An Overview of the Mechanics and Principles of an Ultrasound

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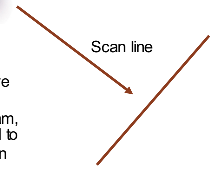
Basic Principles of Pulse Echo

Short pulses transmitted to patient and then reflected back



High frequency used – above human hearing so that it propagates as a narrow beam, thus return can be assumed to come from object along scan line

Acoustic Pulse – Echo concept

- Transducer converts:
  1. Electricity -> Sound – transmits through tissue
  2. Sound -> Electricity to produce echo

Pulse - Echo

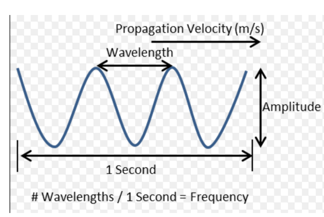
1. Electric pulse is applied to piezoelectrical crystal in probe, thus leading to change in shape of crystal
2. This leads to compression of tissue under probe (acoustic pressure)
3. Tissue compression and rarefaction (decompression) will move away from the crystal – speed of 1540m/s in soft tissue – acoustic wave
   - Rate of compression/rarefaction determines frequency of wave
4. Interaction of pulse with nonhomogenous tissue will lead to scatter and reflection (back to the crystal)
5. Once wave returns to crystal, crystal again deforms, which generates an electric field. Amplitude depends on amount of compression of crystal

Frequency (f)

- Hertz (f) = 1 cycle per second
- We hear at frequencies between 20Hz and 20kHz (20-20,000 cycles per second)
- Echo transducers use frequencies between 2 MHz and up to 12 MHz (2,000,000-12,000,000 cycles per second)

Frequency

- Shorter time between peaks (more cycles) = higher frequency
- Pulse repetition frequency (prf) = rate at which the transmit-receive process repeats, can be several hundred, even thousands of pulses per second
- Shallower scans take shorter time for signal to return, thus allowing higher prf



Pulse Repetition Frequency

- Transducer transmits and receives
  - Occurs at a certain rate (known as pulse repetition frequency, PRF)
    - Several hundred or thousand pulses per second, depending on depth
  - Neonates have shallower targets that allow for higher PRF
  - Processing of information back to the transducer allows creation of image

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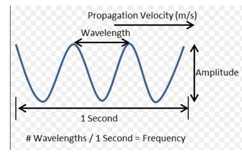
Wavelength

- Distance traveled by sound in 1 cycle
- Inversely proportional to frequency such that shorter wavelength allows for higher frequency
- Smaller wavelength = higher resolution though less penetration
  - Thus in neonates, 12MHz probe will provide more higher resolution but less depth than a 5MHz probe



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Velocity

- Sound propagates through soft tissues at an average speed of 1540m/s
- Speed depends on compressibility and density of material
  - Fastest through muscle
  - Slow through fat

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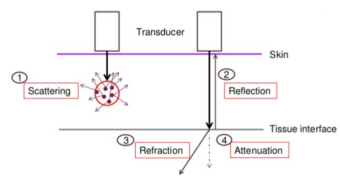
Interaction of ultrasound waves with the body

- Reflection
- Scattering
- Refraction
- Attenuation



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Reflection

- Associated with larger objects (greater surface than ultrasound beam) such as valves or walls
- Occurs when the interfaces have different acoustic impedances that causes reflection of the sound wave
- Large echo/reflection if beam perpendicular to source
  - Can have dropout of signal if beam parallel, eg in 4 chamber apical view when atrial septum is in line with the beam and can have dropout

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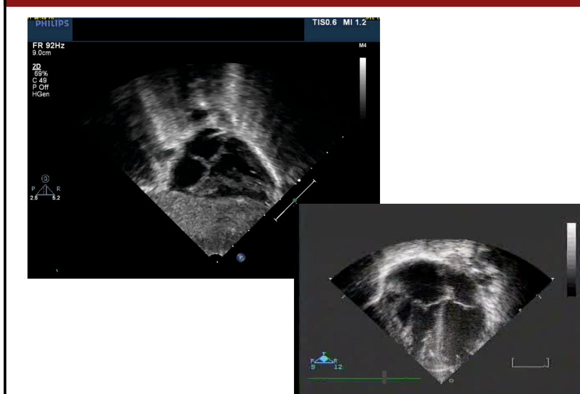

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Scatter

- Responsible for most of the echo images
- Occurs at smaller non-homogenous structures, such as walls of cells, capillaries, etc and sends weak echos in many directions
- Important for differentiating between tissues (ie pericardium from myocardium)

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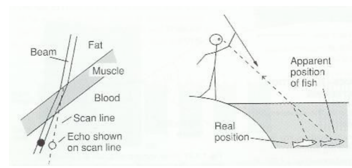
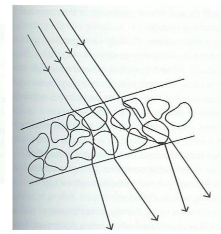
Refraction

- Change of sound direction moving from one material of varying impedance to another
- Deflection/bending of the wave due to different velocities of acoustics between two materials





Skinner et al. Echo for the Neonatologist, reprint 2009.

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Attenuation

- As beam extends further from the probe, the amplitude decreases due to attenuation
- Likely related to conversion of energy to heat
- Thus, signal becomes darker and less resolution
- Varies on medium – air has high attenuation compared with blood or fluid
- Higher frequency has faster attenuation than low frequency transducer

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Various modes of Pulse-Echo scanning

1. A-mode scan
2. M-mode scan
3. B-mode scan

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A Mode scan

- Simplest form of scanning
- No longer used
- Transducer held in place and amplitude determined (time taken for sound to return to probe)

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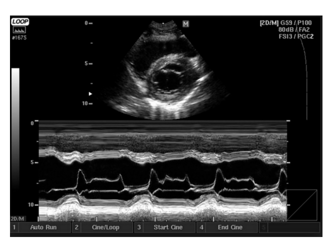
M-mode Scan

- Single line interrogation
- Amplitude expressed as brightness
- Stationary targets are straight lines, while moving tissues draw out waves



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B Mode (2D) Imaging

- Most commonly displayed
- Cross sectional area of the body by 2D
- Need high frame rates for good temporal resolution
  - Ability to detect moving objects in the field of view, i.e. faster than the heart rate

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Probes

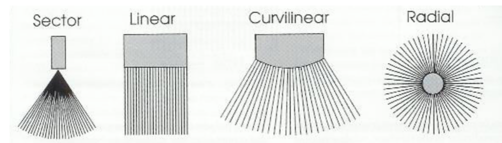

Fig. 1.1.5 Alternative formats of B-mode scans.

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Sector/Phase array Probes

- Large depth of field with small footprint; e.g. used for chest as able to extend beam between ribs

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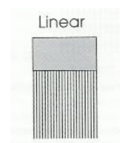
Linear Probe

Wider field of view close to surface, high resolution, good for line placement



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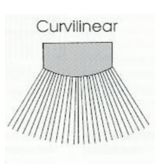
Curvilinear

- Deep penetration and wide field, low frequency, good for abdominal structures



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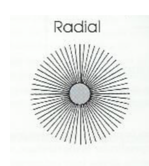
Radial

- Extension of sector scanning, used for viewing inside the body



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Types of Resolution

1. Spatial Resolution
   - Axial Resolution
   - Lateral Resolution
2. Temporal Resolution

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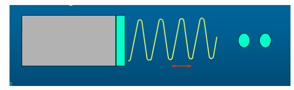
Axial Resolution

- Ability to distinguish between 2 object close together along the scan line
- Affected by frequency
  - Higher frequency, thus shorter wavelength = better axial resolution



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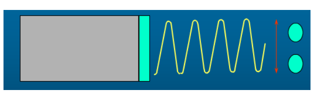
Lateral Resolution

- Ability to distinguish between 2 objects close together perpendicular to the scan line



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Temporal Resolution

- Ability to detect movement of object along its trajectory in its true course – defined as frame rate
- Can improve temporal resolution by decreasing sector width so less area to cover
- Decrease the depth of the image to decrease the pulse repetition frequency

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Remember…

- Higher frequency probe = better resolution but less penetration
- Lower frequency probe = better penetration but worse resolution

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Image Construction from Pulse-Echo concept

- Signal returning from body to transducer is divided into pixels
- Each pixel is assigned a number based on amplitude, ranging from black to white with ranges of grey in between
  - Bright pixels = high amplitude (bone)
  - Dark pixels = low amplitude (e.g. blood)

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Ultrasound Safety

- Heating
  - Absorption within the tissue
  - Generated with non-scanning modes (e.g. PW doppler), deep focus, narrow zoom box
  - Temp rise up 6ºC possible with PW doppler on bone and 2.5ºC on soft tissue
- Cavitation
  - Bubbles can form in liquid with pressure variations
  - If negative pressure deep or long enough, may grow bubble and collapse, releasing energy
  - Risk with low frequency probe, long pulse length high pulse repetition

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