ISUOG Basic Training

Physical Principles of Ultrasound including Safety

Learning objectives

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

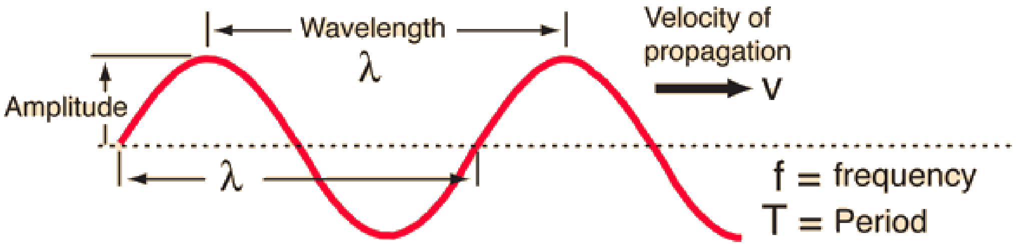
- Explain how an ultrasound image is generated
- Describe the different ultrasound modes used for imaging
- Describe the current international safety standards relating to the thermal index (TI) and the mechanical index (MI)

Key questions

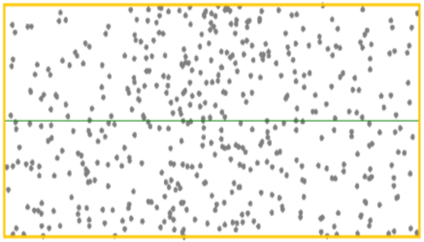
1. What is ultrasound?
2. How is a B-mode real time image produced?
3. How should the ALARA principle be applied?

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



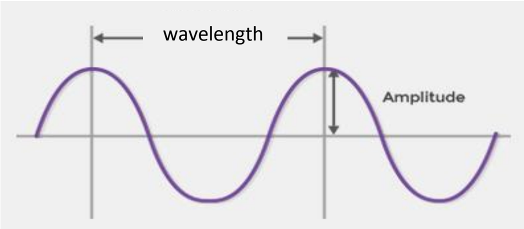
Sound

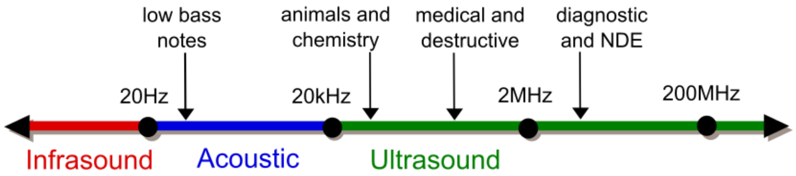


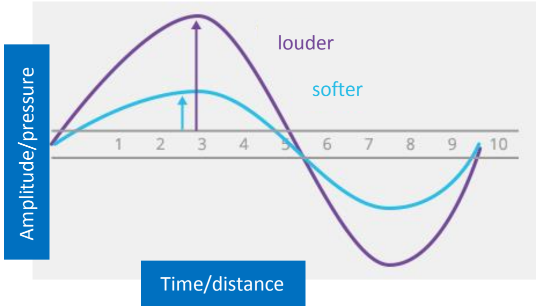
- Compressional wave
- Gas, liquid or solid medium
- Speed of sound depends on medium and temperature
  - Air 343 m/s
  - Water 1482 m/s
  - Steel 5960 m/s
  - **Average in biological tissue 1540 m/s**

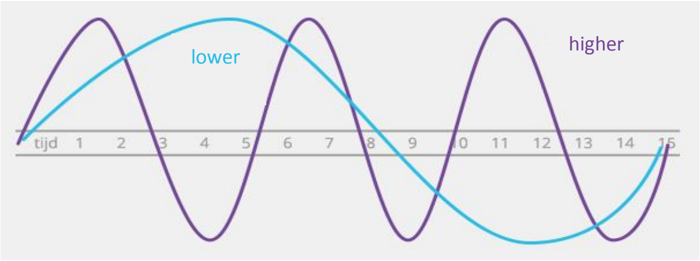
Physics of sound

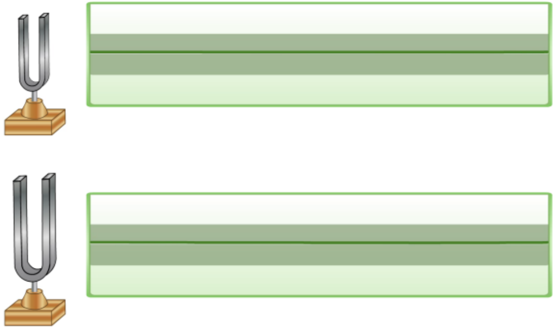
- Medical US ~ 1 – 20 MHz





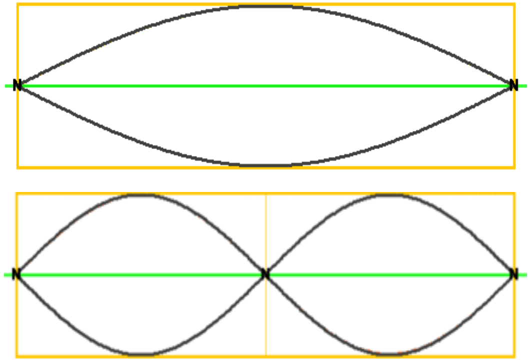


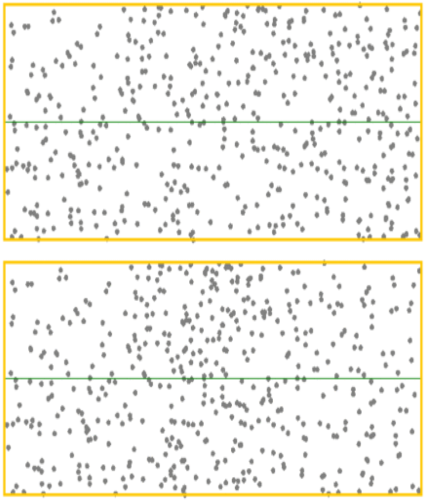


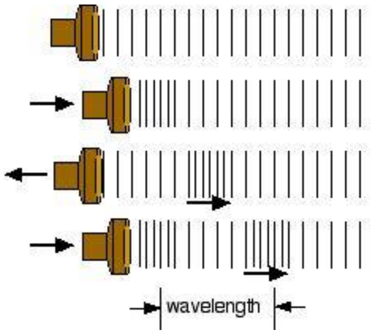


From US to image

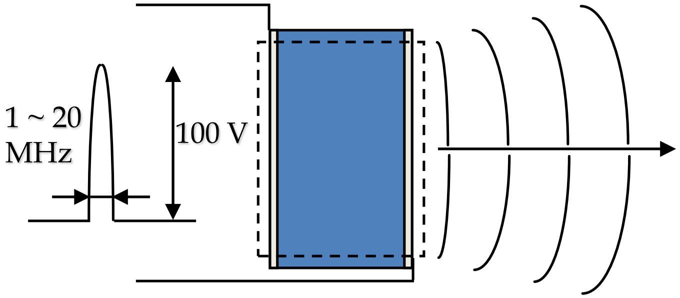
- Piezoelectric effect– ability to generate (transduce) electrical charge in response to applied mechanical stress, & vice versa
- Piezoelectric crystal - quartz, zirconium titanate, modern ceramics

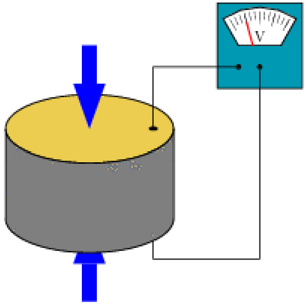






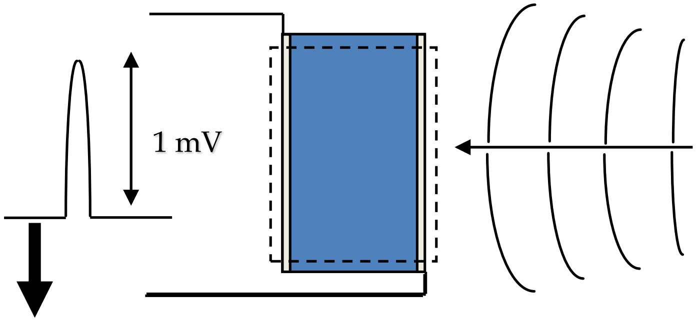
Pulse transmission

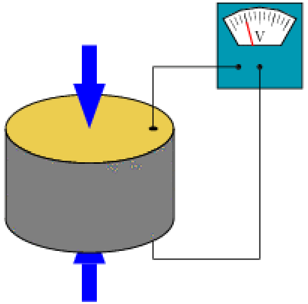




A-mode

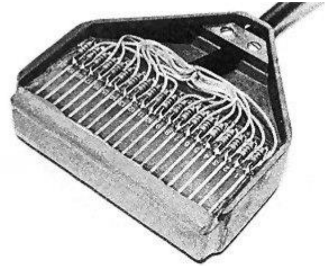
Pulse receiving

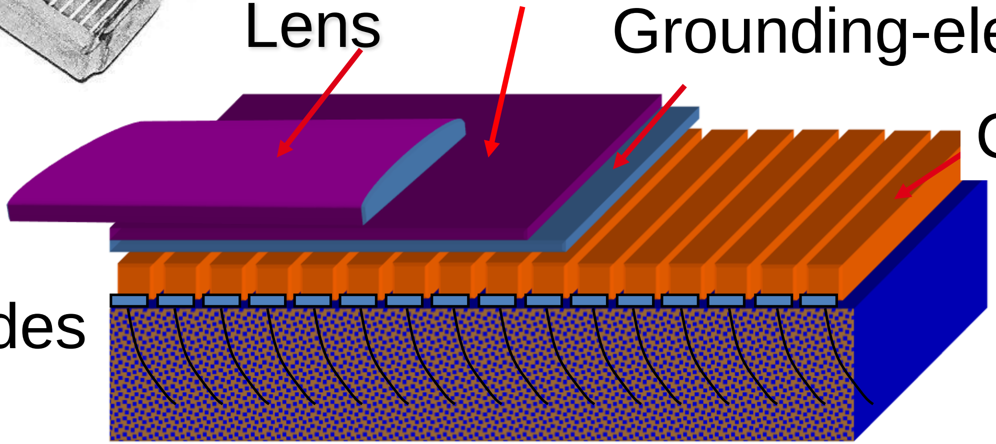




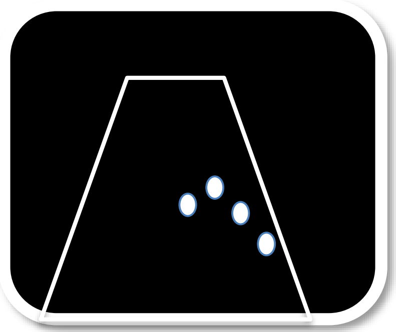
Display on monitor

Ultrasound transducer (probe)



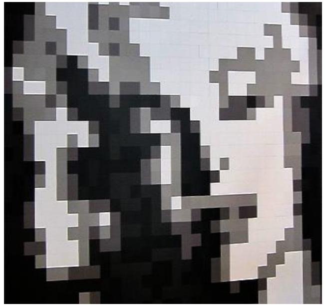


From US to image

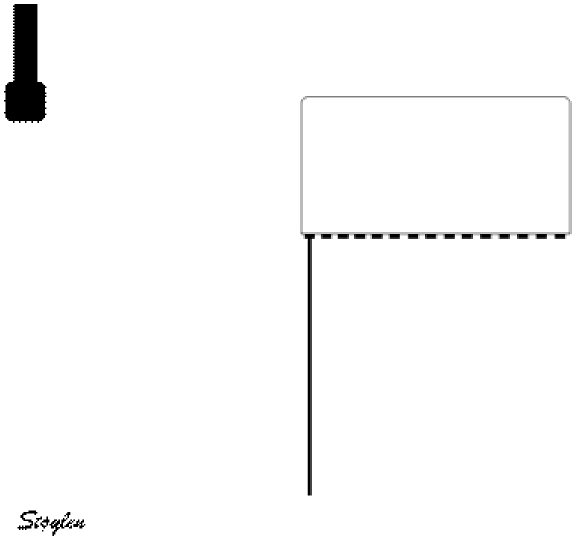


Distance of reflector is calculated
(time window send-receive)

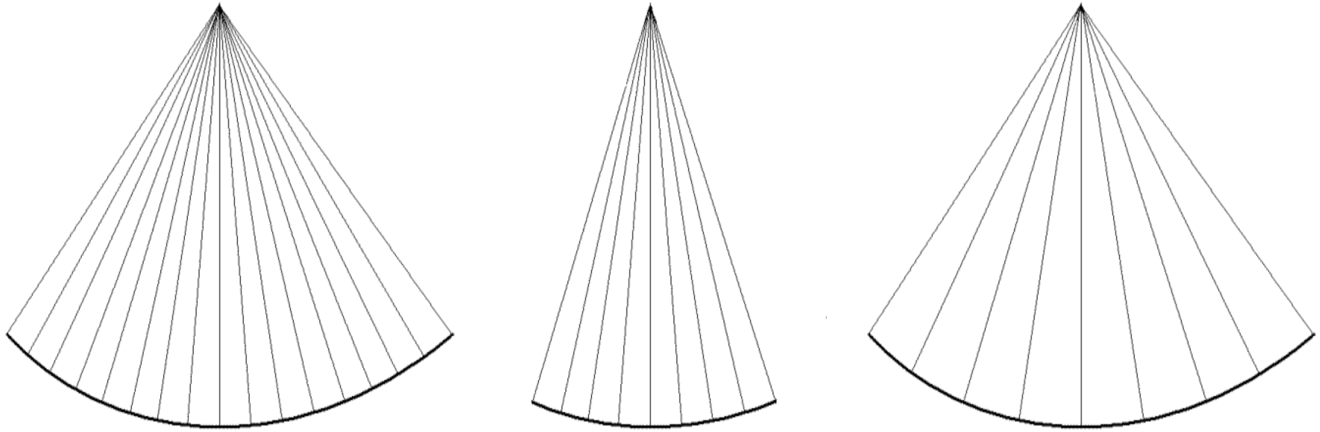
D =½Time of flight x velocity
B-mode (Imaging)



From US to image

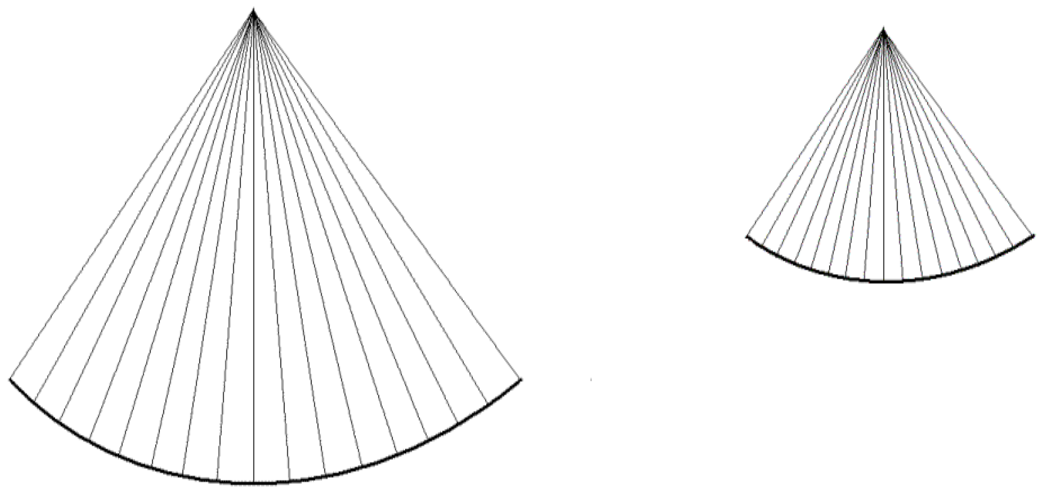


From US to image



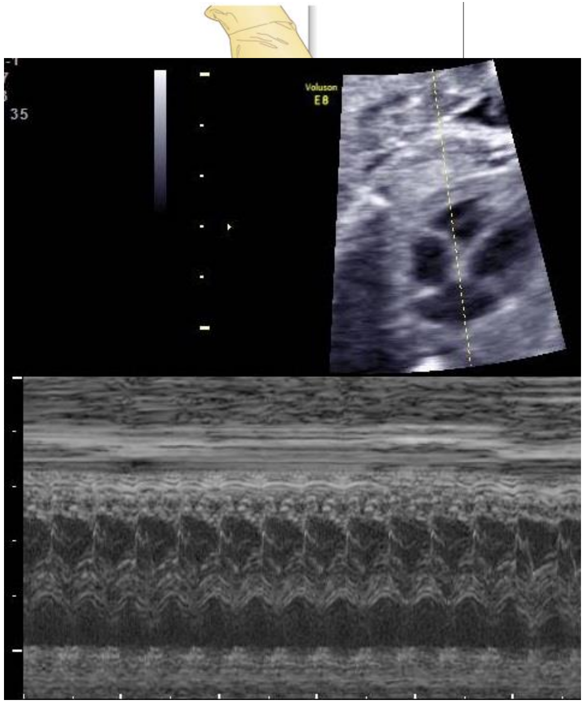
Large angle / width takes time!
Large number of sectors takes time!

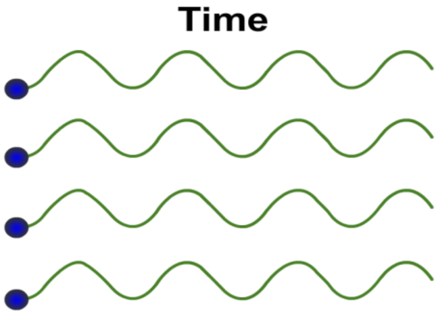
From US to image



Depth takes time!

From US to image





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

M-Mode (Motion)

Frequency, resolution & penetration

Both
21 weeks!

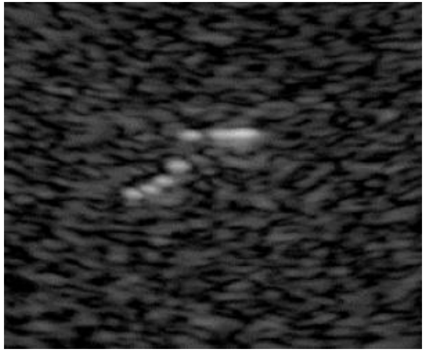
- Low frequency:
  - Less resolution
  - More penetration

- High frequency:
  - High resolution
  - Less penetration

3.5 mHz	=	10-20 cm
5.0 mHZ	=	5-10 cm
7.5 mHz	=	2-5 cm
10.0 mHz	=	1-4 cm

Image - resolution

- Lateral resolution
- Axial resolution
- Temporal resolution



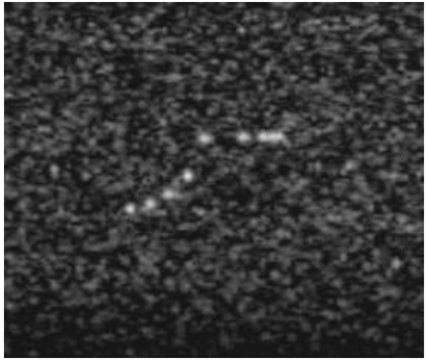
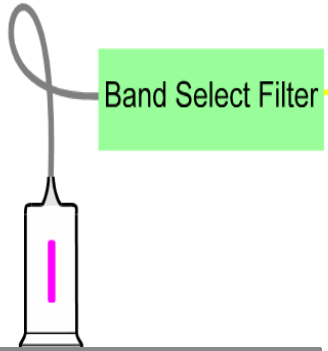


Image enhancement

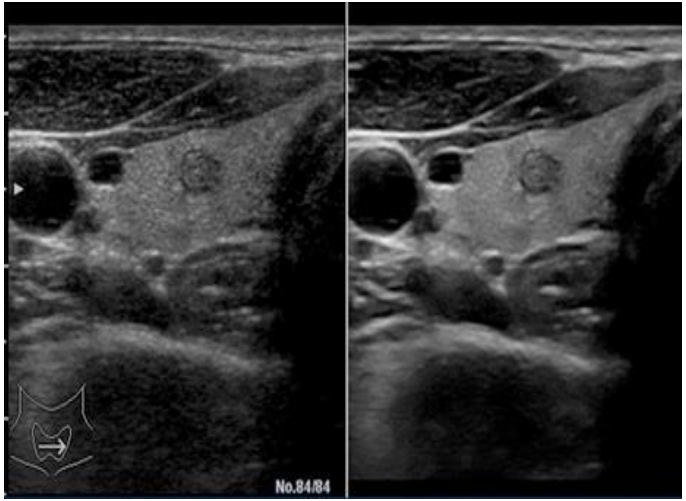


Less penetration

Increased axial resolution

Tissue harmonic imaging

– 2f, 3f, 4f : laws of physics
– Probe also able to receive harmonic frequencies



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

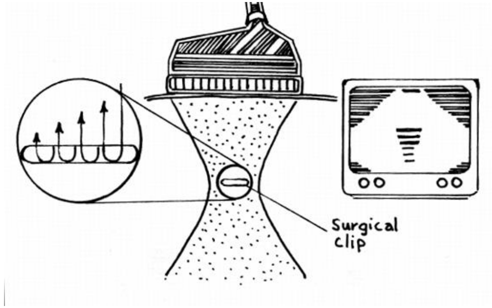
Artefacts

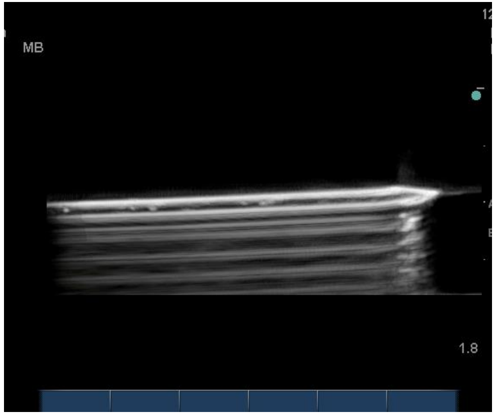
Posterior enhancement/amplification

- 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

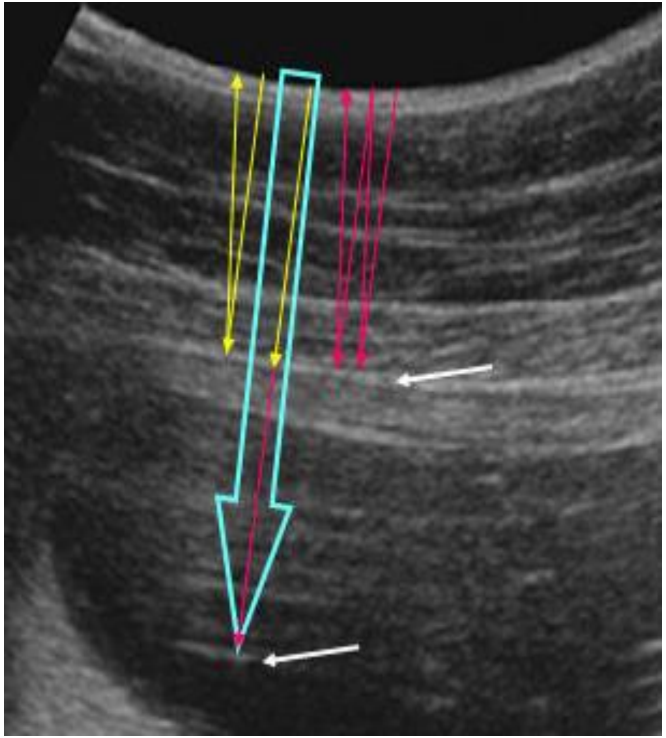




- Occurs when US beam encounters 2 strong parallel reflectors
- Multiple parallel echoes result from back-and-forth travel of US between 2 reflecting surfaces

Change angle of insonation

Artefacts
Reverberation

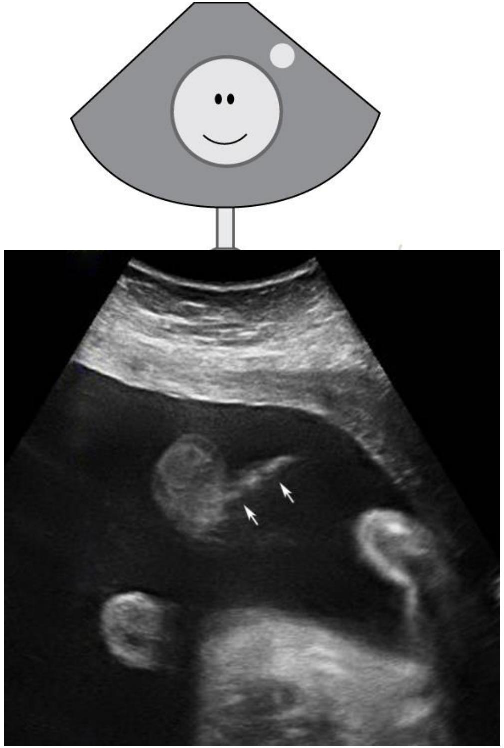


- Probe face & subcutaneous tissue interface provide parallel reflectors

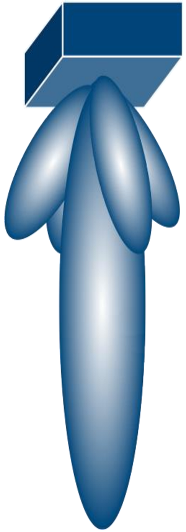
Change angle of insonation

Artefacts

Side lobe artifact

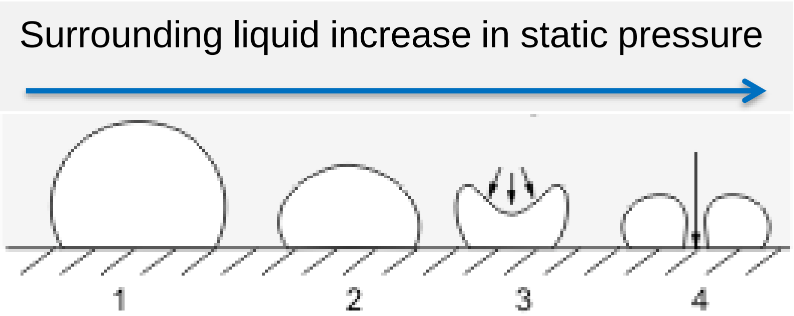


- Results from strong reflector that lies outside the incident beam, but within side lobe of central beam
- Echoes from reflector are displayed as if originating from within central beam



Safety issues – biological effects

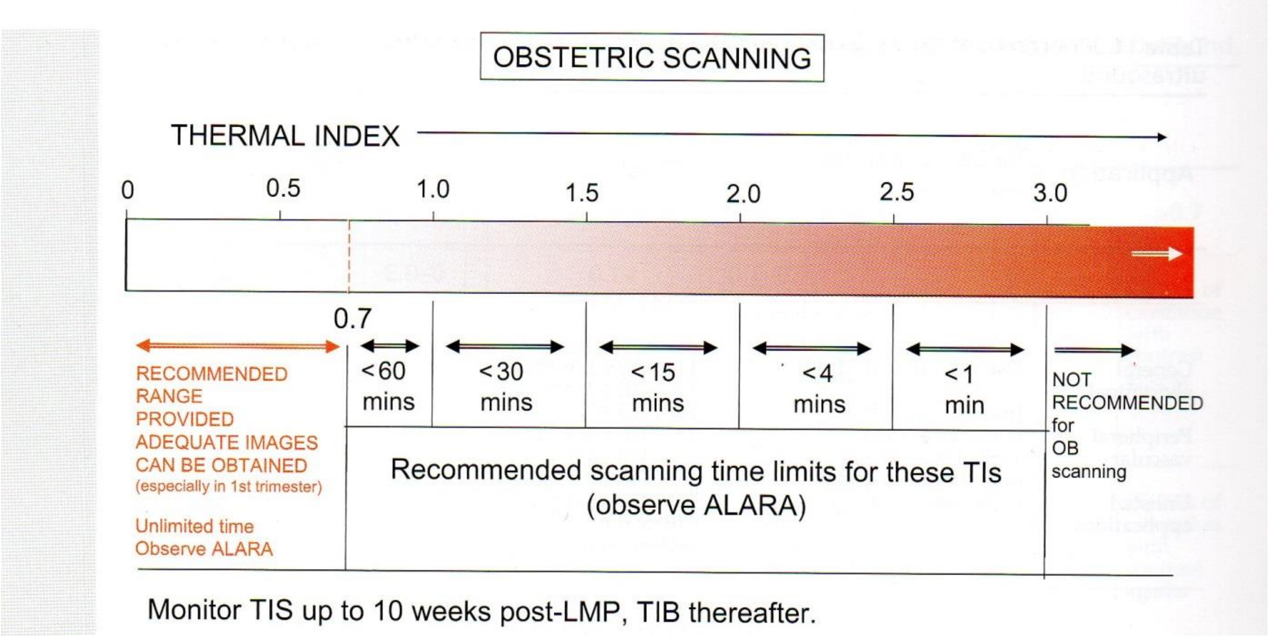
- Increased movement of molecules -> results in rise in temperature
- Gas bubble can collapse (cavitation) -> results in pressure wave released into the surrounding tissue



Safety issues – TI, MI & ALARA

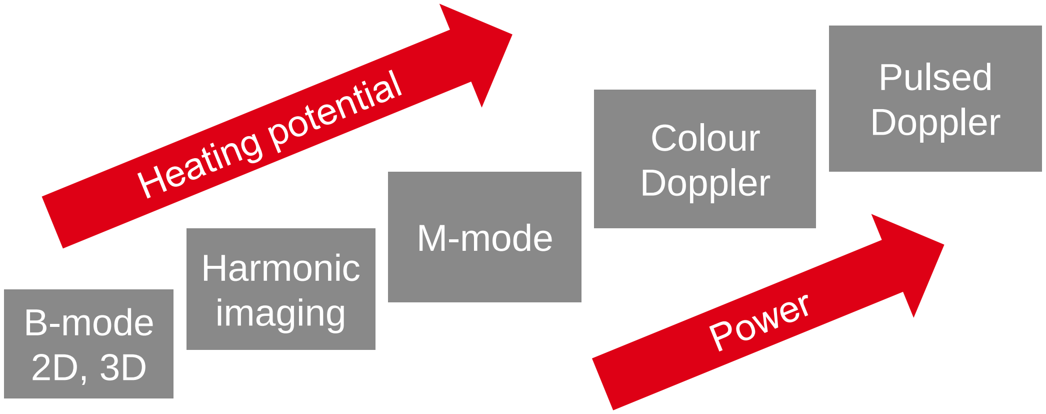
- Thermal Index = TI (<1.0)
  (power needed to increase temperature by 1 °C)
- Mechanical Index = MI (<1.0)
- ALARA principle - as low as reasonably achievable

Scanning times & TI



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

Safety issues - power levels



Safety statements

- International Society Ultrasound in Obstetrics & Gynecology (ISUOG) http://www.isuog.org/StandardsAndGuidelines/Statements+and+Guidelines/Safety+Statements/
- British Medical Ultrasound Society (BMUS)
  https://www.bmus.org/static/uploads/resources/STATEMENT_ON_THE_SAFE_USE_AND_POTENTIAL_HAZARDS_OF_DIAGNOSTIC_ULTRASOUND.pdf
- 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