Introduction to Medical Ultrasound

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Lecture Objectives & Outline

- Lecture participants will learn
  - Ultrasound physics
  - Ultrasound image formation and artifacts
  - Abdominal and FAST imaging introduction

- Lecture Outline
  - Ultrasound physics
  - Ultrasound image formation
  - Ultrasound transducers and artifacts
  - Abdominal ultrasound scan planes and images

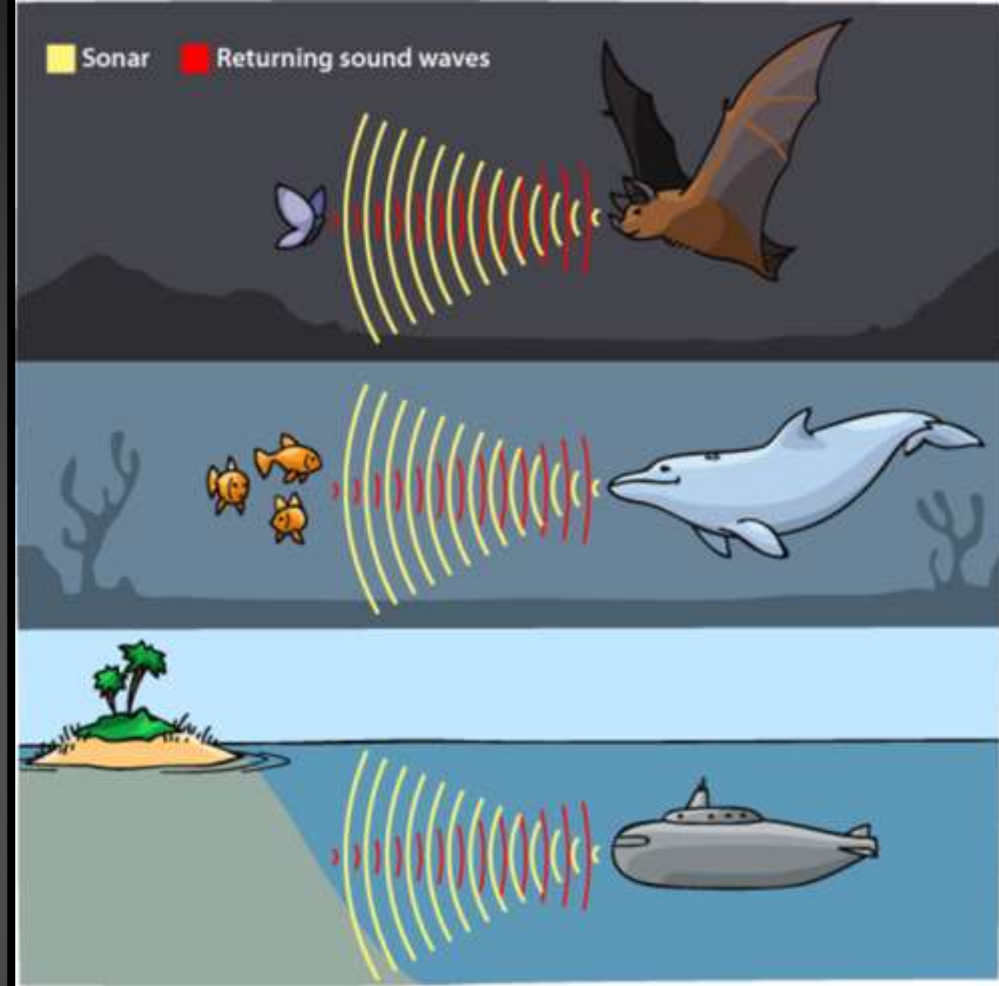
What is Ultrasound?

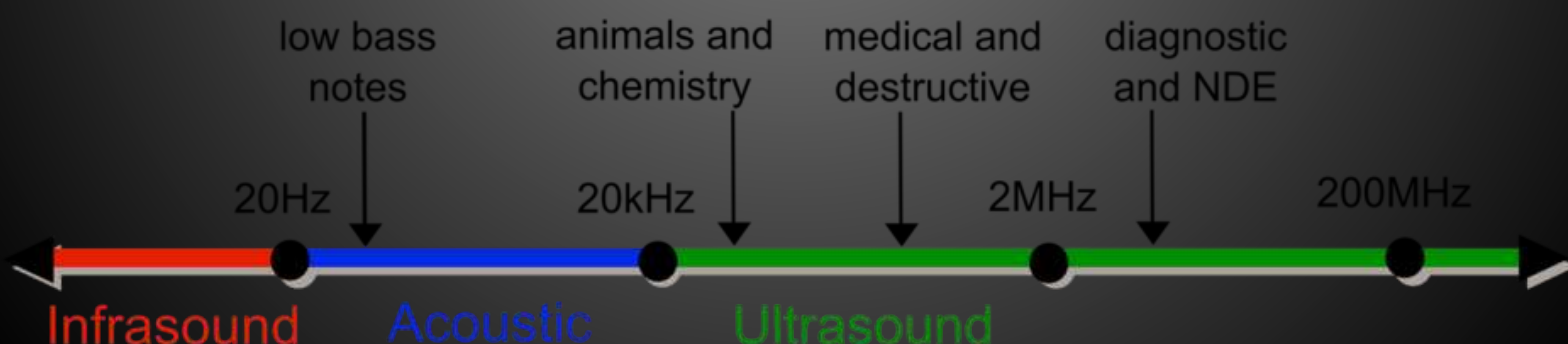
- Medical imaging technique that exposes the body to high frequency mechanical, longitudinal sound waves and generates images based on their returning echoes

- Similar to echolocation used by bats, whales and SONAR of submarines

- Frequencies exceed the upper limit of human hearing (20,000 Hz), typically 2MHz to 16 MHz

- Noninvasive, safe modality that allows real time imaging with numerous medical applications


Sonar
Returning sound waves


low bass notes
animals and chemistry
medical and destructive
diagnostic and NDE
20Hz
20kHz
2MHz
200MHz
Infrasound
Acoustic
Ultrasound

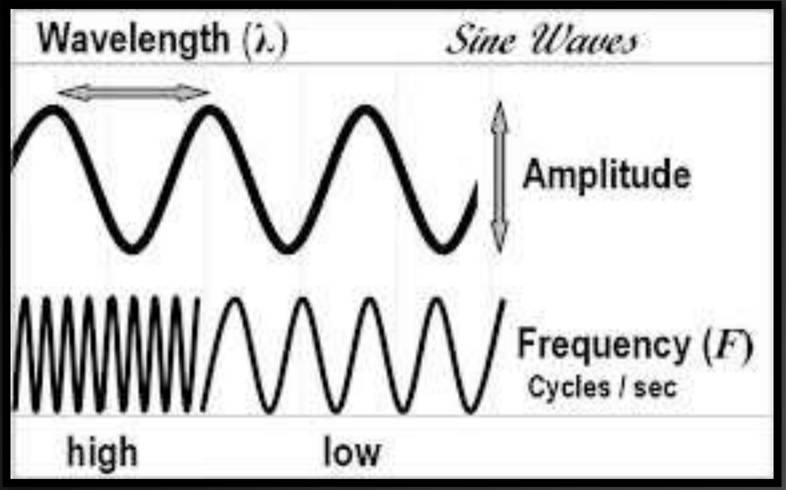
Properties of Sound Wave

- Velocity - speed with which a sound wave travels through a medium (cm/sec), determined by density and stiffness of the medium it travels in (slowest in air, fastest in solids)

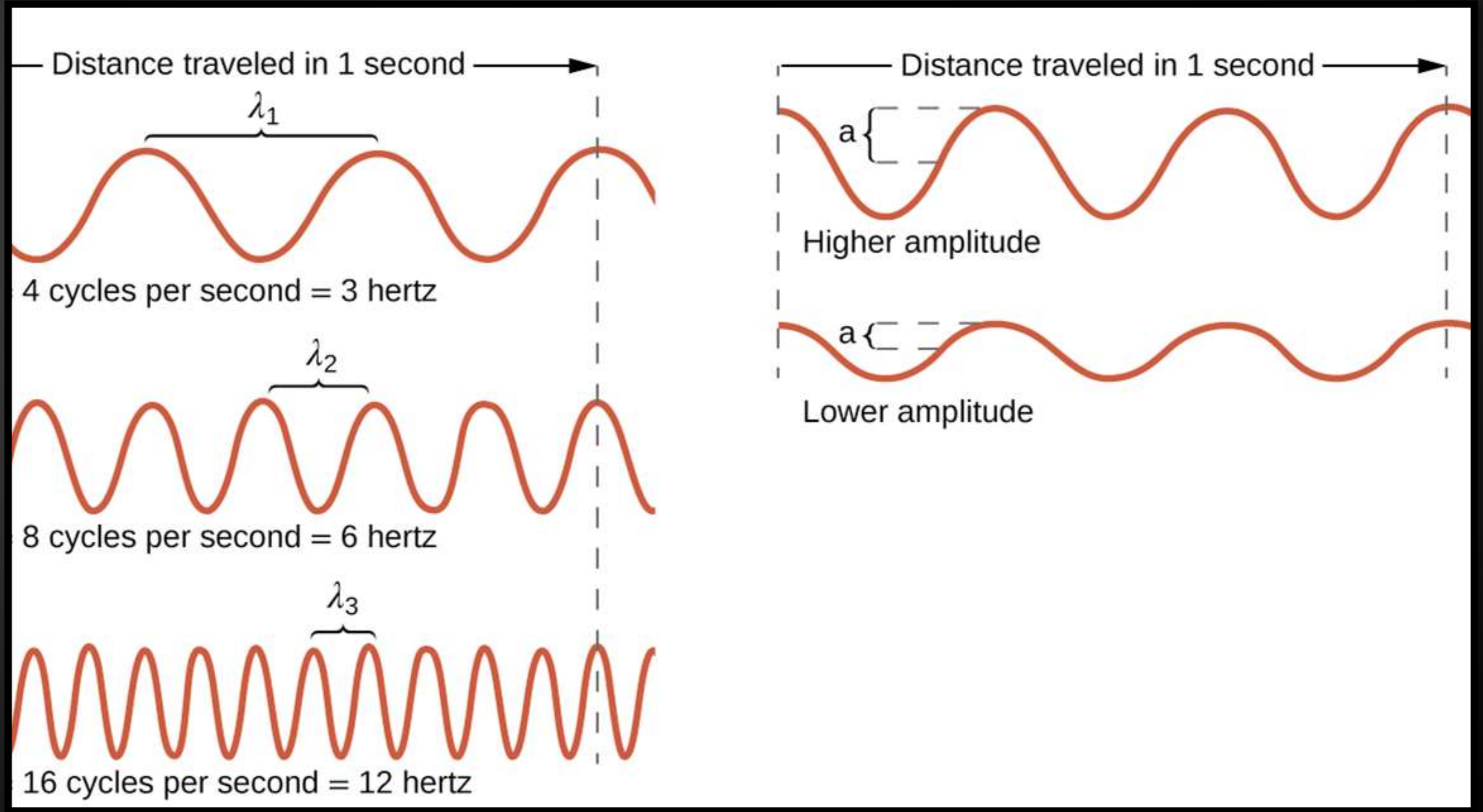
- Frequency - rate of oscillations (cycles per second), Units = Hertz (Hz) = 1 cycle per second

- Wavelength - distance required to complete one cycle

- Amplitude - strength/intensity of sound wave at any point in time



Wavelength (λ)
Sine Waves
Amplitude
Frequency (F)
Cycles / sec
high
low



Distance traveled in 1 second
λ1
4 cycles per second = 3 hertz
λ2
8 cycles per second = 6 hertz
λ3
16 cycles per second = 12 hertz
Distance traveled in 1 second
a
Higher amplitude
a
Lower amplitude

How Ultrasound Works

- Transducer creates sound waves and receives echoes using the pizoelectric effect
- Pizoelectric crystals within the transducer change shape when electric current is applied, causing vibrations and production of mechanical sound waves (electrical signal to acoustic/mechanical)
- Need gel as the high frequency sound cannot travel through air

- Sound waves travel into the body and hit a boundary/interface between tissues (fluid-soft tissue, soft tissue-bone). Some sound reflects off these internal structures while some travel further into tissue (transmission)
- Reflected echoes are transformed back into electric signals by the pizoelectric elements and the computer generates an image

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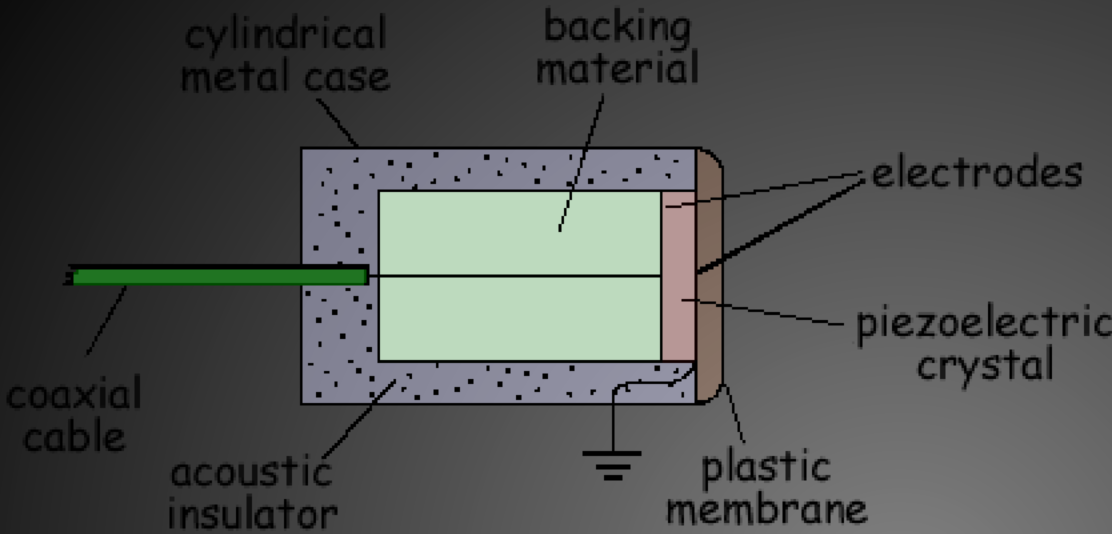

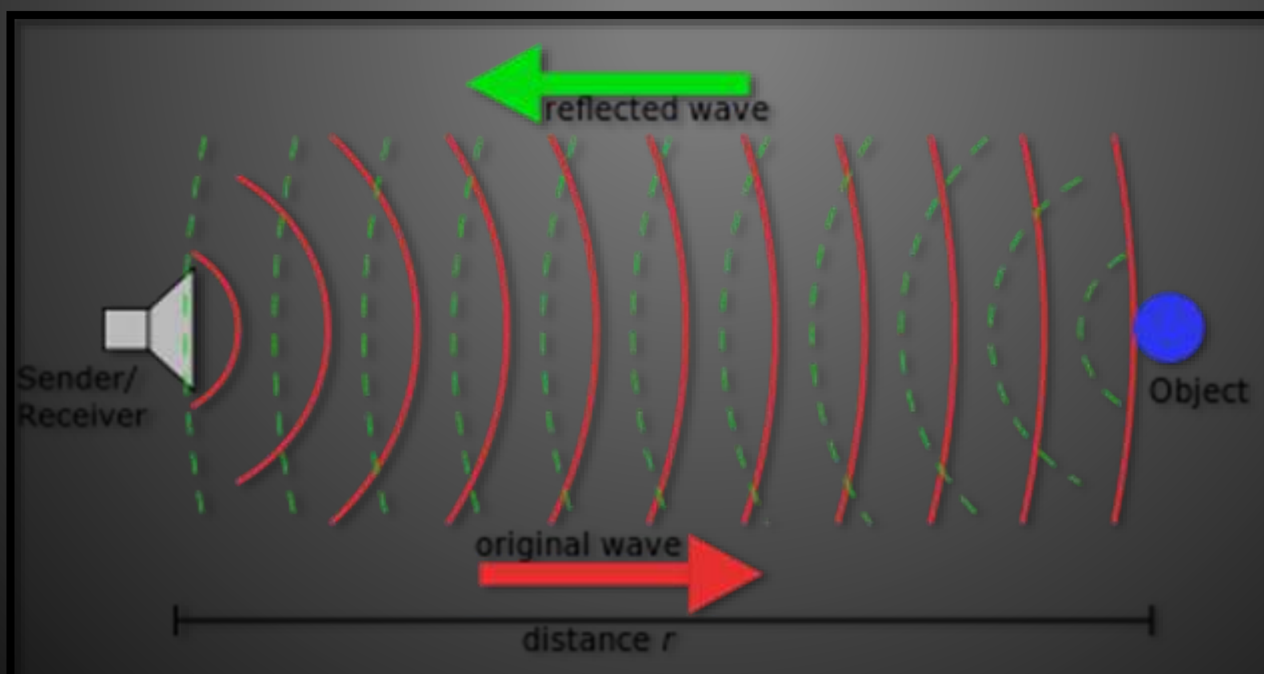

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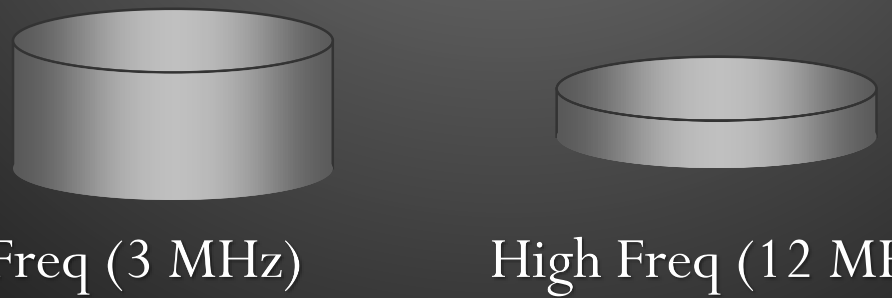
Pizoelectric Crystals and Frequency

- The frequency of the probe is determined by the thickness of the pizoelectric crystals
- Thinner elements produce HIGHER frequencies, whereas thicker elements produce LOWER frequencies
- Higher frequency, less penetration/travel distance
- Lower frequency, deeper penetration



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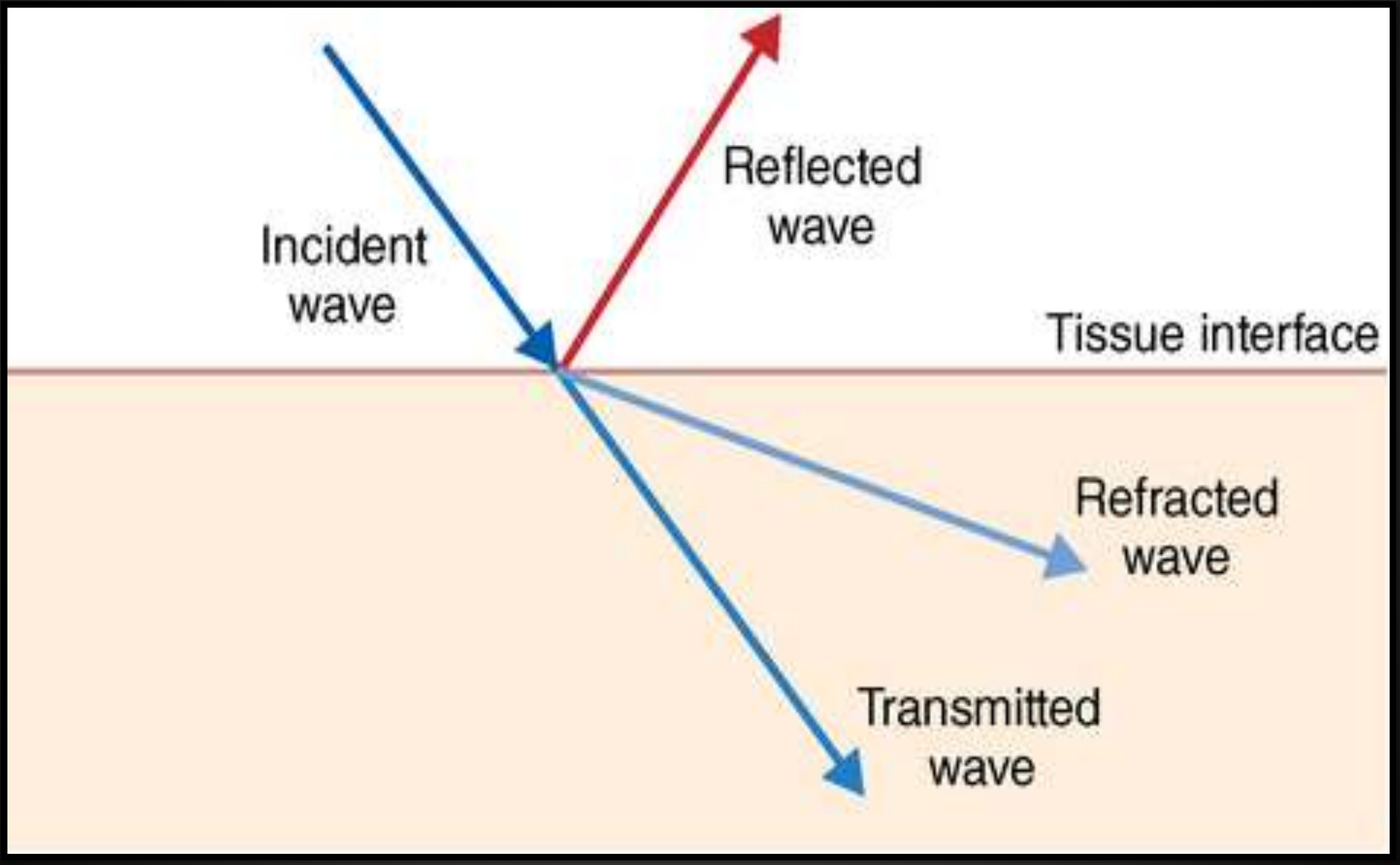
Interaction with Tissues

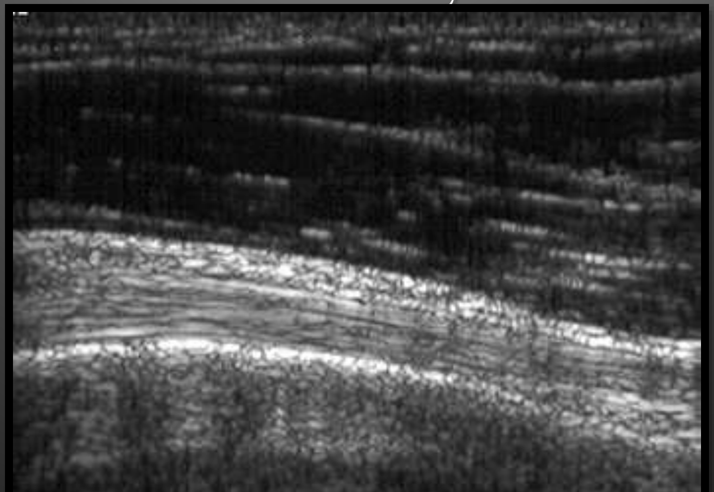
- Reflection
- Transmission
- Scattering/refraction - redirection of sound wave caused by small reflector or rough interface
- Attenuation - the deeper the wave travels in the body, the weaker it becomes
- Air>bone>muscle>soft tissue>blood>water are listed in order of ability to attenuate the sound beam (via reflection, absorption, and refraction and proportional to frequency)

Interaction with Tissues



Strength of the Echoes

- Reflected echoes are transformed back into electric signals by the pizoelectric elements, signals then processed by the computer and produce greyscale 'dots' on the screen
- Brightness of the dots is proportional the the strength of the returning sound wave
- Location of dot is determined by the travel time



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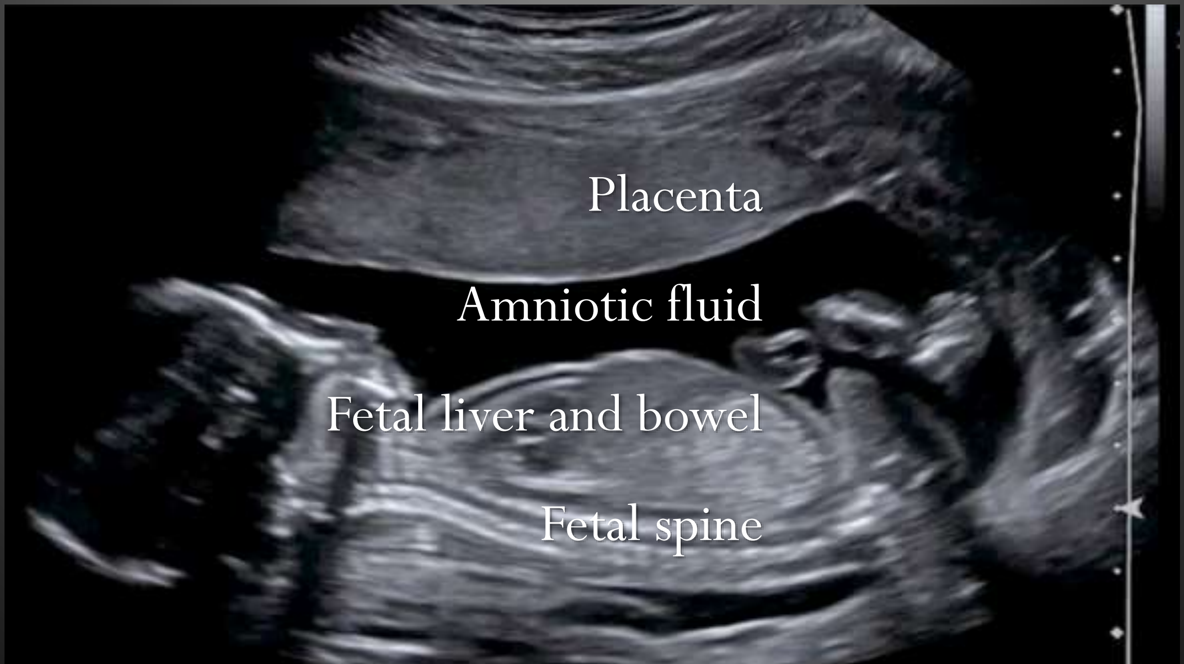
Strength of Echoes

- Strong reflectors = White dots (diaphragm, osseous, stones)
- Weaker reflectors = Grey dots (LN, solid viscera)
- No reflectors = No dots (simple fluid, blood vessels)



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Ultrasound Terms

- Echogenicity - Amount of echoes an organ/structure has, ie the ability to return the signal in ultrasound examinations

- A structure is echogenic if it has internal echoes, ie it is capable of reflecting sound waves. The term echogenic is used in comparison to other imaged/surrounding structures

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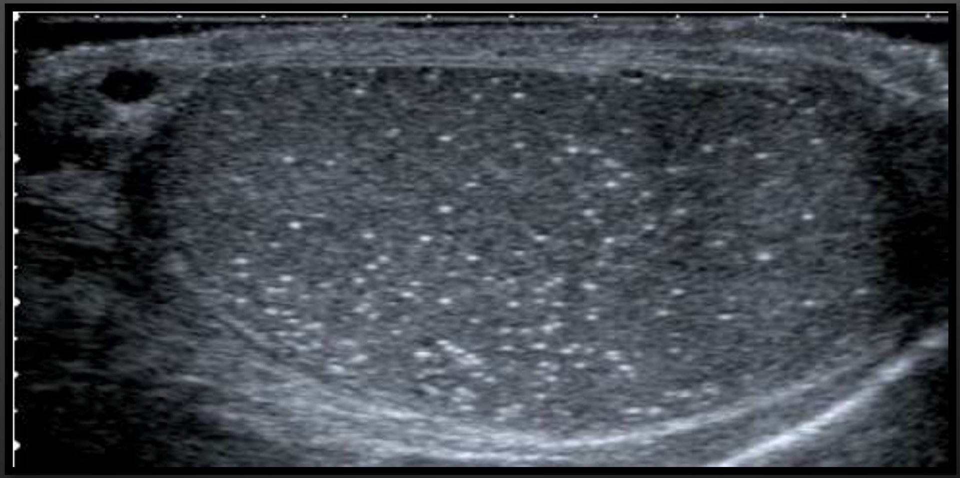
Ultrasound Terms

- Anechoic = no echoes (simple fluid, gallbladder, urine, cyst)
- Hypoechoic = low level internal echoes (LN, liver mass)
- Isoechoic = equal echoes to surrounding tissue (solid viscera)
- Hyperechoic / Echogenic = bright internal echoes (bone, fat)



Isoechoic testis containing echogenic foci

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Frequency vs Resolution

- Higher frequency, better resolution (NB: cannot penetrate deep into the body), used for superficial structures
- Lower frequency, less resolution (may penetrate deep into body), used for deeper structures

High frequency

Superficial

Carotid and jugular vessels

Lower frequency

Deeper structures

Liver and diaphragm

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Transducers - Probes

- Generally described by the size and shape of their face (so-called footprint)
- 3 basic types used in emergency setting: linear, curvilinear, phased array

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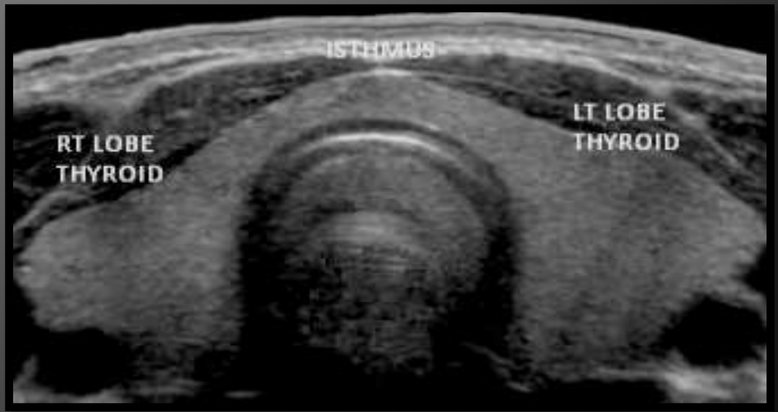
Linear probe

- Higher frequency 5-13 MHz with better resolution, lesser penetration therefore superficial imaging
- Crystals aligned in linear fashion with flat head and produce sound waves in straight line to produce rectangular image



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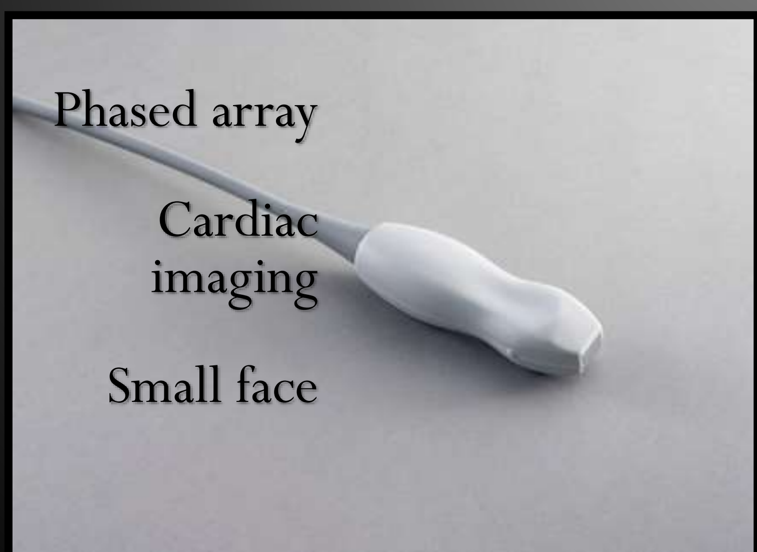
Curvilinear (convex) probe

- Low frequency 1-8 MHz with better penetration, lesser resolution therefore deeper structure imaging (abd and pelv)
- Crystals aligned along a curved surface and produce sound waves that produce wide field of view image

Phased array probe

- 2-8 MHz with small/flat footprint, used in cardiac imaging in small spaces between ribs
- Crystals grouped closely together and produce sound waves that originate from single point and fan outward



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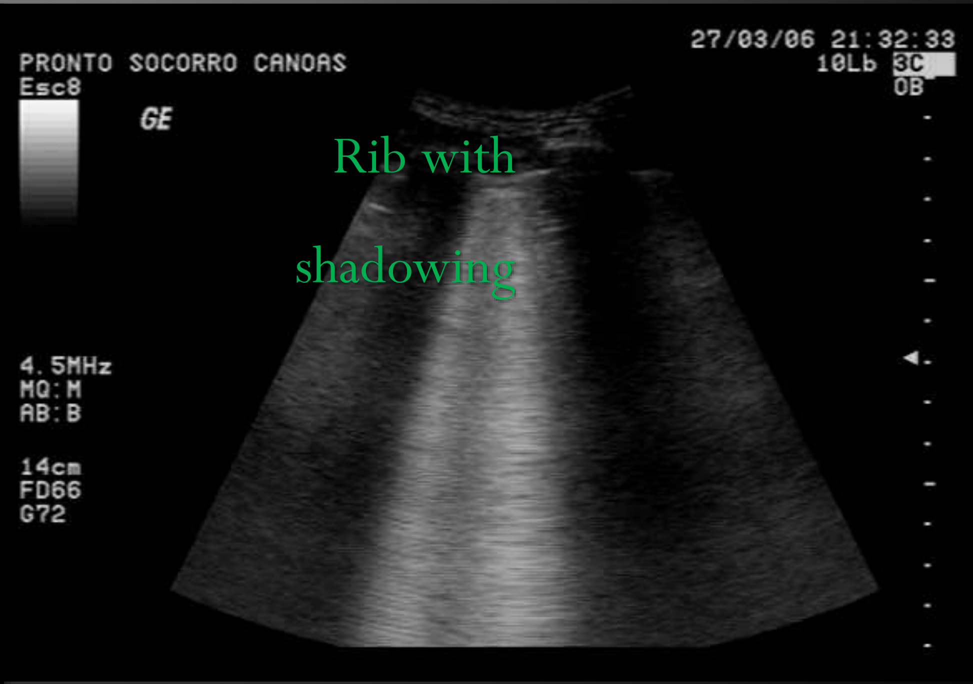
Artifact

- Ultrasound software makes the assumption that all waves travel straight, maintain constant speed (1540m/s), and reflect straight back
- In reality, the sound waves do not follow these strict rules, which leads to artifact
- Artifact can be used to the sonographer's and sonologist's advantage

Posterior acoustic shadowing

Hyperechoic structures reflect a majority of sound waves, leaving a dark shadow behind them



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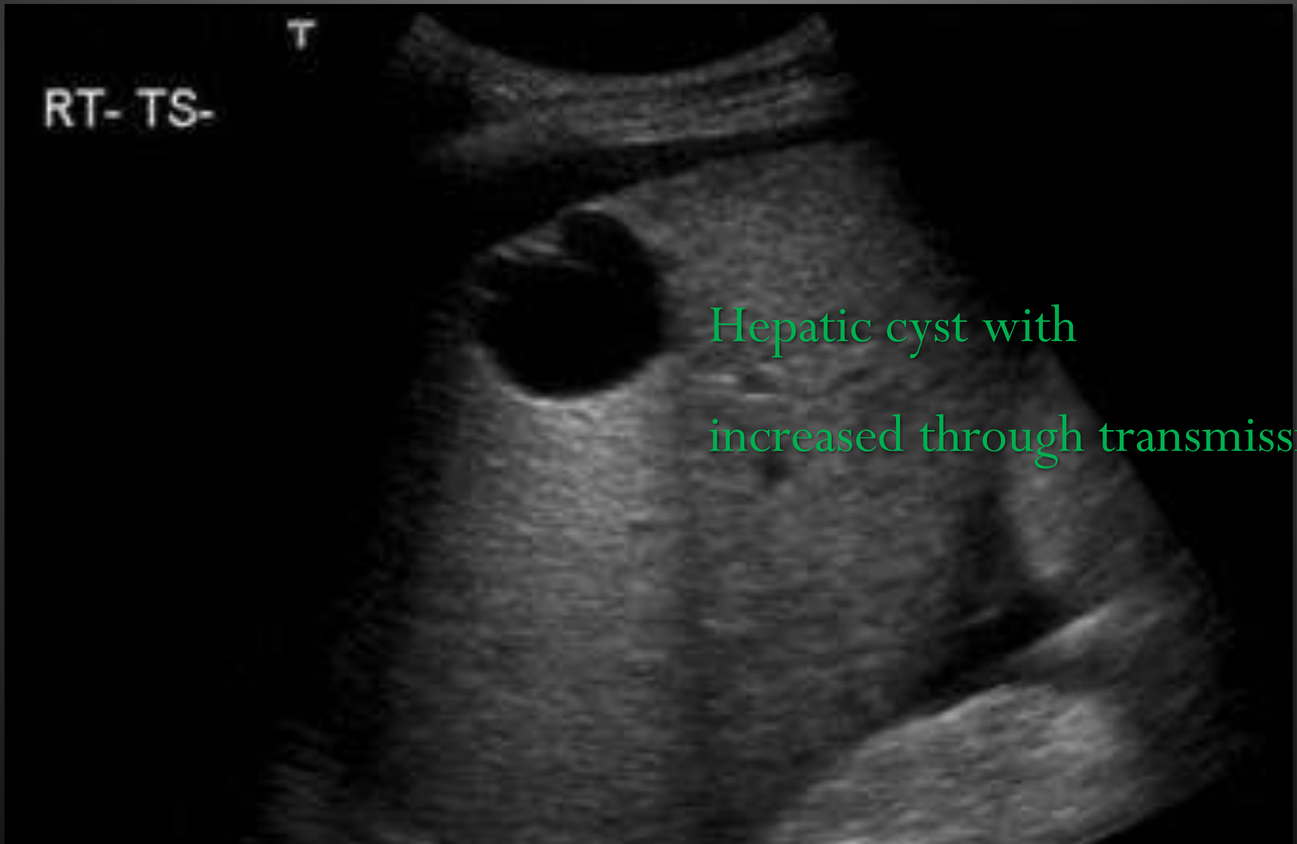
Increased through transmission

Anechoic structures do not reflect sound waves, leaving a bright band behind them



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Mirror image artifact

In clinical imaging, a duplicated structure is commonly identified at level of the diaphragm, with the pleural-air interface acting as the strong reflector

Beware!

NOT a second mass

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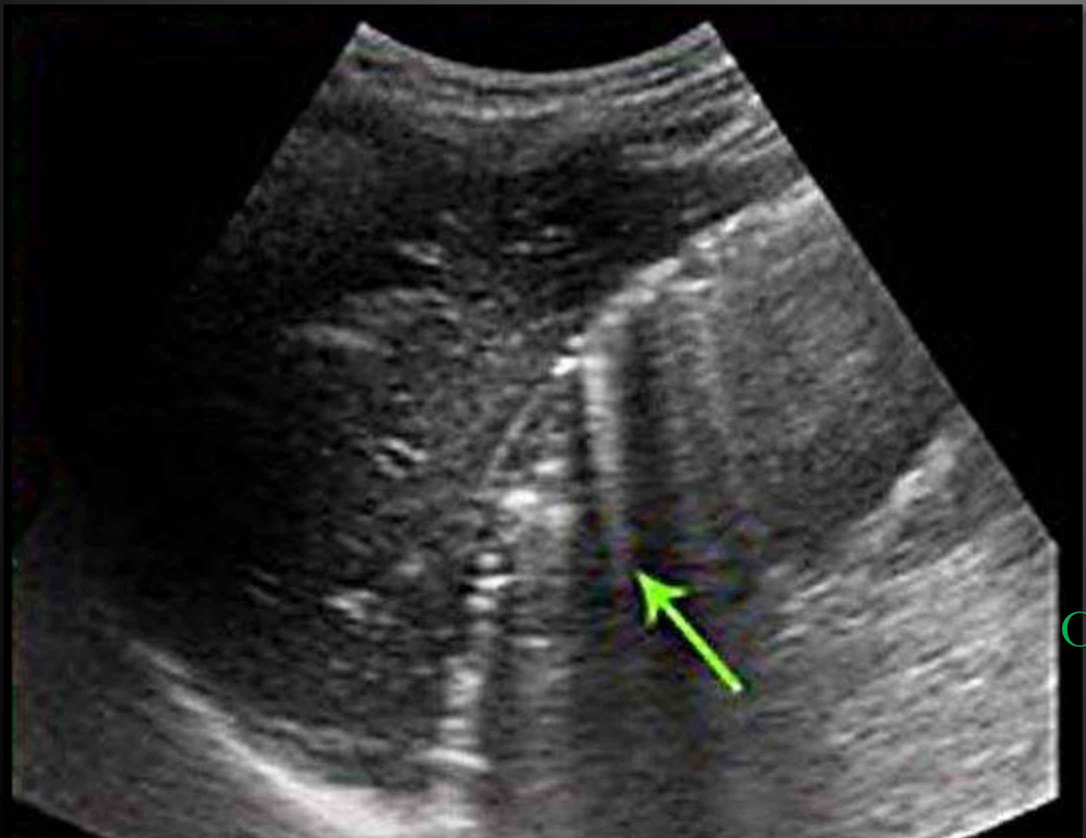
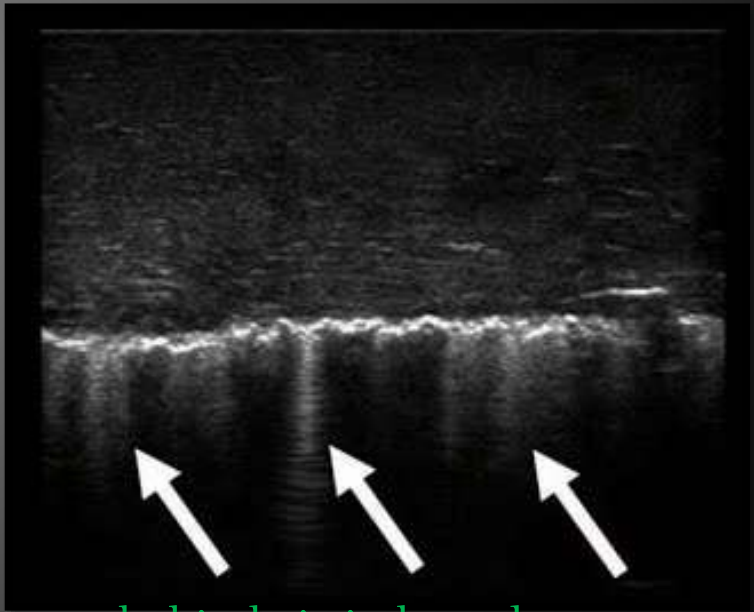
Ring down artifact

Resonant vibrations within fluid trapped between tetrahedron of air bubbles create a continuous sound wave that is transmitted back to the transducer





Occurs behind air in bowel

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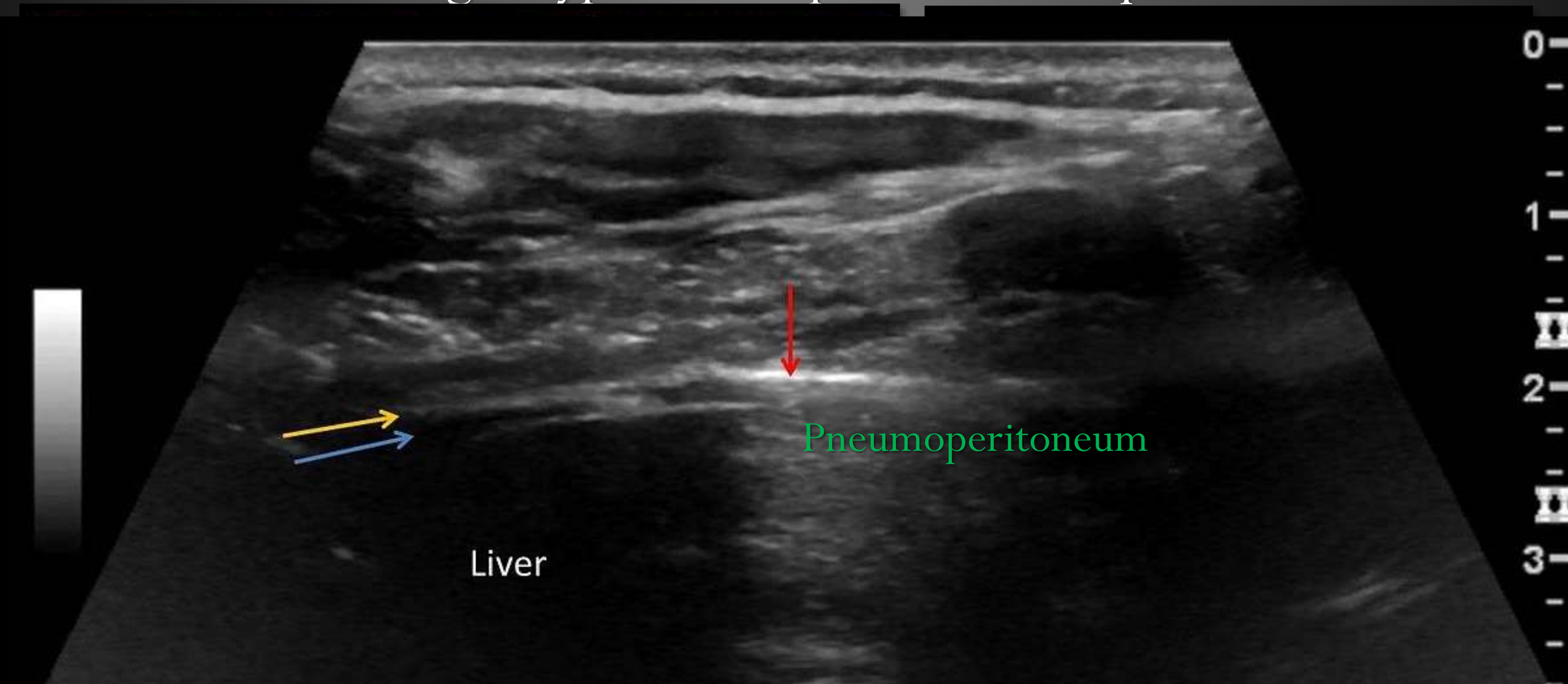
Peritoneal stripe sign

Presence of tiny bubbles of free air in addition to the acoustic mismatch at interface between soft tissue and air produces bright hyperechoic peritoneal stripe



Imaging with Ultrasound

Transducer orientation

Scan planes

Abdominal, pelvic, and cardiac images

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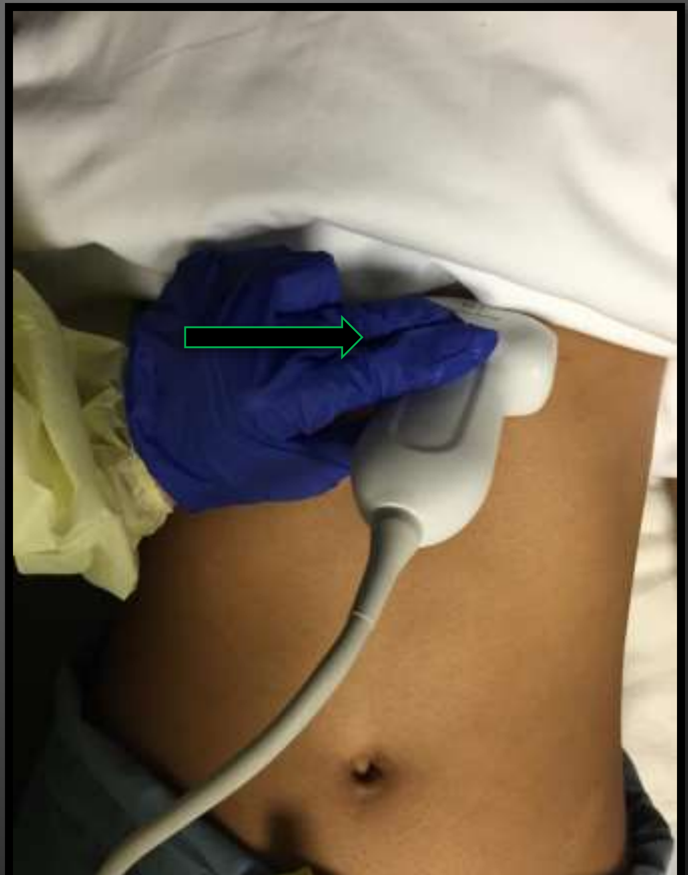
Orientation of Transducer

- Conventionally, the probe notch is toward the patient's head during longitudinal scan and toward patient's right side during a transverse scan

Notch toward patient head in longitudinal scanning

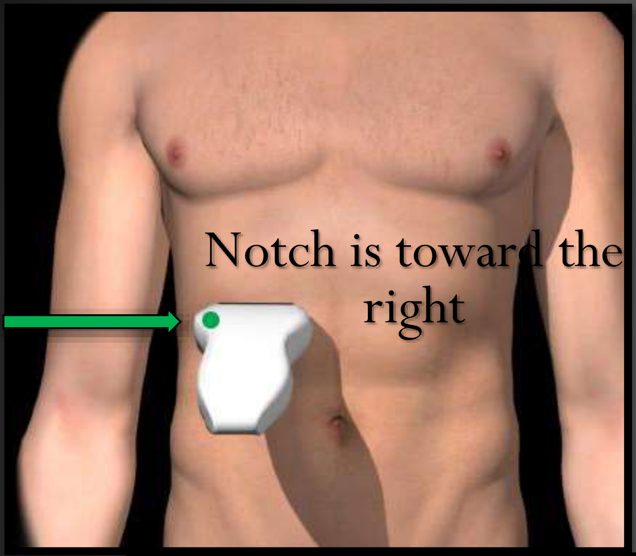
Orientation of Transducer

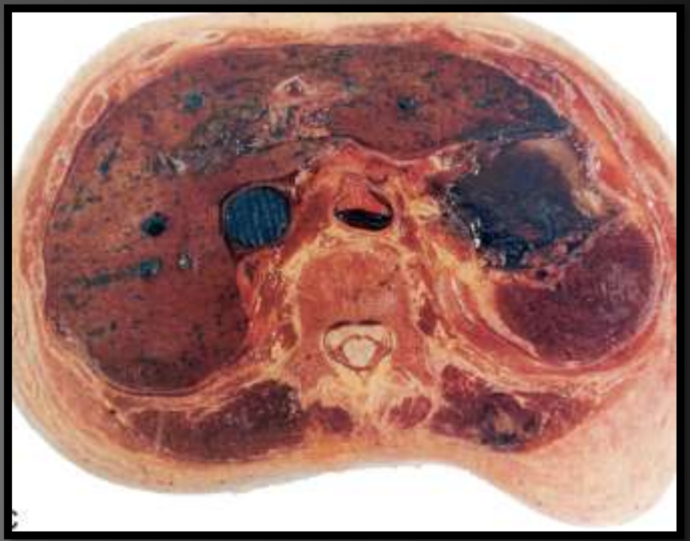
- Conventionally, the probe notch is toward the patient's right during a transverse scan and toward the patient's head during a longitudinal scan

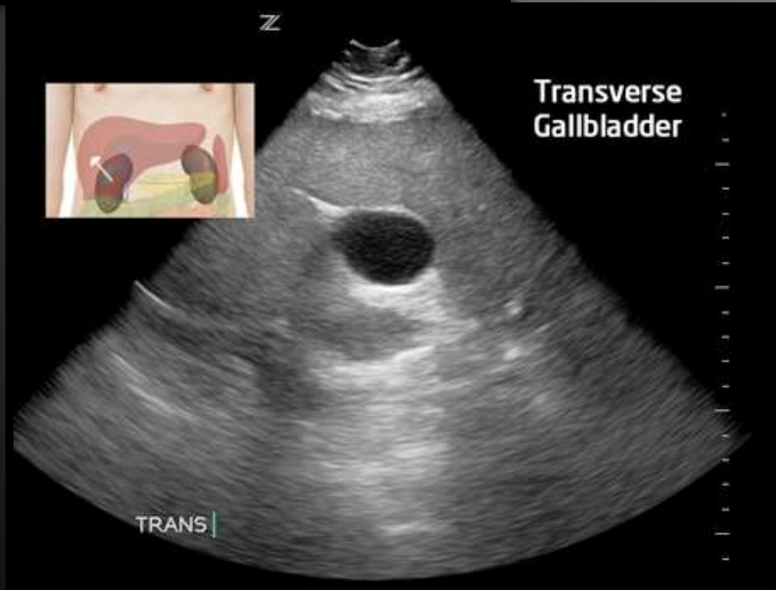


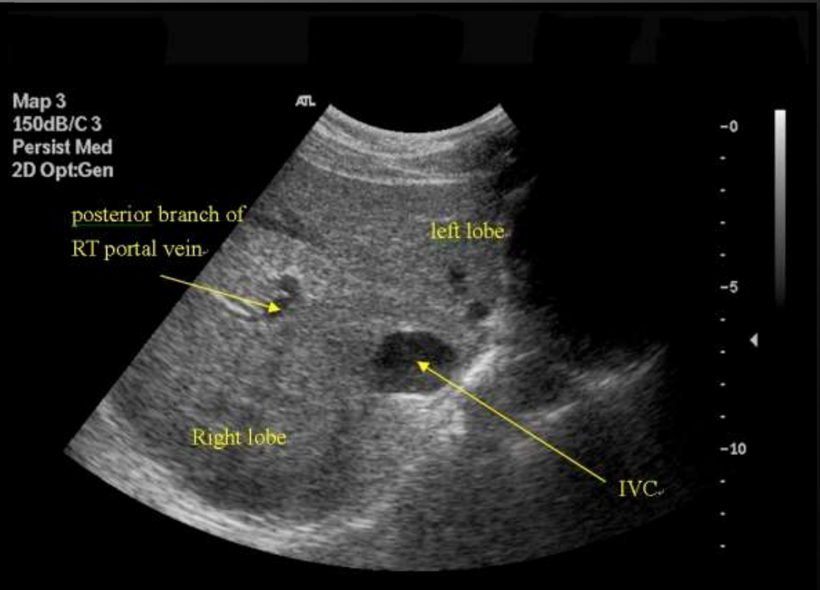
Notch toward patient right in transverse scanning

Transverse Plane

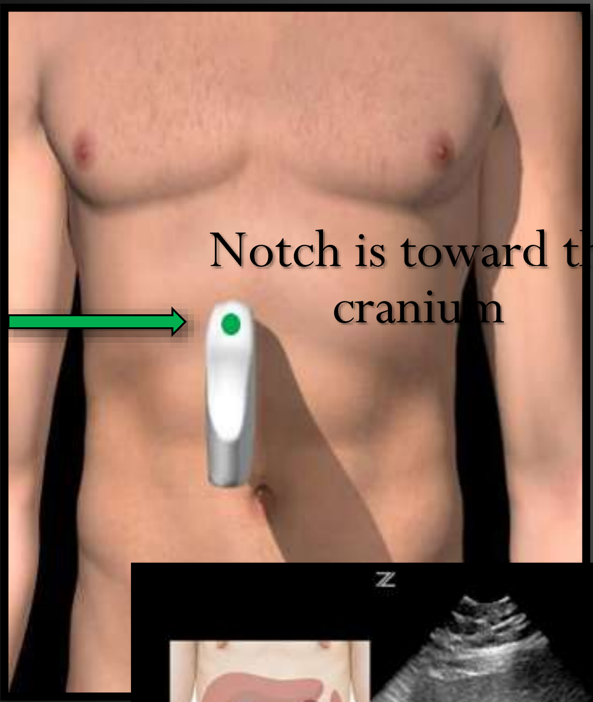




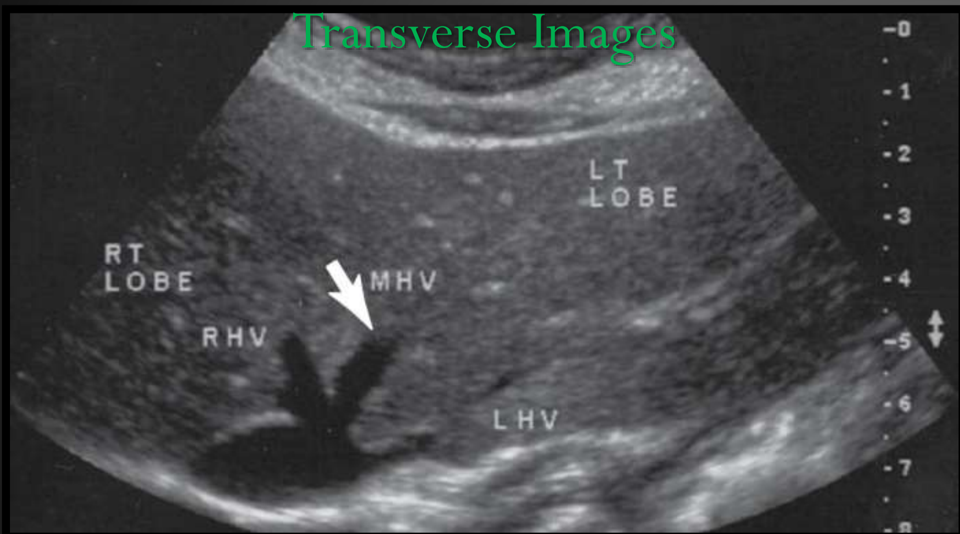


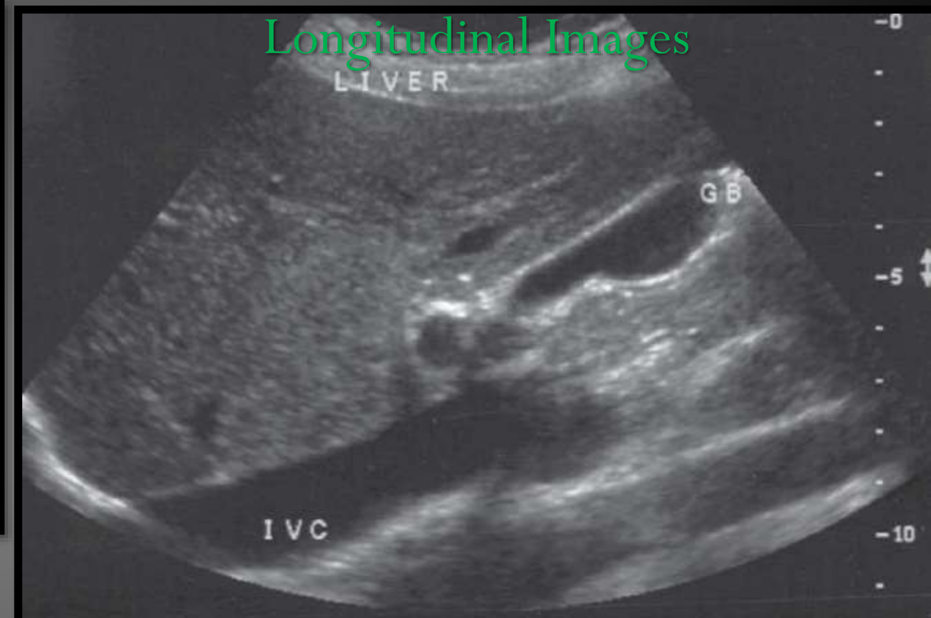


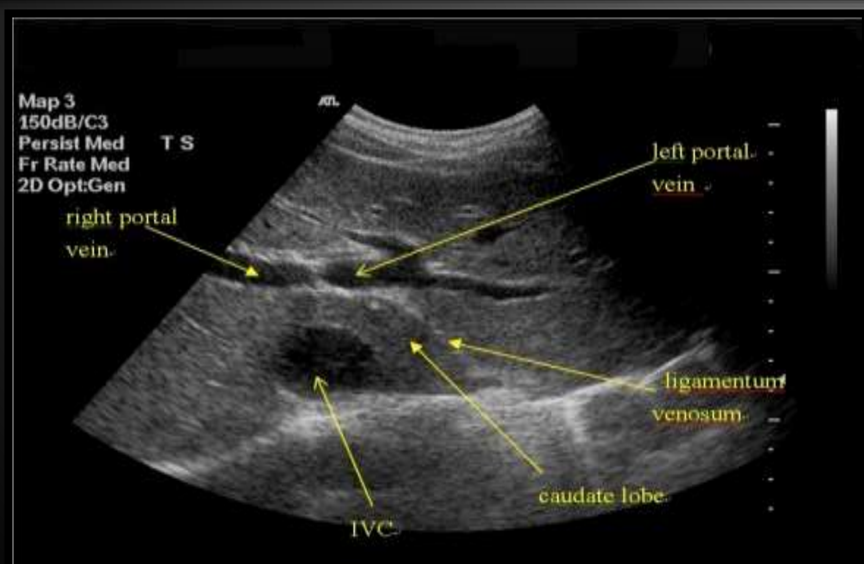
Longitudinal Plane



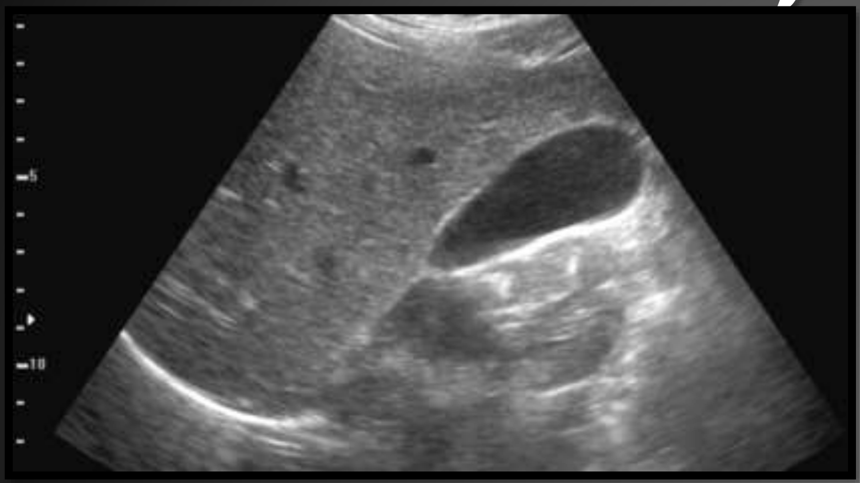
Anatomy: Liver

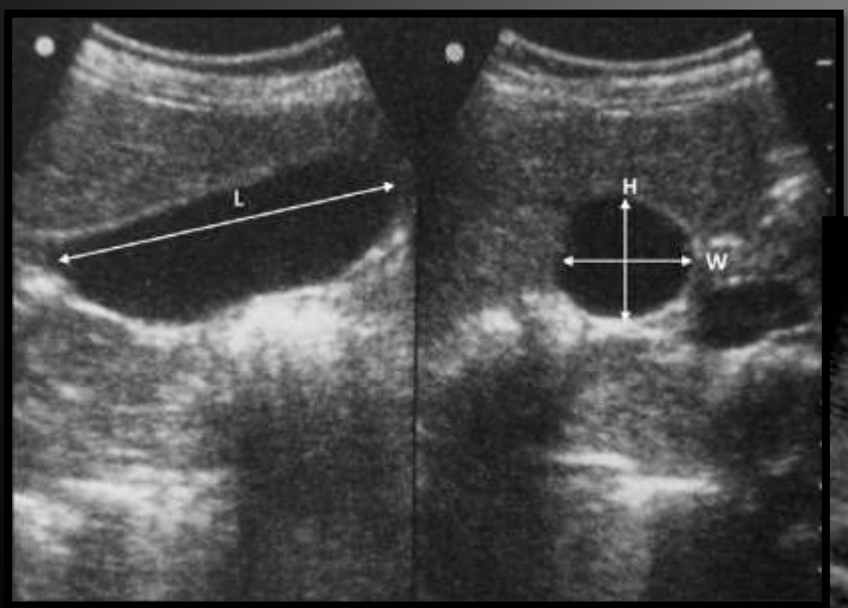


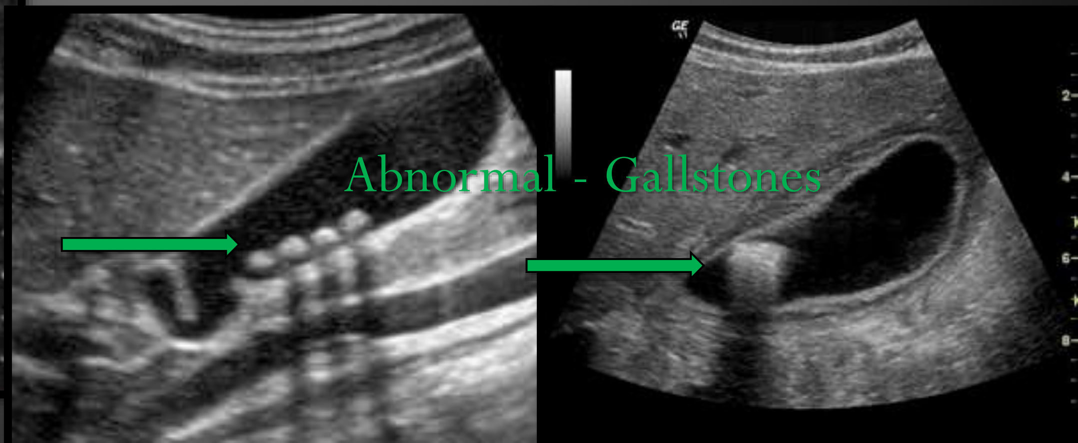




Anatomy: Gallbladder

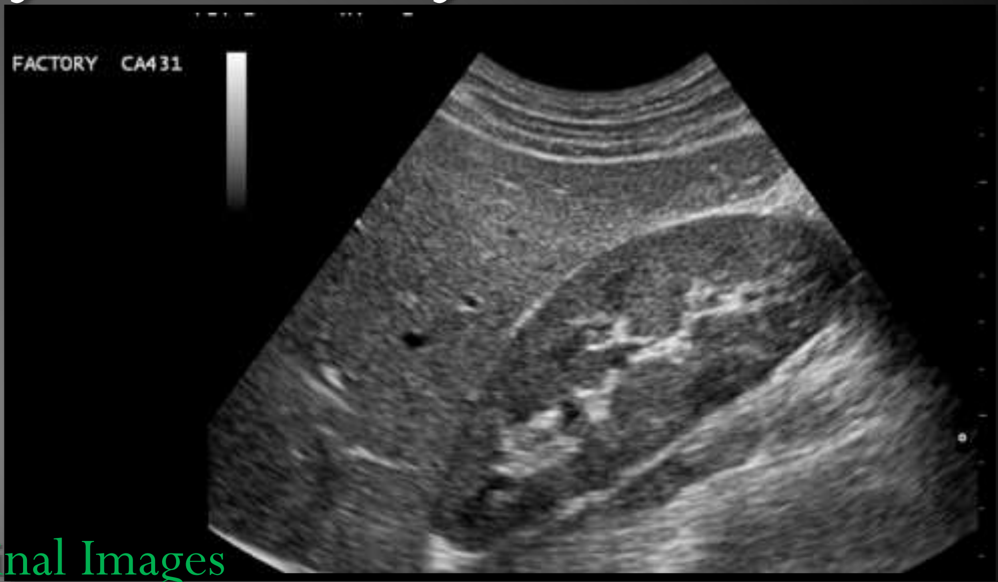




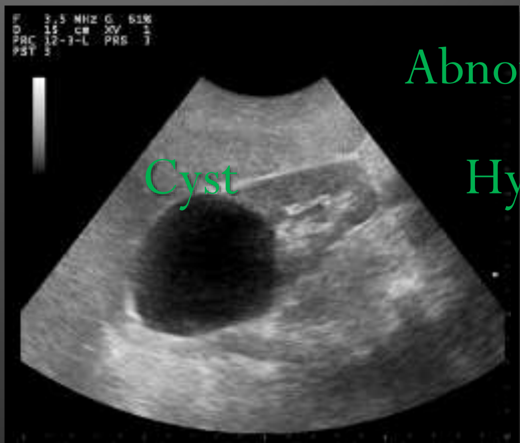


Anatomy: Kidneys

Transverse Image



Longitudinal Images



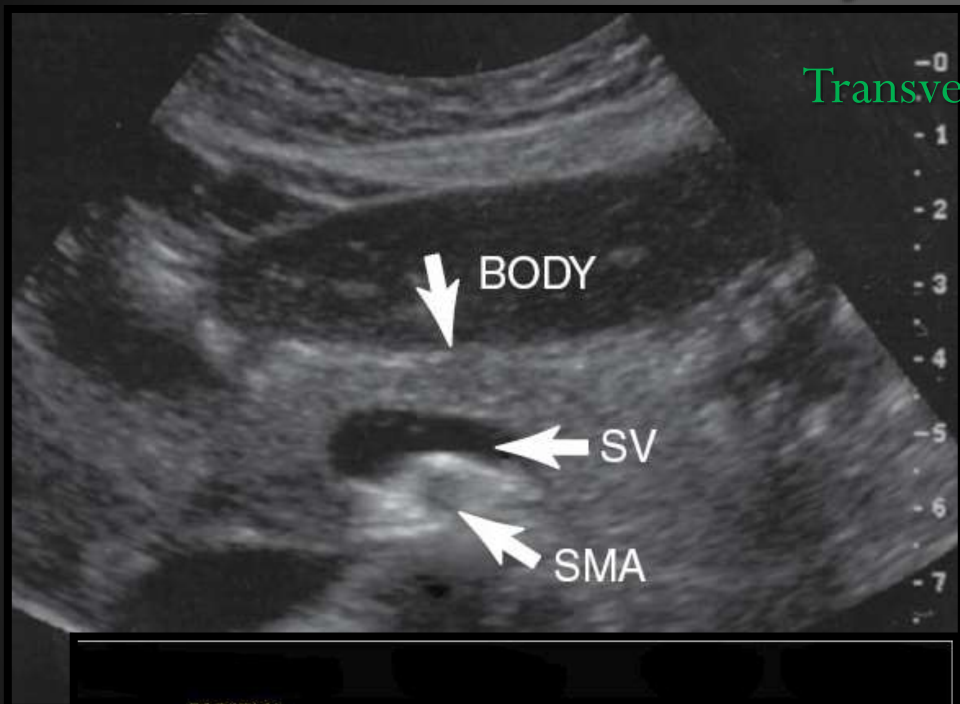
Abnormal

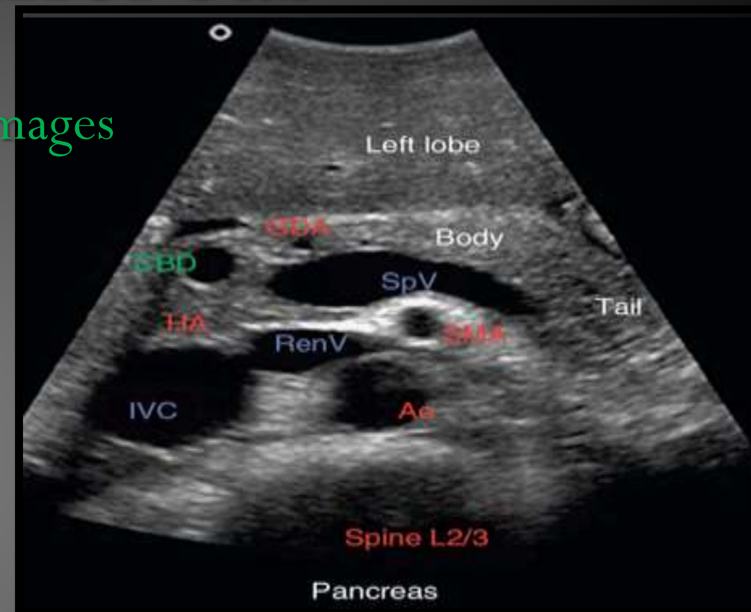
Cyst

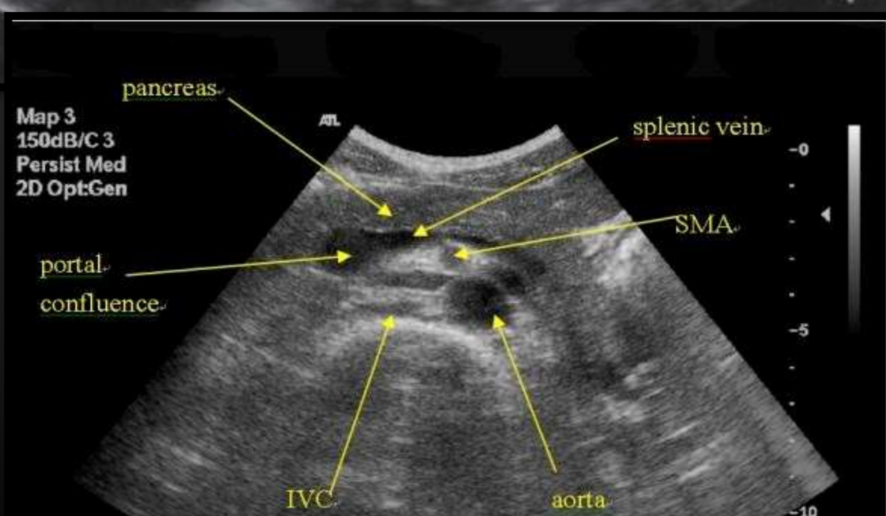
Hydronephrosis

Anatomy: Pancreas

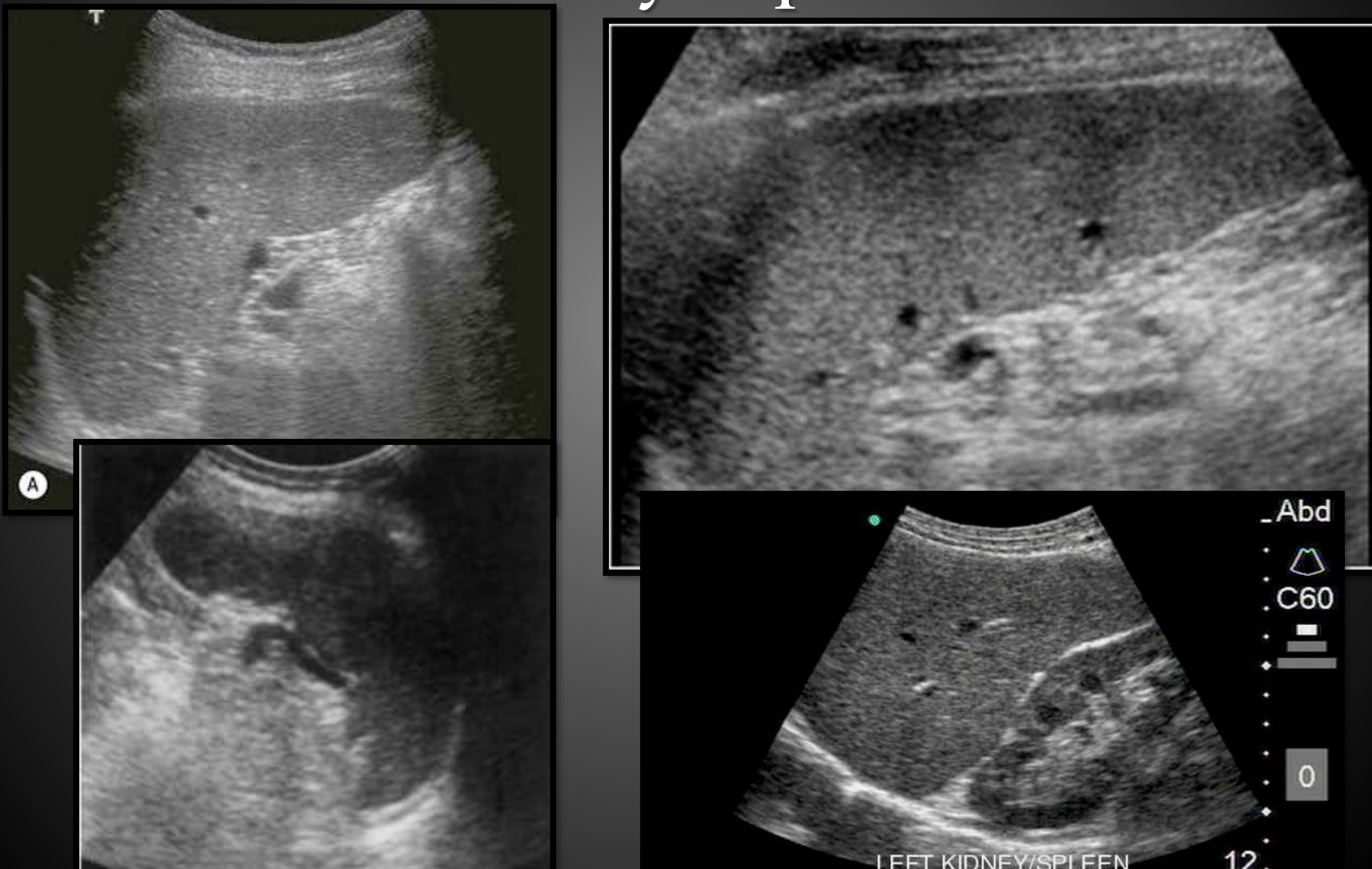
Transverse Images



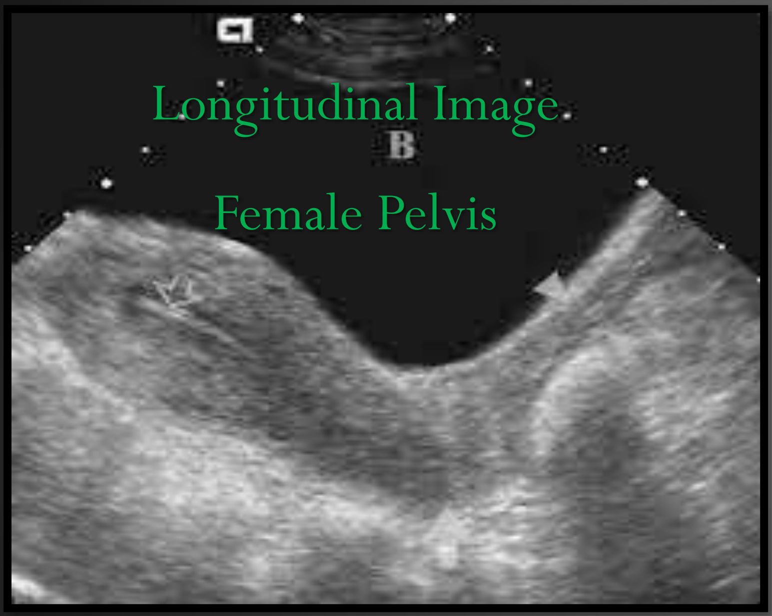




Anatomy: Spleen

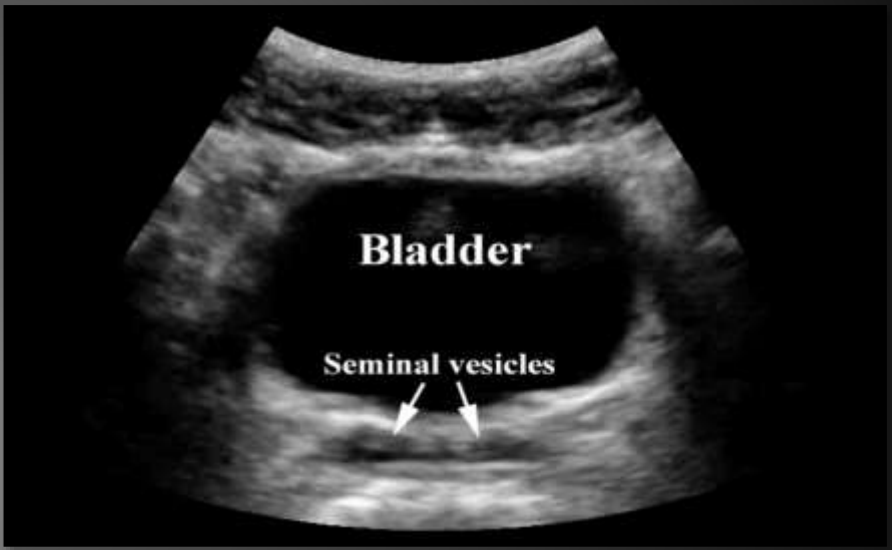


Anatomy: Pelvis



Longitudinal Image

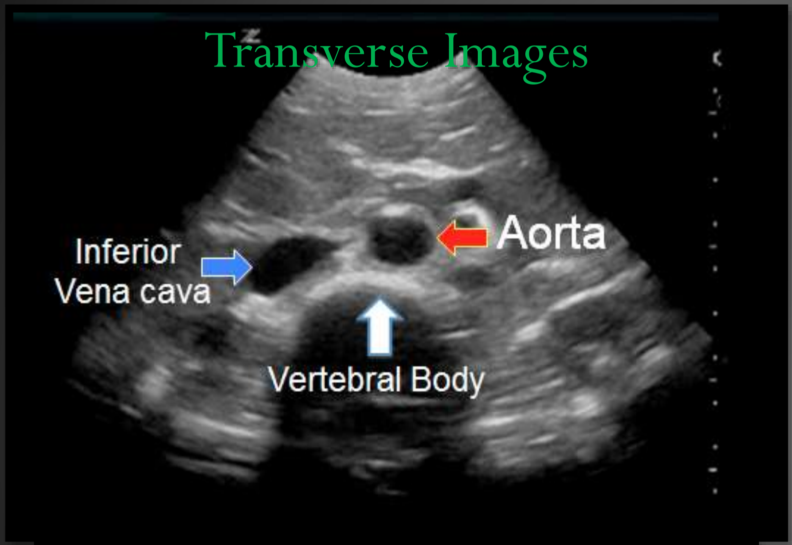
Female Pelvis



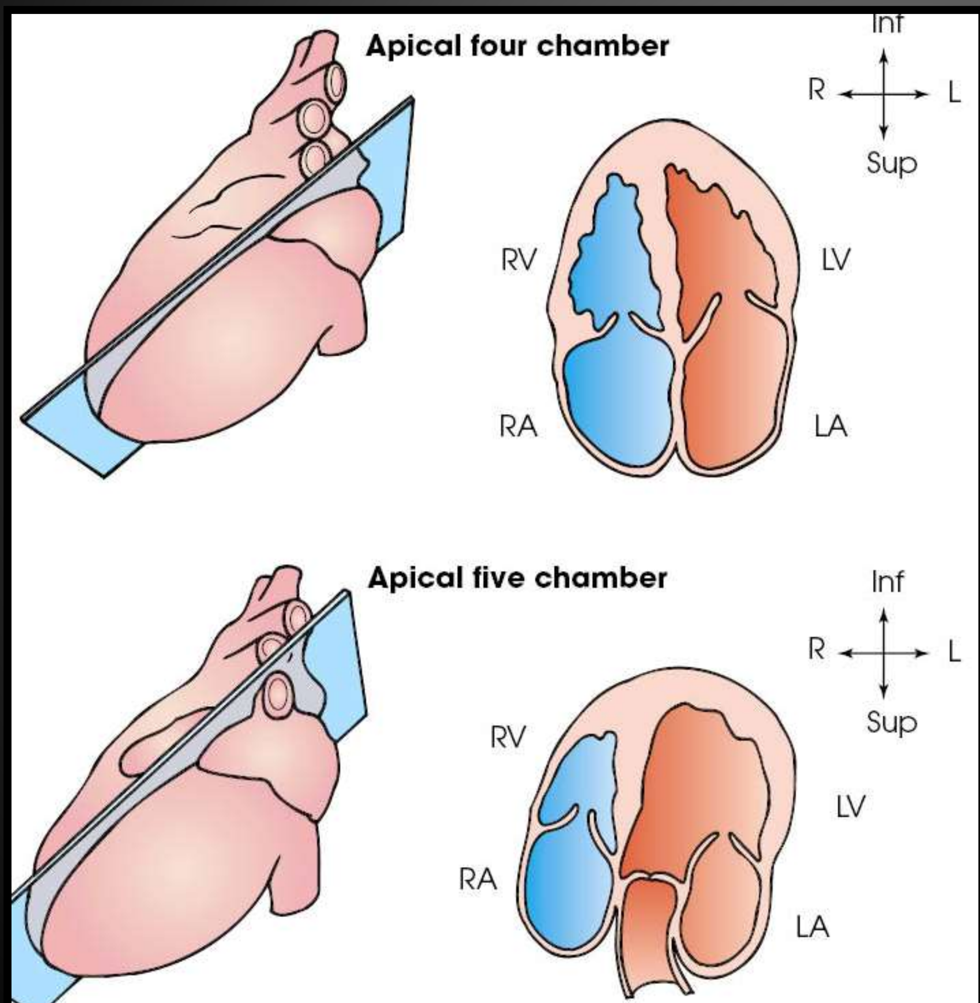
Transverse Images

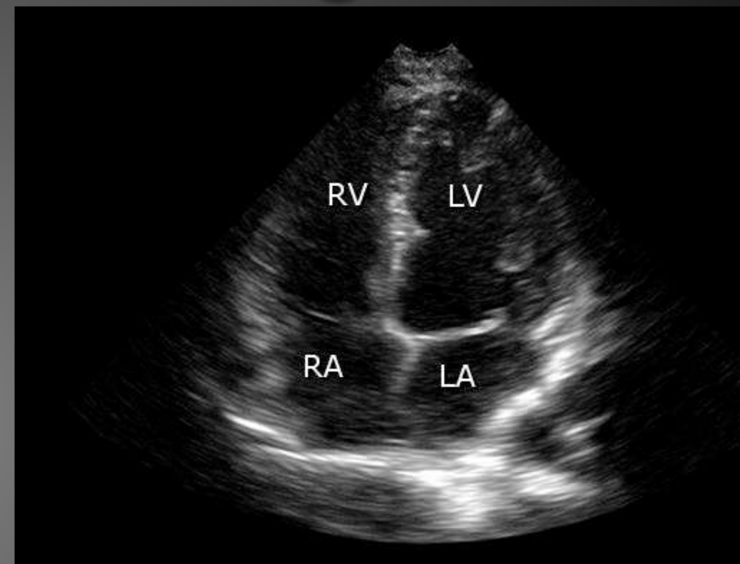
Female Pelvis

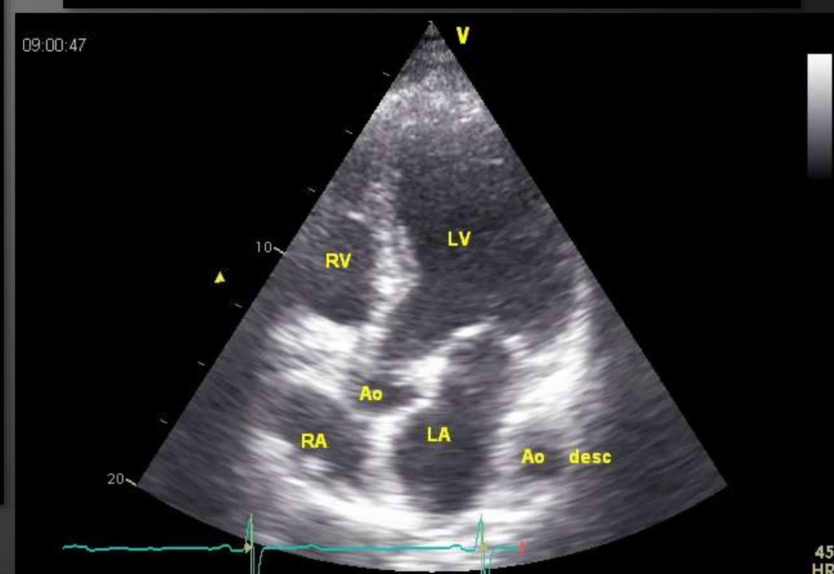
Anatomy: Aorta



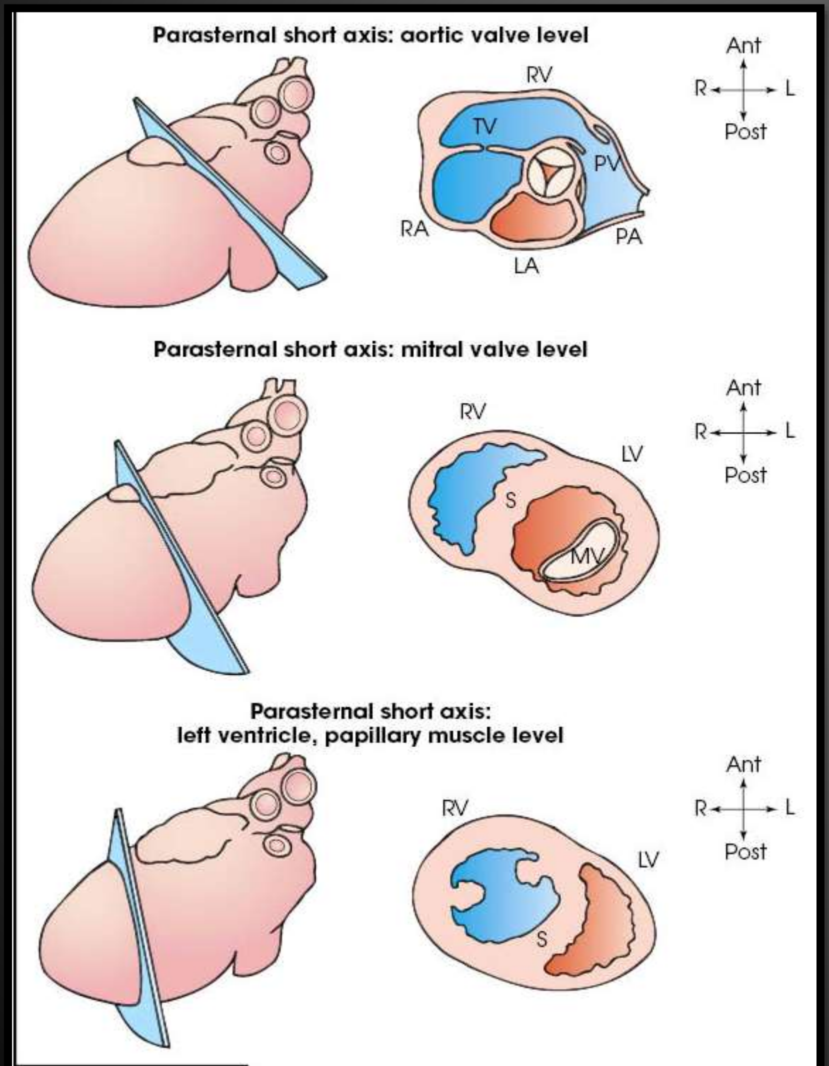
Anatomy: Heart in Long Axis

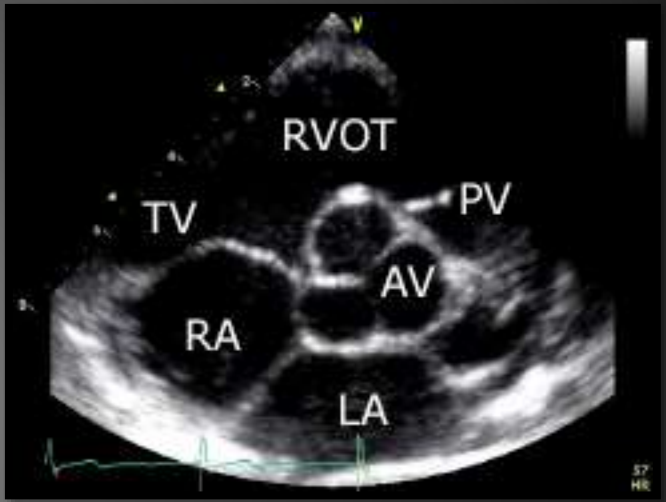






Anatomy: Heart in Short Axis





Thank you for your time and attention

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