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Brief Overview of the Physics of Ultrasound

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Disclosures

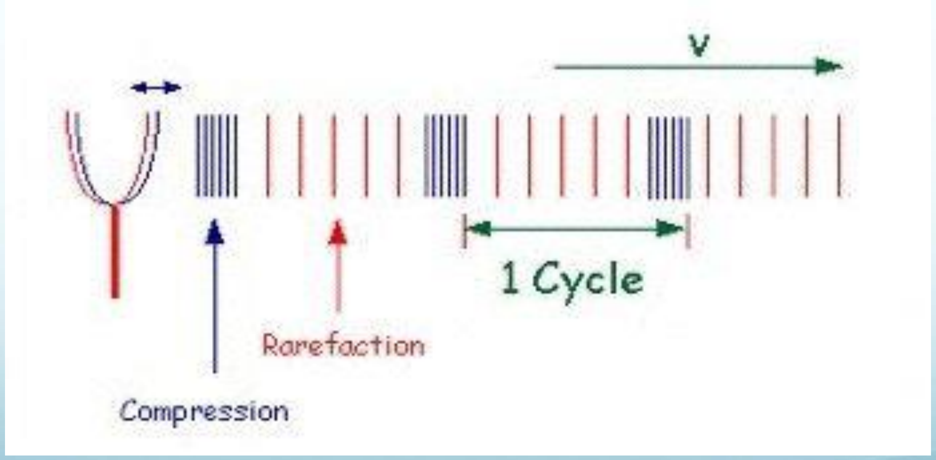
- I have no relevant disclosures

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

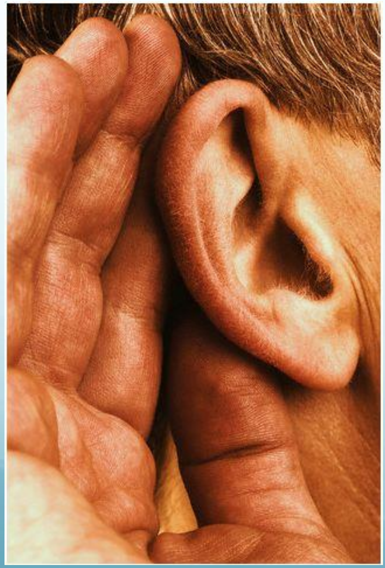
What is ultrasound?

- 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



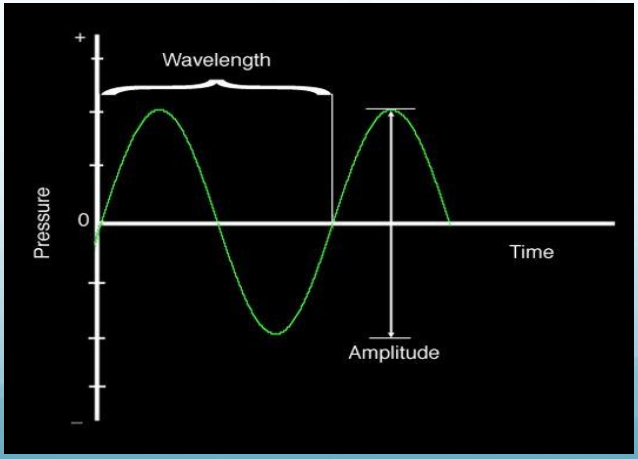
What is ultrasound?

- 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
- $f = c/\lambda$ ($c \approx 1540\ m\ s^{-1}$ in soft tissue)
- Therefore for diagnostic ultrasound of 2-20MHz, frequency in tissue is approximately 1 - 0.1 mm in tissue

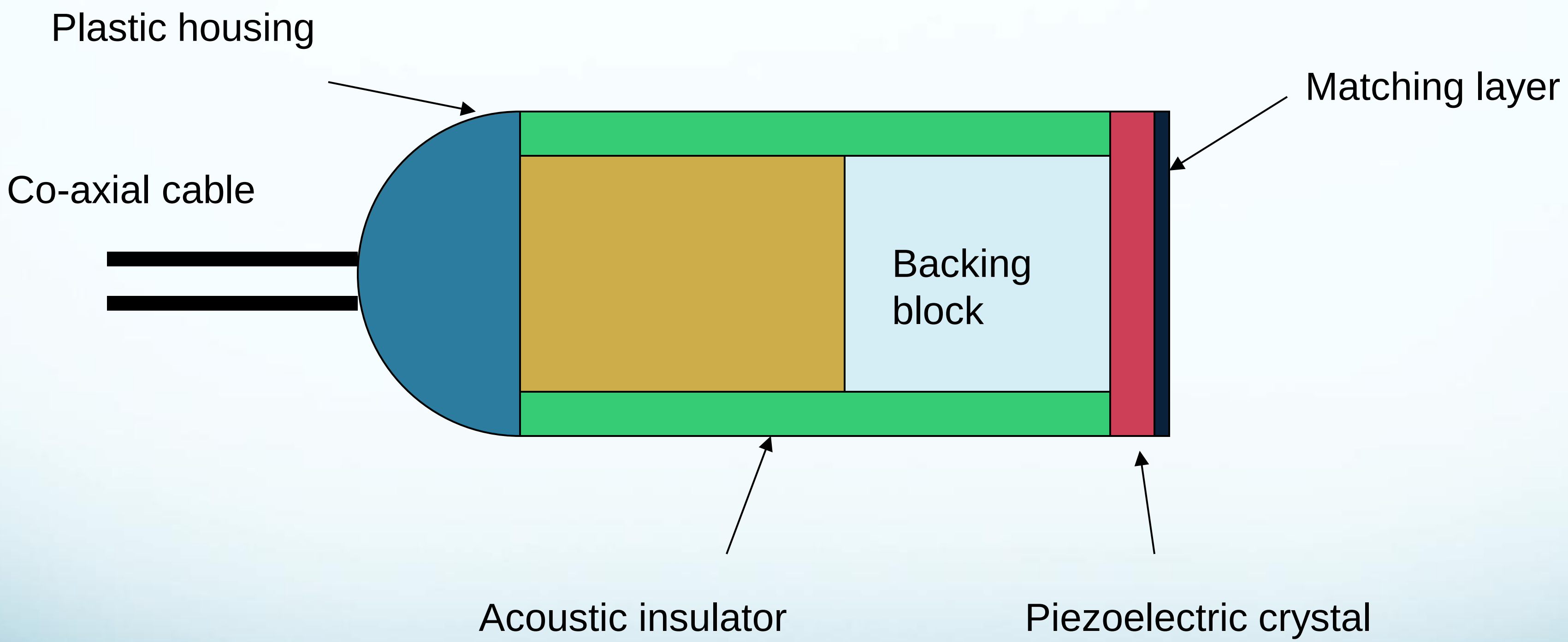


Generation of Ultrasound

- 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



Speed of ultrasound in tissue

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

Medium	Speed of sound (ms-1)
Air	331
Muscle	1,585
Fat	1,450
Soft Tissue (average)	1,540

Speed of ultrasound in tissue

- In clinical practice, speed of US in tissue is almost constant at 1540 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 $\rightarrow$ sound
- If large molecules are present, chaotic vibration occurs $\rightarrow$ 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!

Attenuation and depth penetration

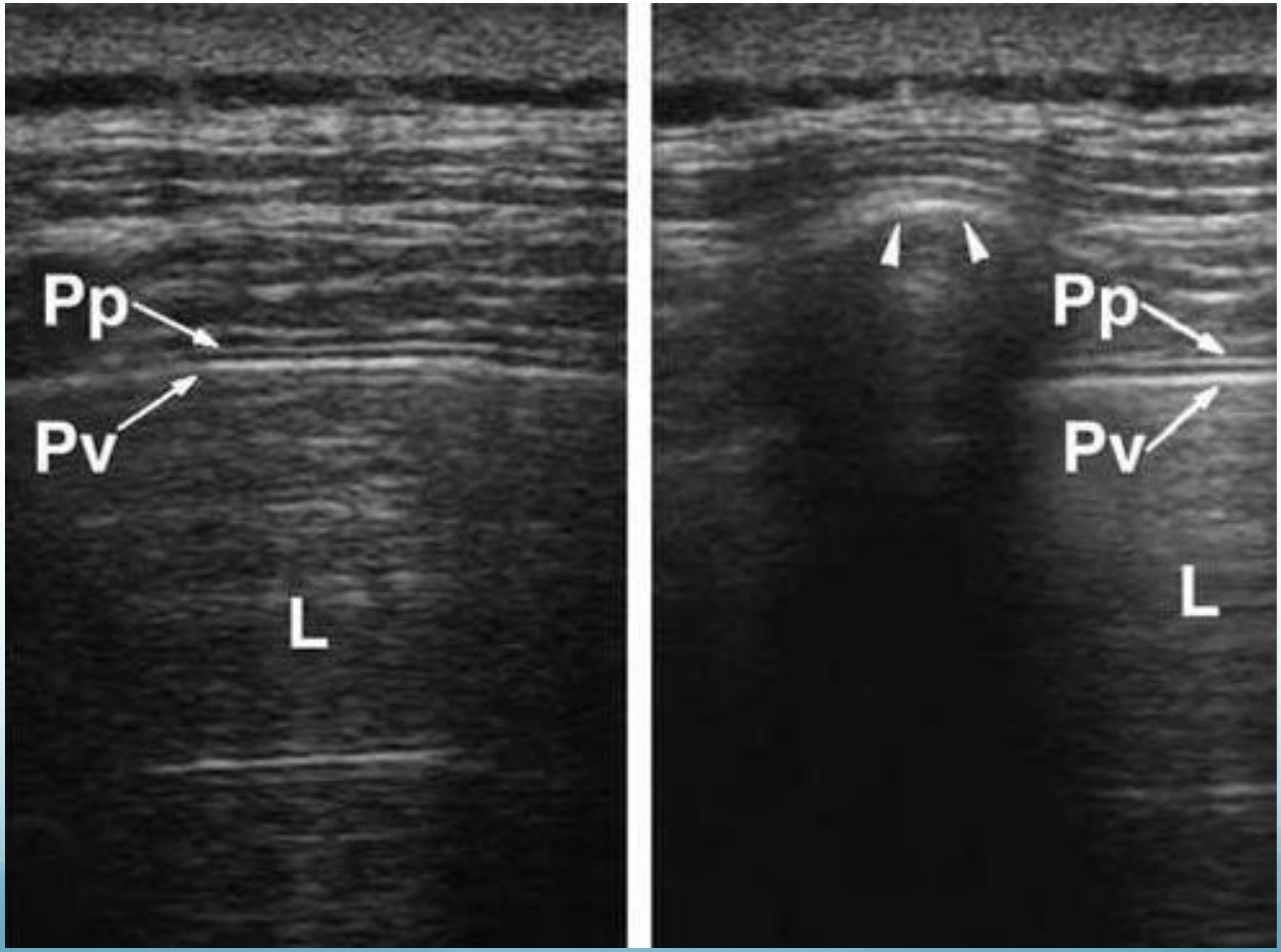
- Absorption is proportional to ultrasound frequency
- Higher frequency probes have smaller depth penetration.

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

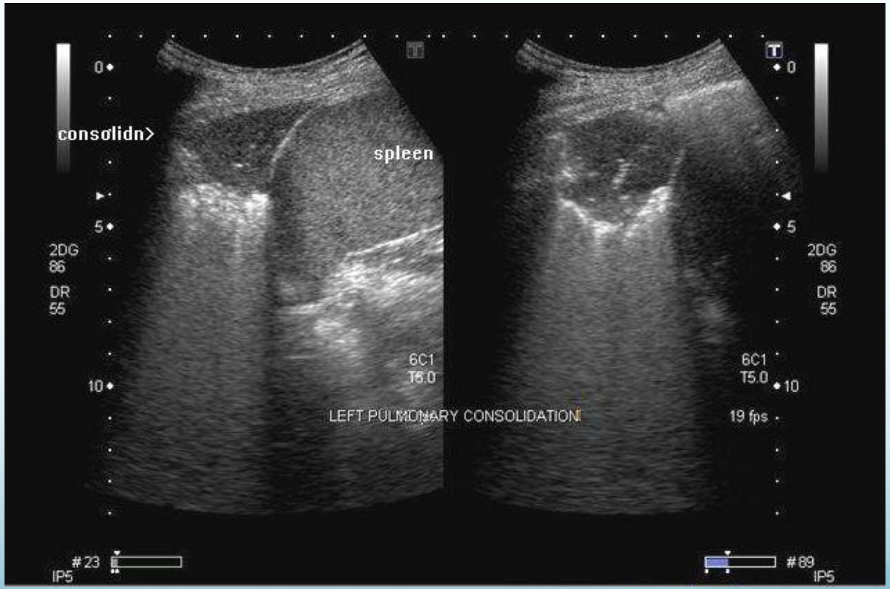
- Whenever transmitted ultrasound crosses an interface between two tissues with different impedence, some ultrasound is reflected
- Amount depends on difference in impedence
- Ultrasound which is not reflected carries on and can be used to image deeper structures

Reflection

Interface	Reflection co-efficient (%)
Soft Tissue - Air	99
Soft Tissue - Bone	66
Fat - Muscle	1.08
Muscle - Liver	1.5

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?

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