneous tissue interface provide parallel reflectors

Change angle of insonation
Artefacts
Side lobe artifact

- Results from strong reflector that lies outside the incident beam, but within side lobe of central beam
- Echoes from reflector are displayed as if originating from within central beam
Safety issues – biological effects

• Increased movement of molecules -> results in rise in temperature
• Gas bubble can collapse (cavitation) -> results in pressure wave released into the surrounding tissue
Safety issues – TI, MI & ALARA

• Thermal Index = TI (<1.0)  
  (power needed to increase temperature by 1 °C)

• Mechanical Index = MI (<1.0)

• ALARA principle - as low as reasonably achievable
Scanning times & TI

The Safe Use of Ultrasound in Medical Diagnosis (3rd ed): 2012; The British Institute of Radiology, 154.
Safety issues - power levels

Heating potential

Power

B-mode 2D, 3D
Harmonic imaging
M-mode
Colour Doppler
Pulsed Doppler
Safety statements

- International Society Ultrasound in Obstetrics & Gynecology (ISUOG)

- British Medical Ultrasound Society (BMUS)

- American Institute of Ultrasound in Medicine (AIUM)
  http://www.aium.org/resources/statements.aspx
Key points

1. Understand how an ultrasound beam produces an image
2. Recognise artefacts, and know how to avoid them
3. Understand the factors important to obtain an optimal Doppler signal
4. Be aware of the principles behind TI and MI