

Ultrasound Physics & Knobology



Hong Kong College of Emergency Medicine



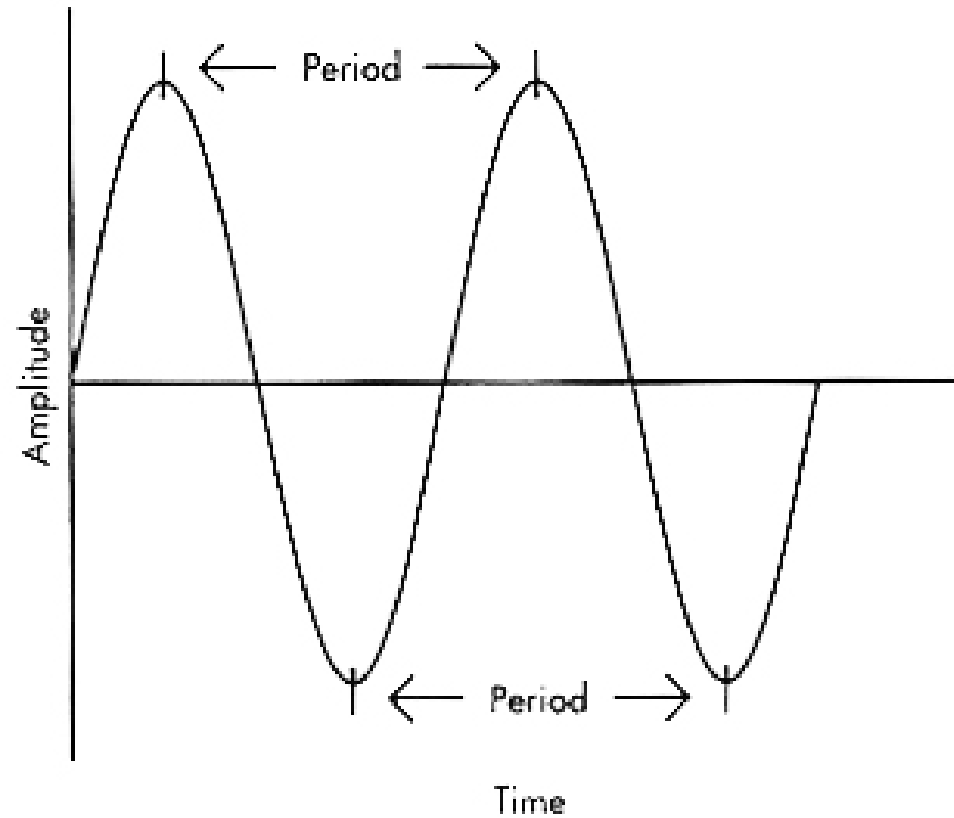
What is Ultrasound?

- Human sensitivity: 20 - 20,000Hz
- Ultrasound: > 20,000Hz
- Diagnostic Ultrasound: 2.5 - 14 MHz

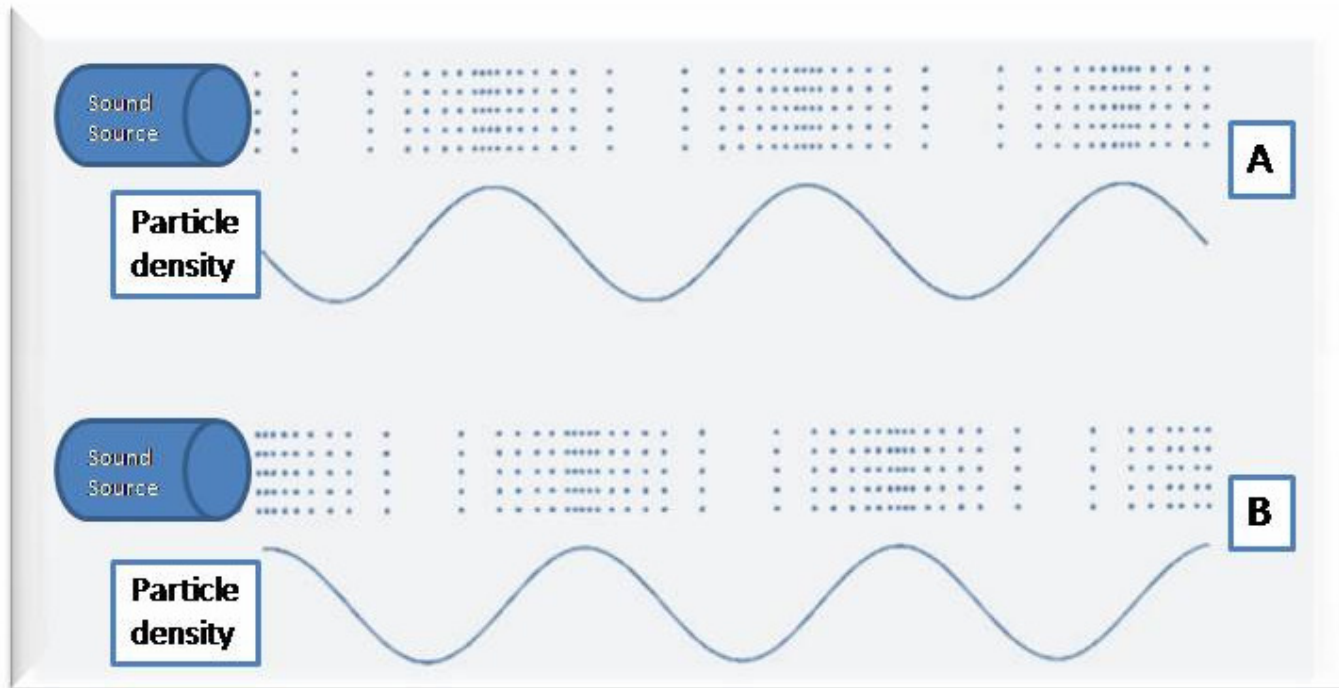


Definition/ Terminology

- Cycle
- Frequency: cycles per second
- Wave length
- Period
- Amplitude
- Compression - area of high density
- Rarefaction - area of low density
- velocity = $\lambda \times f$
= constant for a given medium



Variation in particle density at one point as a function of time



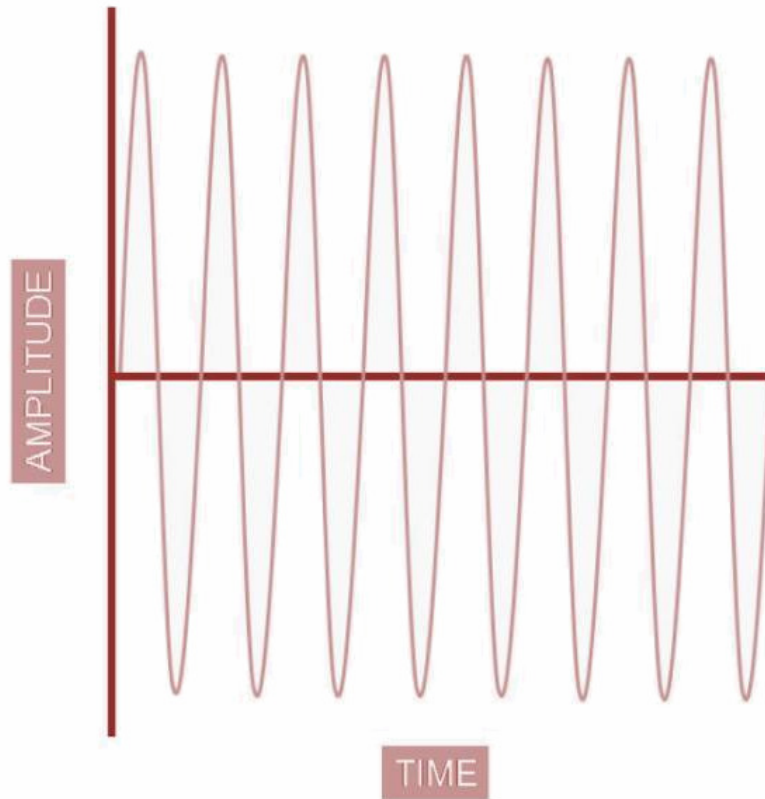
A, Initial observation.

B, After a short time, regions of high & low density are displaced to the right



Ultrasound Production

- Piezoelectric effect:
 - Crystals vibrate at given frequency when an alternating current is applied
 - Crystal acts as speaker and microphone
- Continuous mode:
 - therapeutic systems
 - continuous-wave Doppler (CW)
- Pulsed-echo mode:
 - all other applications

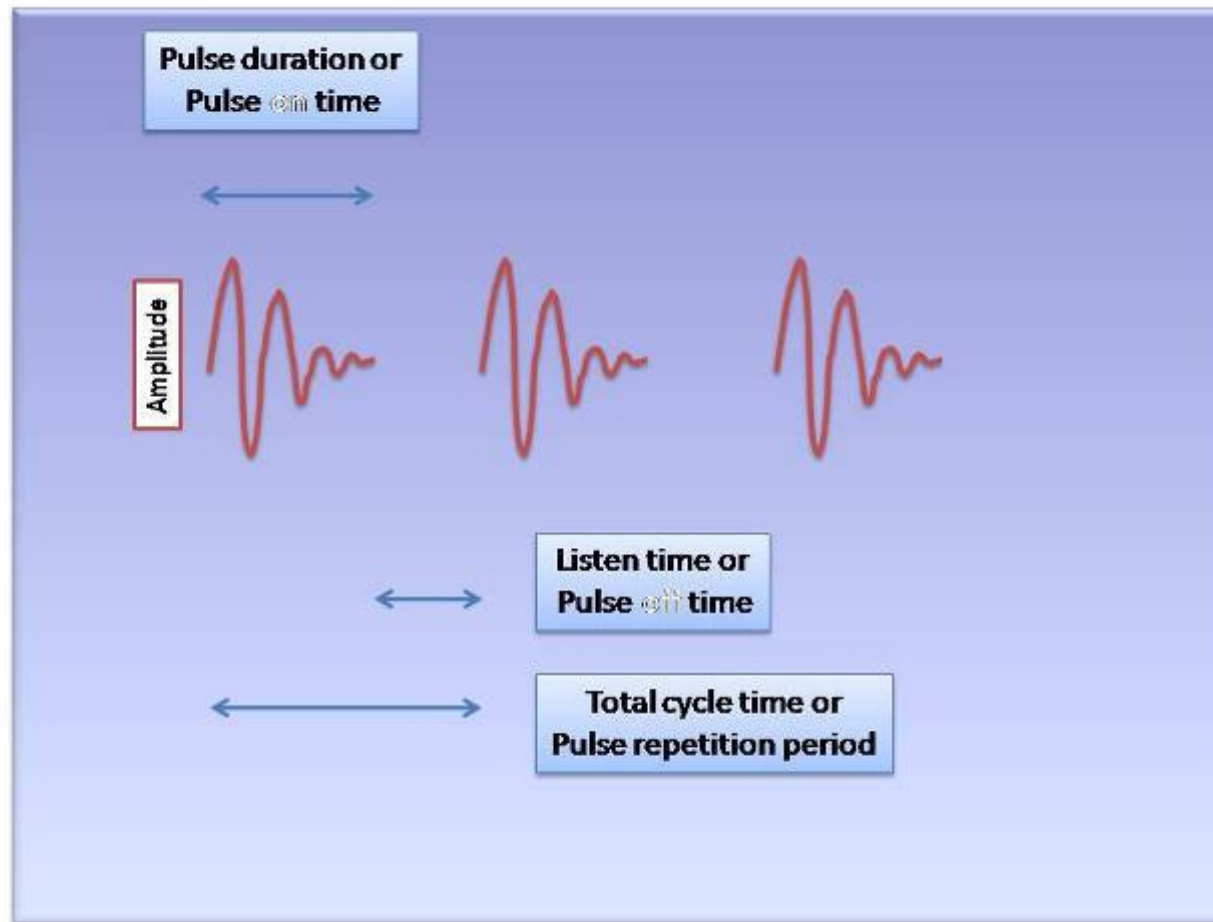


Continuous-wave output



Pulsed Echo

- Signal generation = only ~1% of the entire pulse cycle
- On times; off times
- Time of signal return proportional to distance traveled

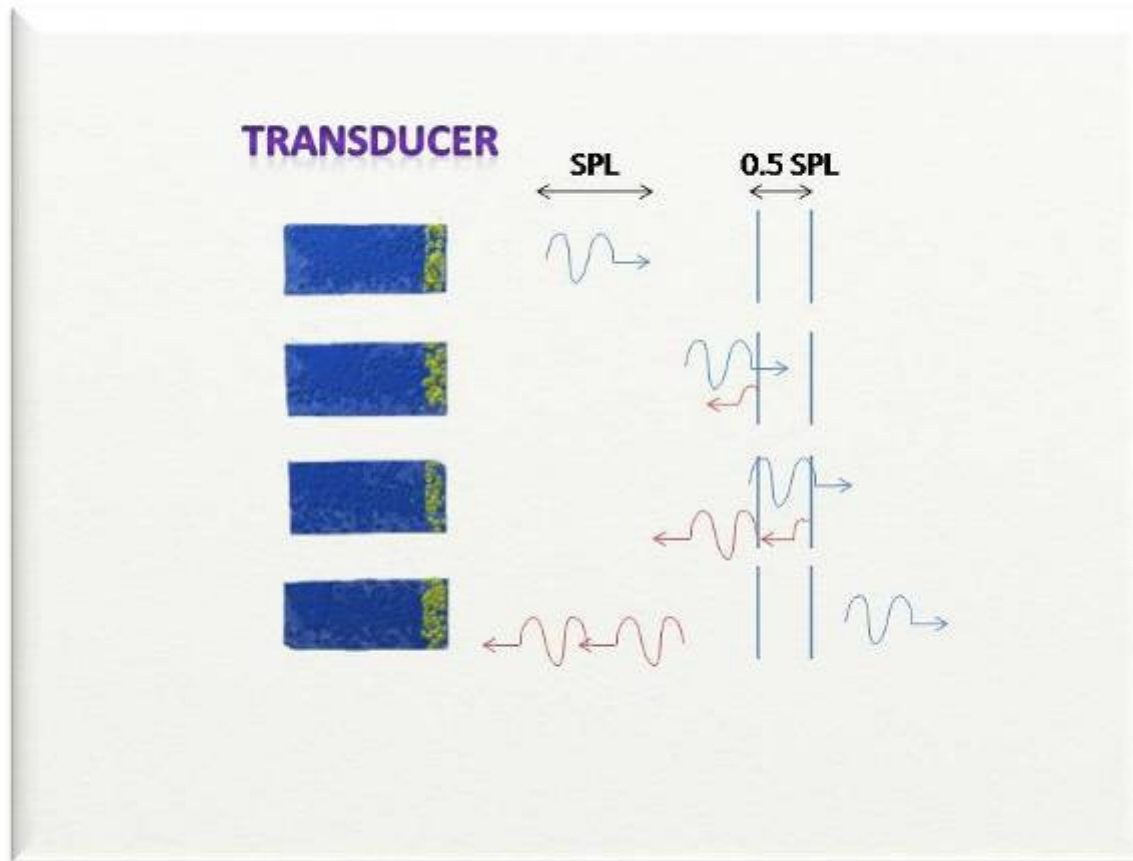


Pulsed wave output

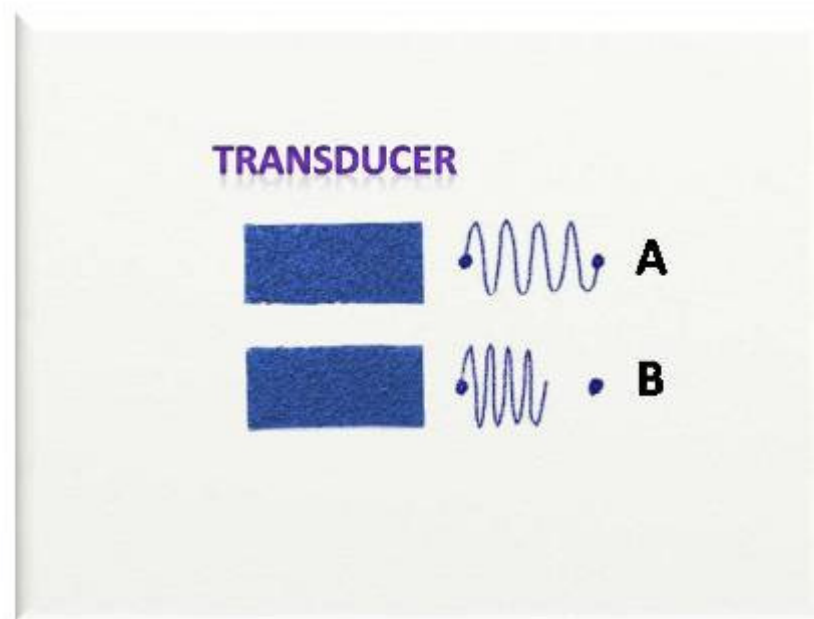


Pulsed Echo

- **PRF**: pulse repetition frequency
 - Very important in Color Doppler
- **SPL**: spatial pulse length
 - = wavelength x no. of cycles
- Maximal resolution = 0.5 SPL
 - The smallest distance between 2 points that USG can delineate



SPL with maximal resolution. Two objects (vertical lines) are separated by 0.5 SPL. The echo from each interface is shown by dashed lines. The objects are just resolvable.



Pulse length shortened by increasing the frequency.

A The four-cycle pulse from a low-frequency transducer includes both objects within the SPL.

B The four-cycle pulse from a high-frequency transducer has a shorter spatial pulse length and can resolve objects located more closely together.



Ultrasound Transmission

- 1540 m/s
 - Velocity assumed the same for all tissue in calculation (which is not totally true)
- Acoustic impedance
- Attenuation
- Reflection
- Refraction
- Scatter: objects irregular or smaller than the ultrasound beam



Windows

- Getting a good acoustic window is important for scanning accuracy and image quality
- Solid organ or fluid filled area
 - Liver
 - Urinary bladder
 - Spleen
 - Fluid filled stomach (for pancreatic scan)



Resolution

- Ability to delineate between two different objects
- **Axial resolution:**
 - high frequency
 - = shorter SPL
 - = better axial resolution but lower penetration



Resolution

■ Lateral Resolution

- Sound beam: width of the crystal
- Compressed down the pathway
- **Near field**
- **Focal zone**: best lateral resolution
- **Far field**
- **Dead zone**: distance between the transducer face and the first identifiable echo



Resolution

■ Temporal Resolution

- Frame per second
- Multiple focal zones
 - decreases frame rate
 - decrease temporal resolution

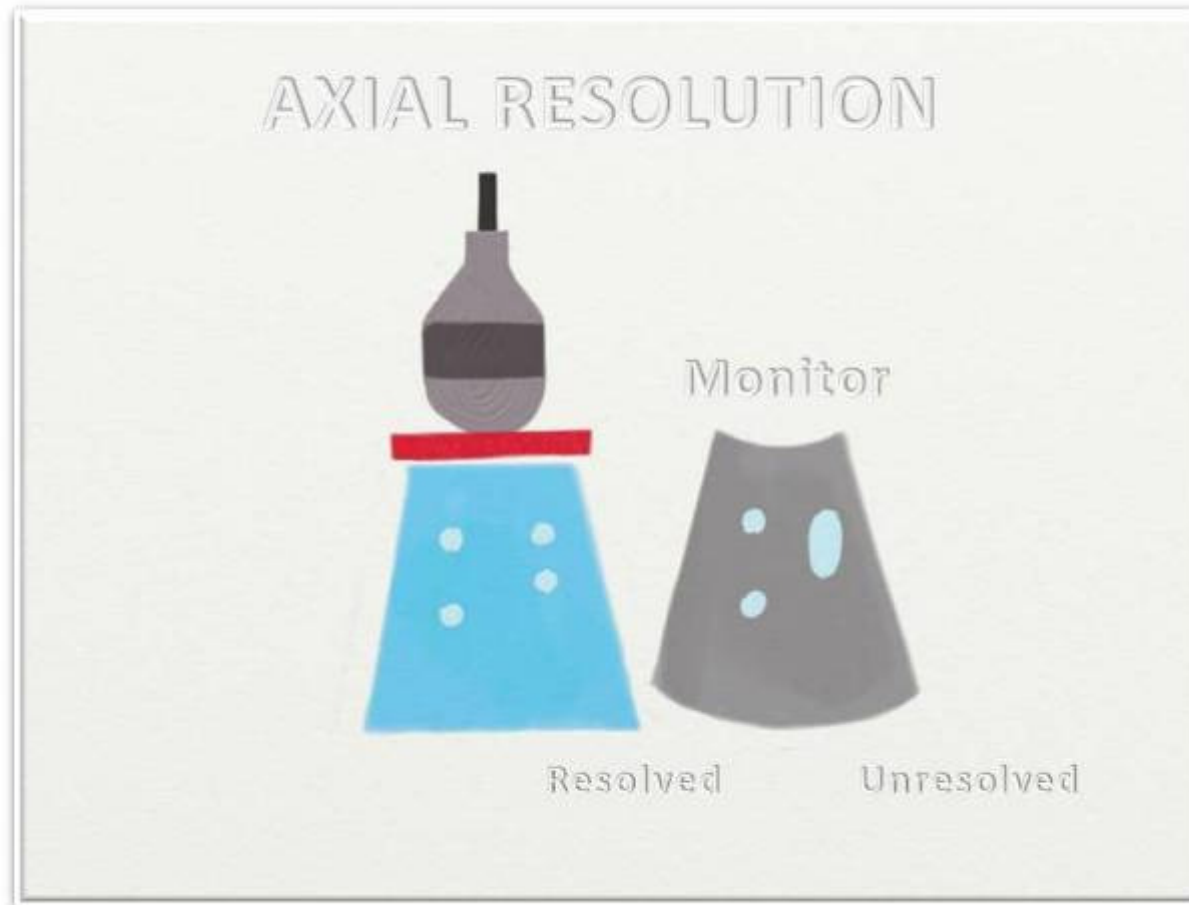


Diagram illustrating Axial Resolution

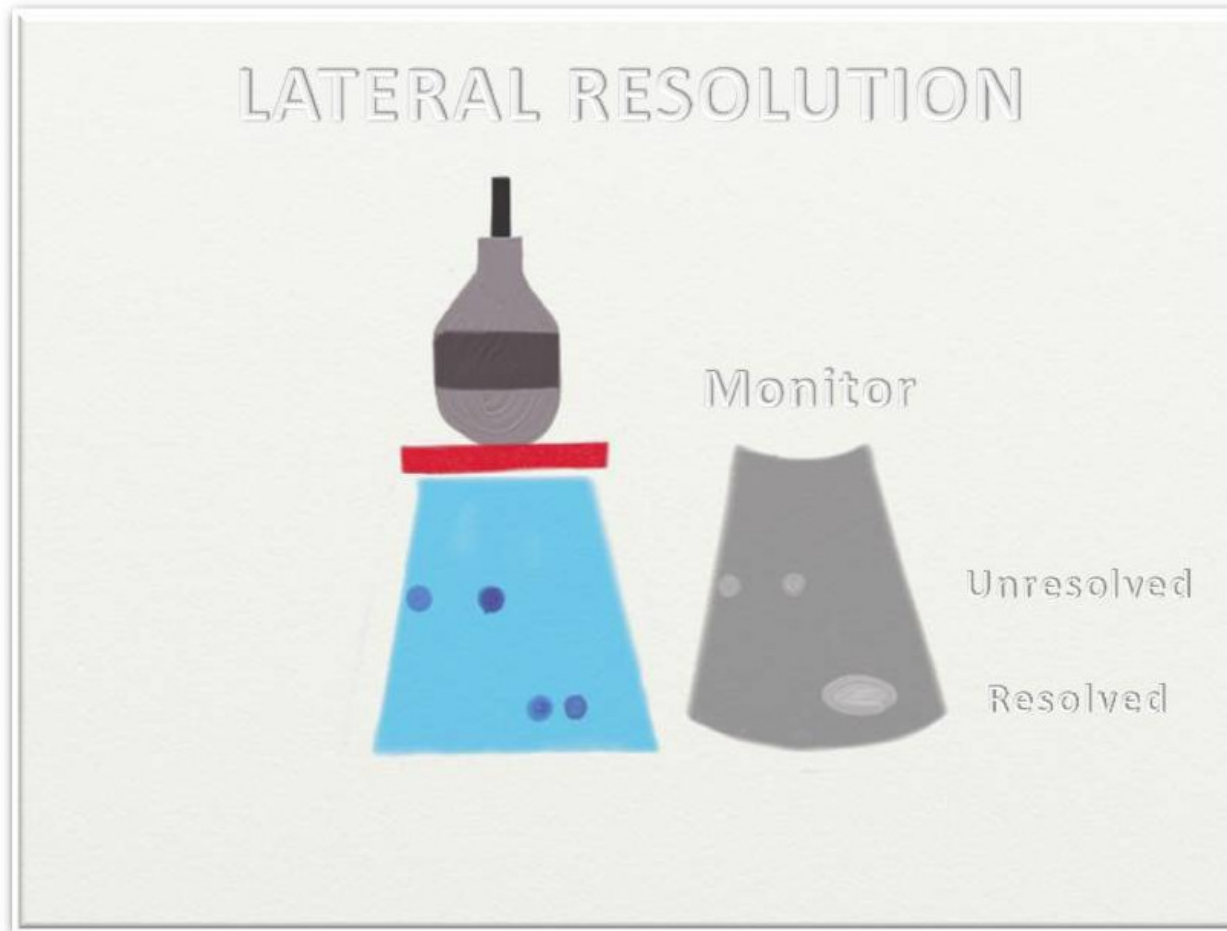


Diagram illustrating Lateral Resolution

Modes

- A mode: amplitude
- B mode: brightness
- Real time (frames/sec)
- M mode: motion





Doppler Ultrasound

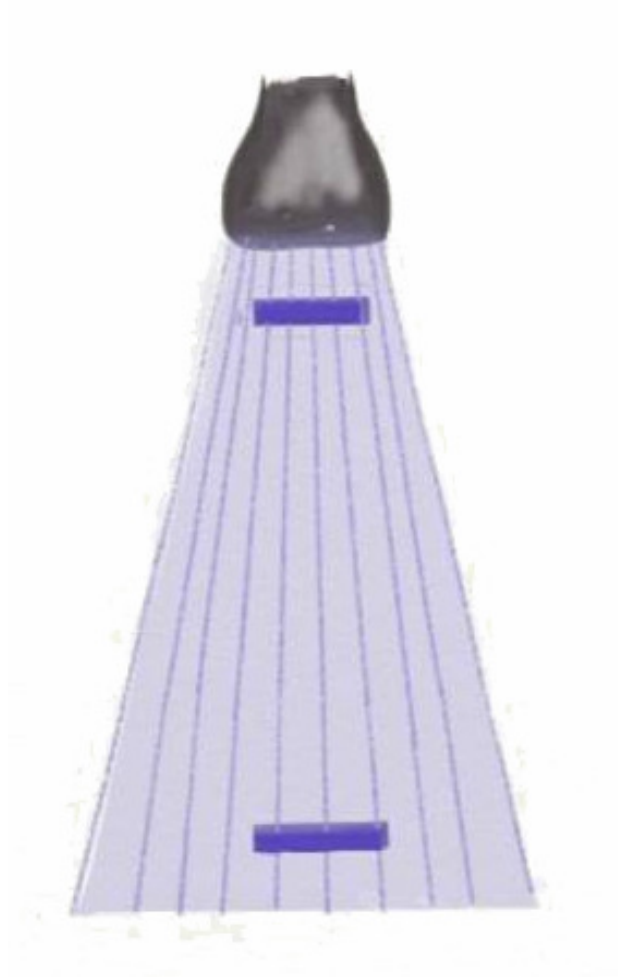
- Continuous wave (CW)
 - Seldom used, not a/v in most AED machines
- Pulsed wave (PW)
- Color Doppler
- Duplex Doppler
 - Putting Color Doppler on top of Grey-scale B mode
- Power Doppler



Transducers

■ Formats

- linear - rectangular field of view
- sector - pie-shaped field of view

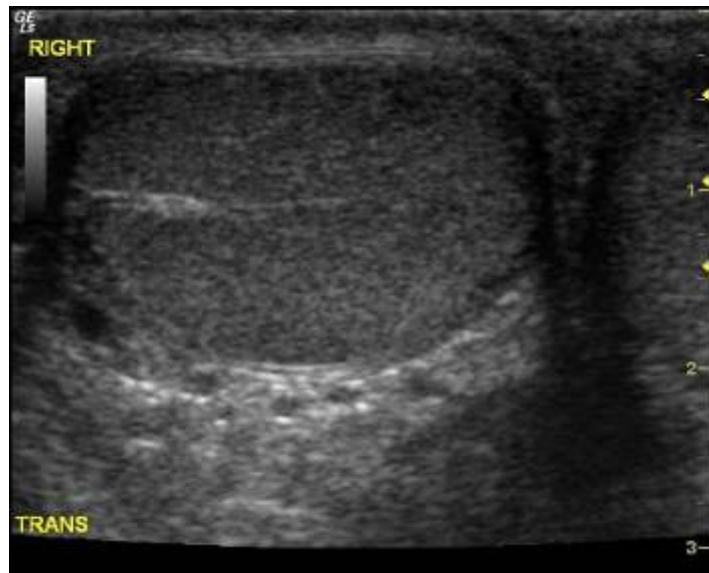


In sector scanning, the resolution becomes poorer at increasing depth.



Transducers

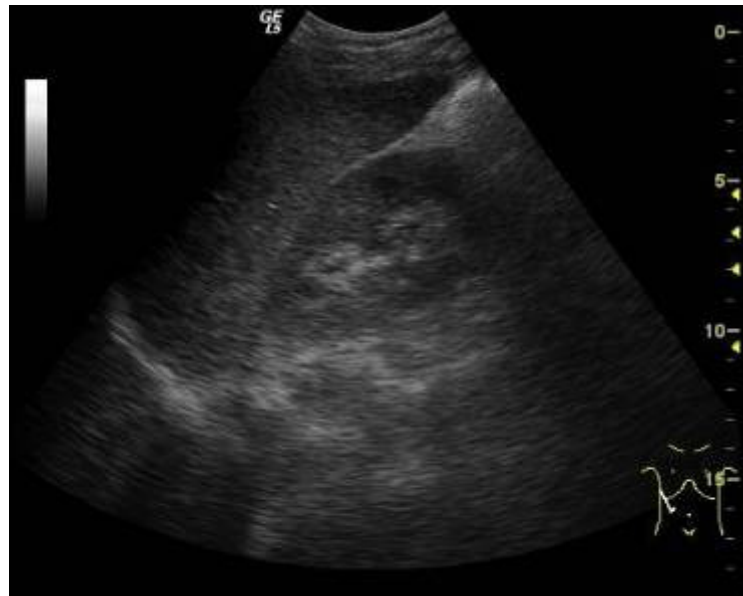
- Mechanical Probe: seldom used now
- Electronic Probe:
 - Linear array transducers
 - piezoelectric elements linearly arranged
 - sequentially activated to produce an image
 - Phased array transducers
 - smaller scanning surface (foot print)
 - good for echocardiography
 - more expensive
 - elements are activated with phase differences to allow steering of the ultrasound signal



Linear array image of testicle



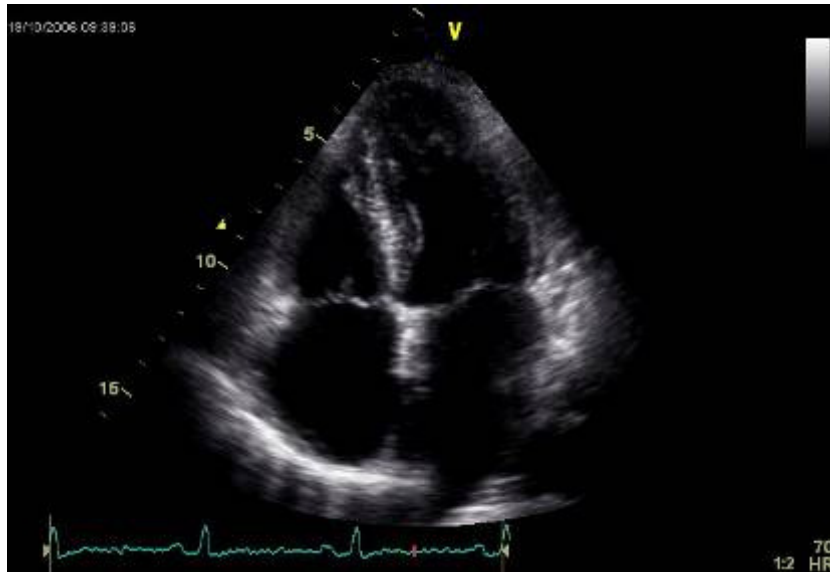
Linear array transducer



Convex array image of RUQ



Convex array transducer



Phased array (cardiac) image



Phased array transducer



Scanning Skills

- Try different windows
- A lot of gel
- Transducer movements:
 - Rotate
 - Angle (Tip-toe)
 - Pivot (fan-shaped movement)
- Transducer placement basics:
 - longitudinal view
 - transverse view
 - coronal view



Knobology

- Power
- Gain
- TGC; DGC; STC
- Dynamic range
- Depth
- Zoom/magnification
- Freeze
- Calculations
- Print





Image Optimization

Adjust the following in order:

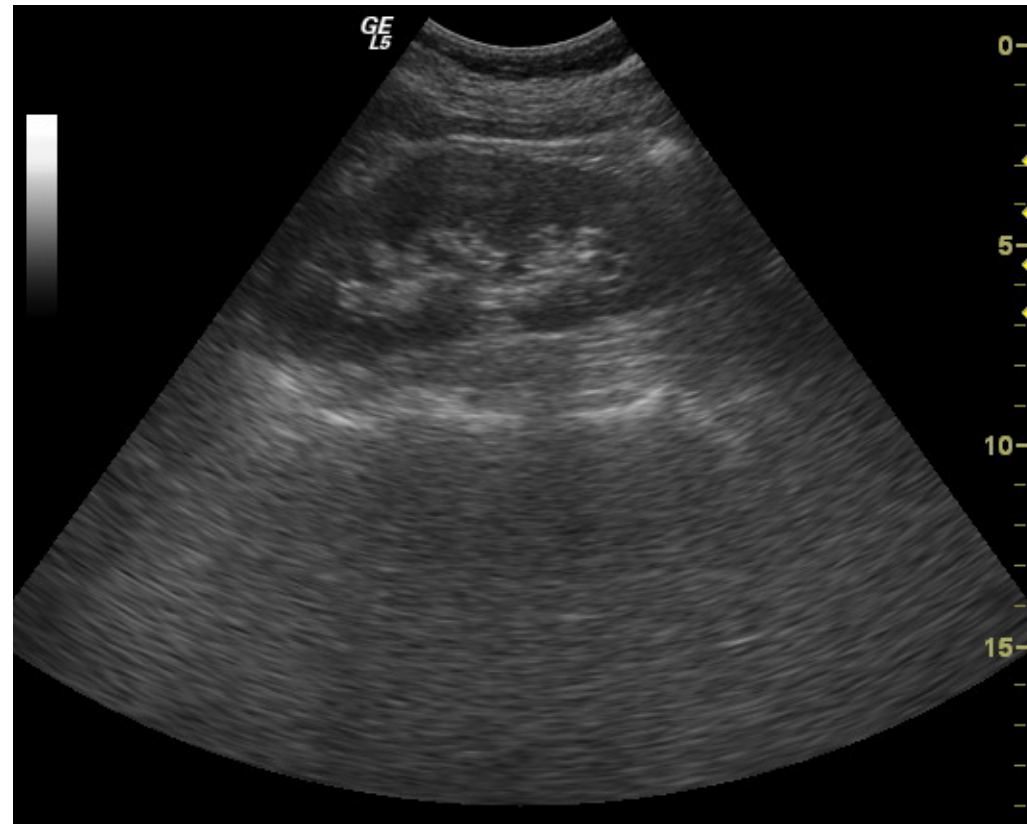
- **Depth**
- **Focus**
- **TGC**
- **Zoom**
- **Gain**
- **Dynamic Range (contrast)**



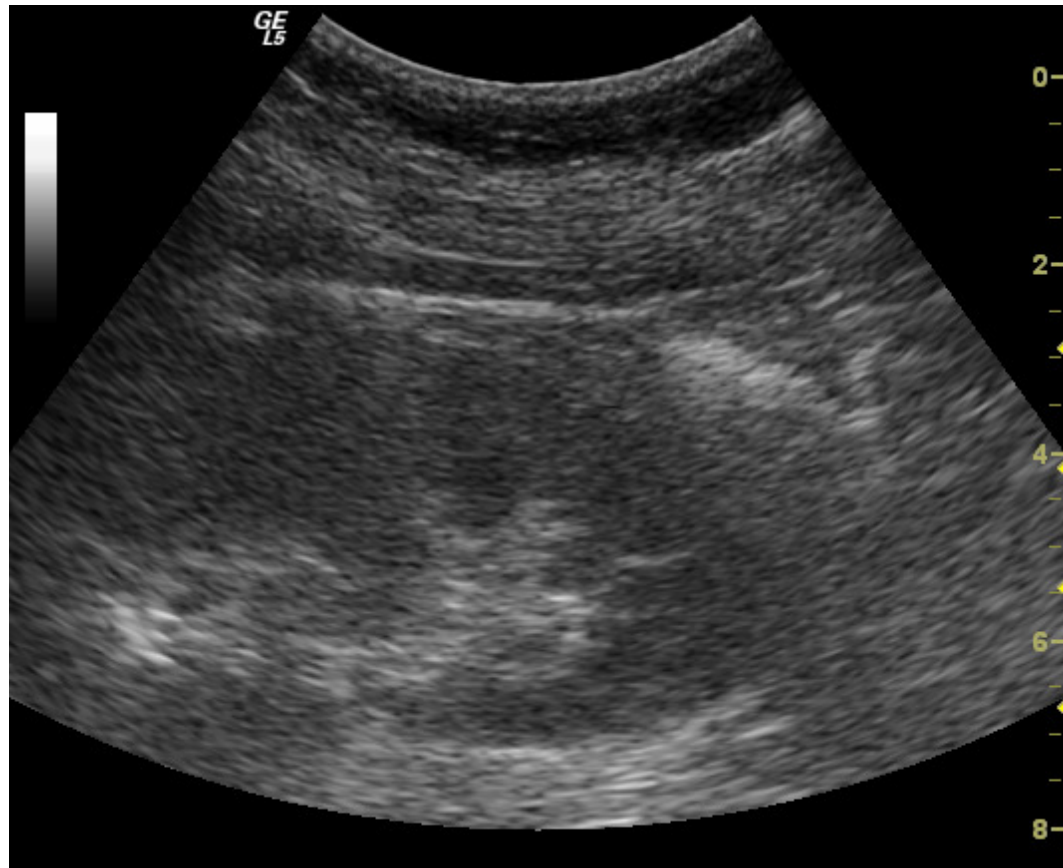
Depth

- Start with higher “Depth”
- Decrease “Depth” to put area of interest at $\frac{3}{4}$ depth of screen
- Leave a small area behind to observe useful artifacts e.g. shadowing, enhancement

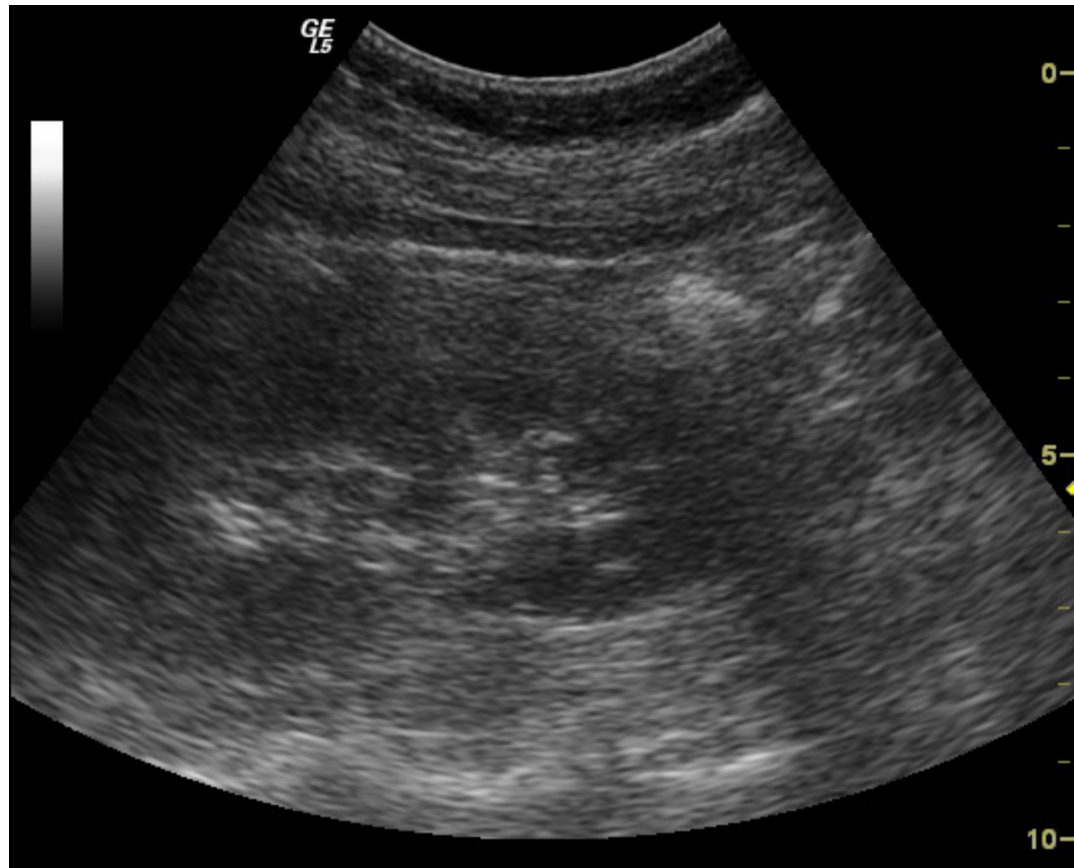
Depth (too much !)



Depth (too little !)



Depth (just right !)



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34

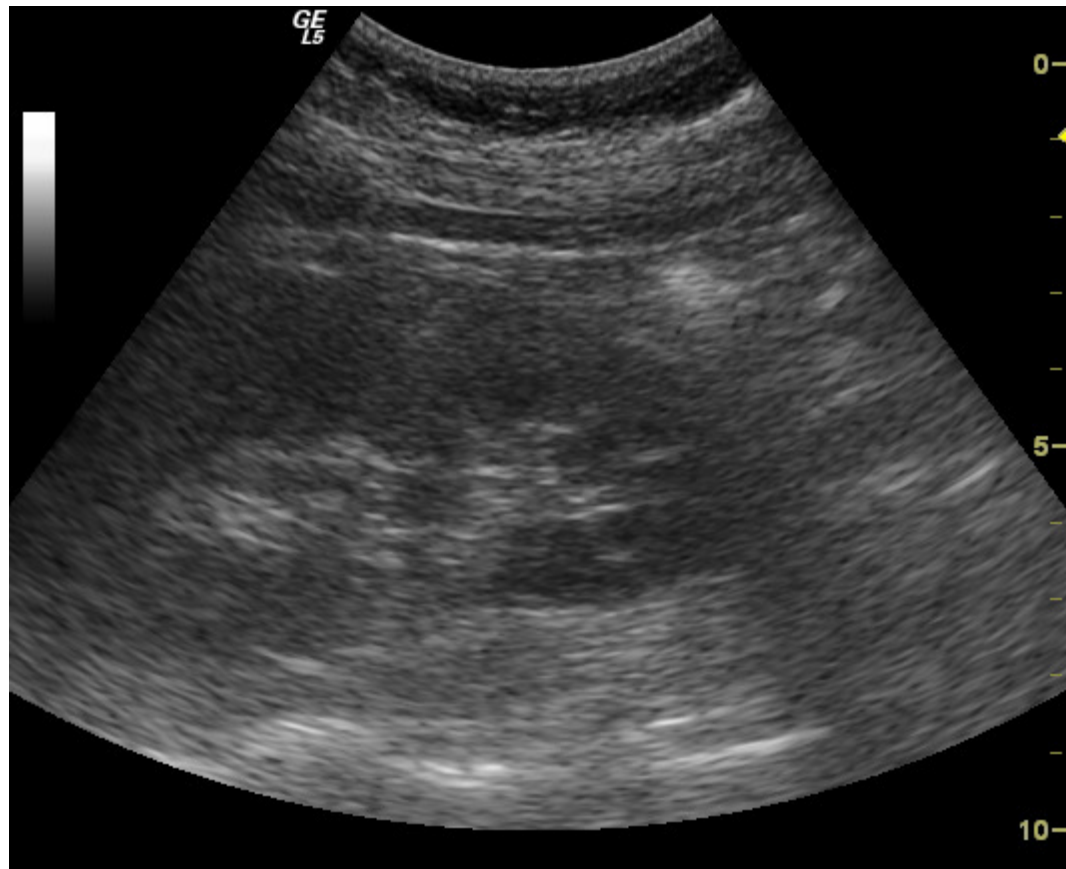


Focus

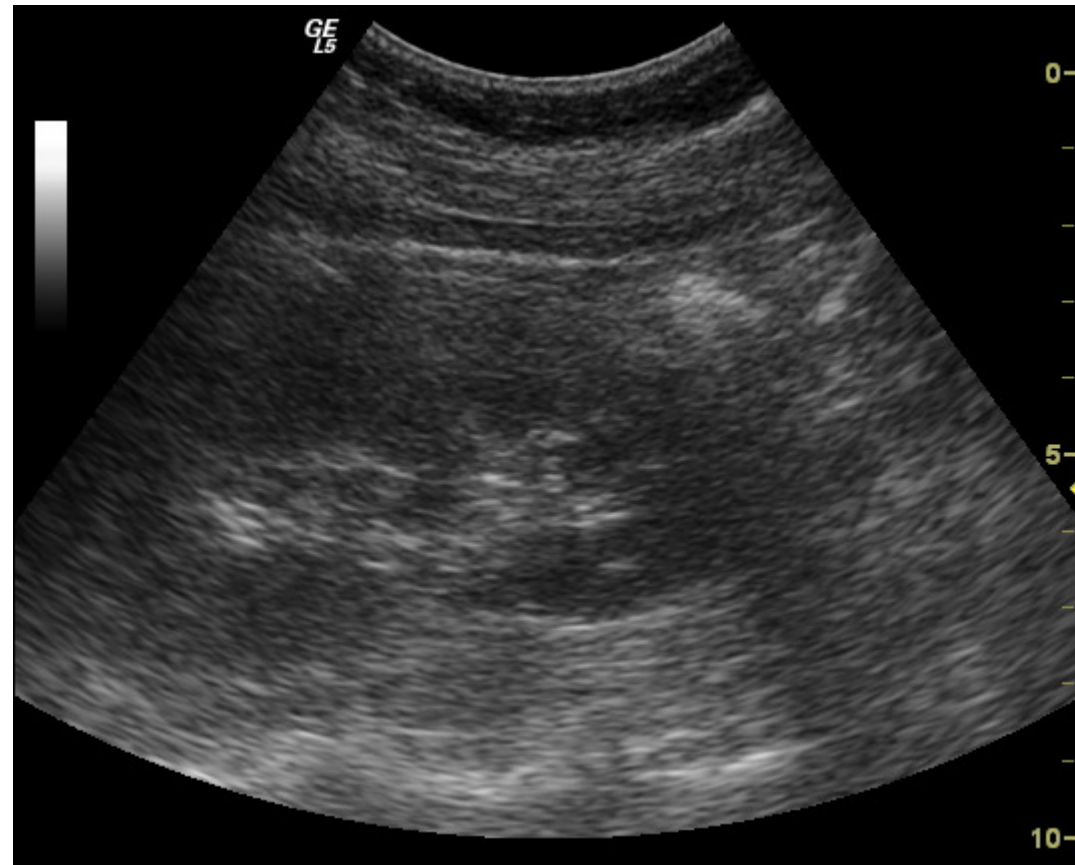
- Focal zone = best lateral resolution
- Adjust focus to the level of the point of interest
- Most modern machines can have multiple focal zones
- Increase number of focal zone → decrease frame rate



Focus (out focus !)



Focus (good !)



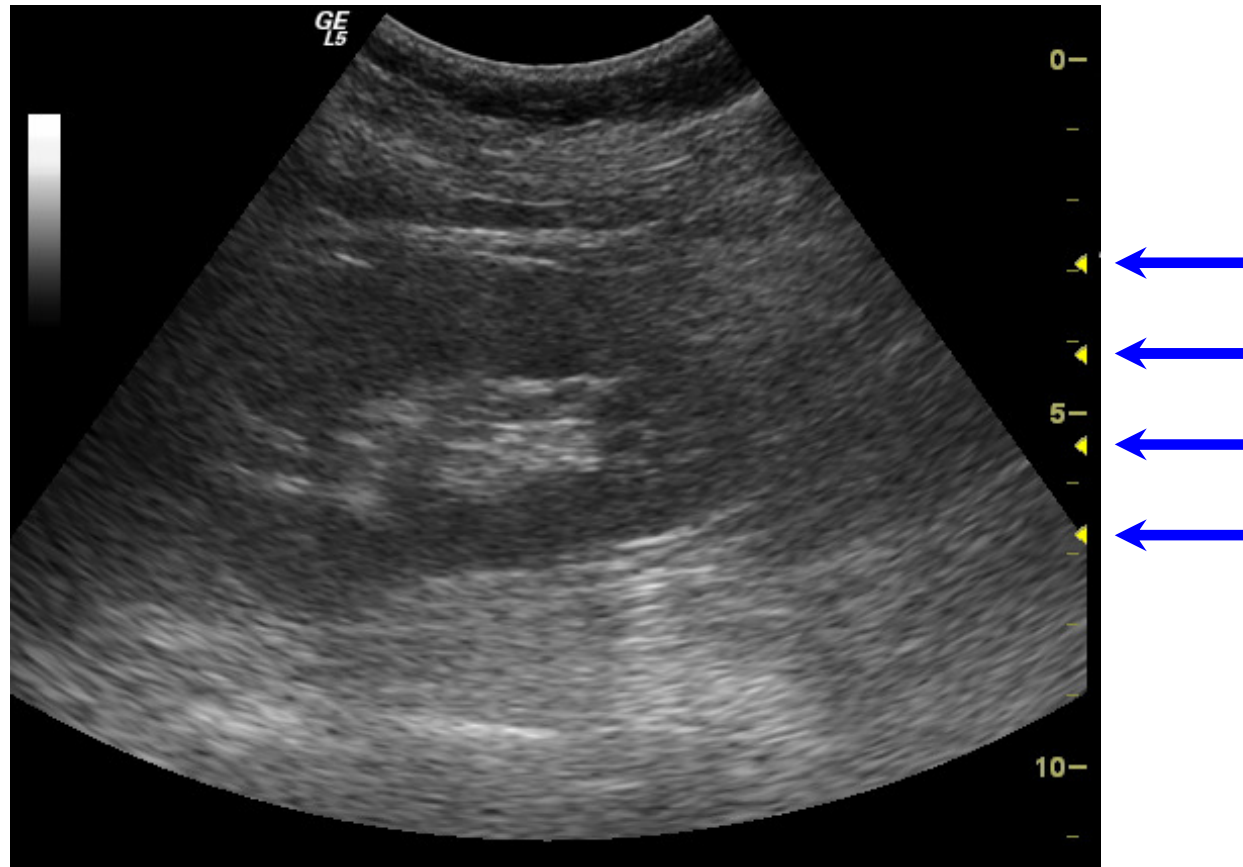
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Focus (multiple !)





TGC

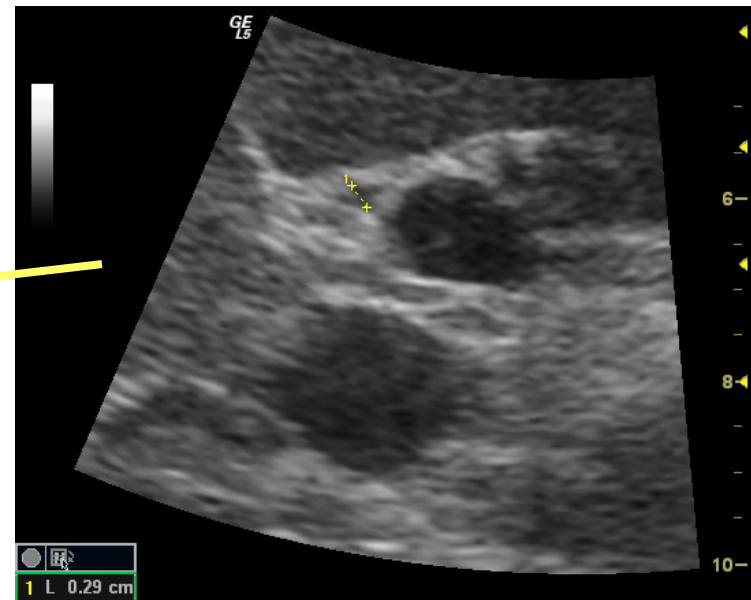
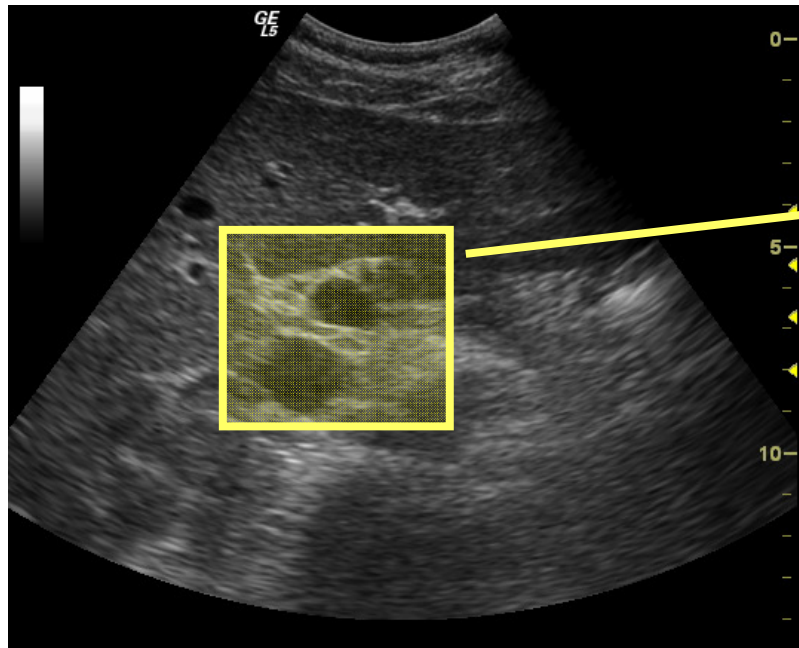
- Adjust TGC to obtain a smooth grey-scale picture
- Transit of TGC knobs should be gradual
- $TGC = DGC = STC$
 - TGC: time gain compensation
 - DGC: distance gain compensation
 - STC: spatial time compensation

Zoom



- Zoom in to magnify point of interest
- Write-zoom: improve image quality
- Read-zoom: only magnification
- Useful situation:
 - Measurement of CBD
 - M-mode documentation of foetal pulsation

Zoom



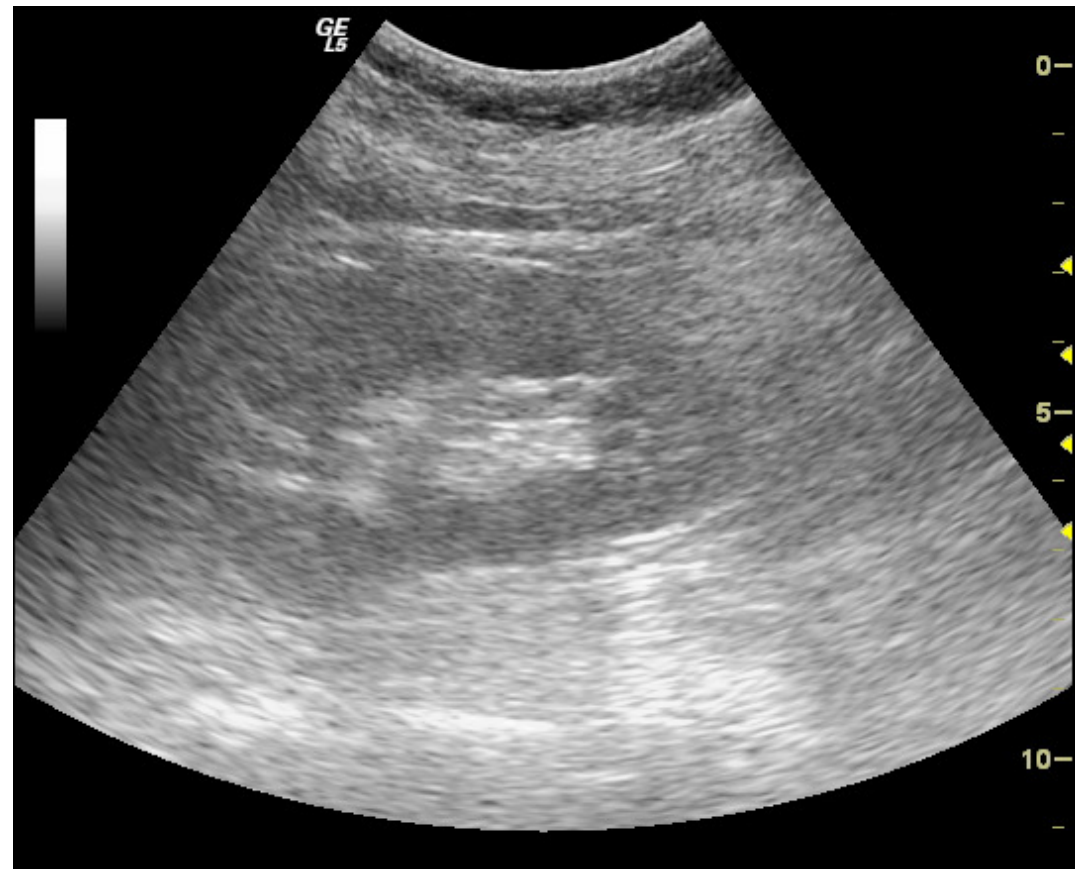


Gain

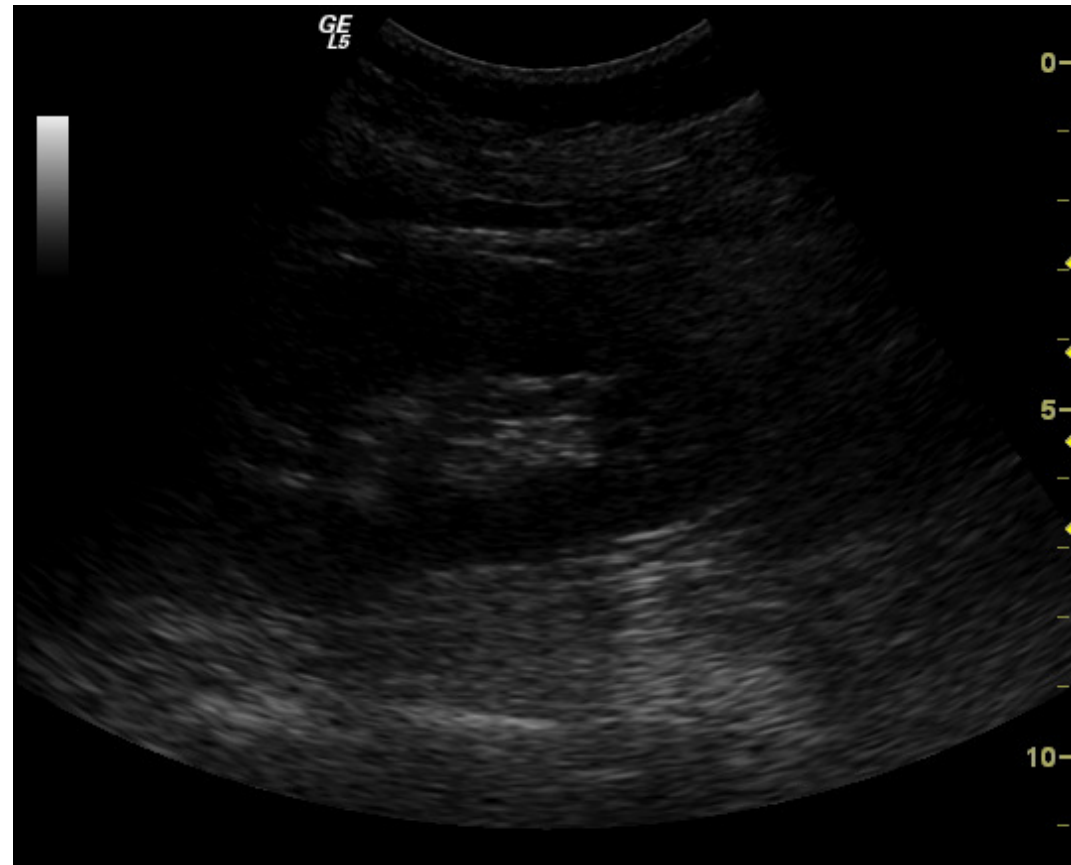
- Optimize gain to obtain most details
- Most beginners use too high gain
- High gain can obscure many details



Gain (too high !)



Gain (too low !)

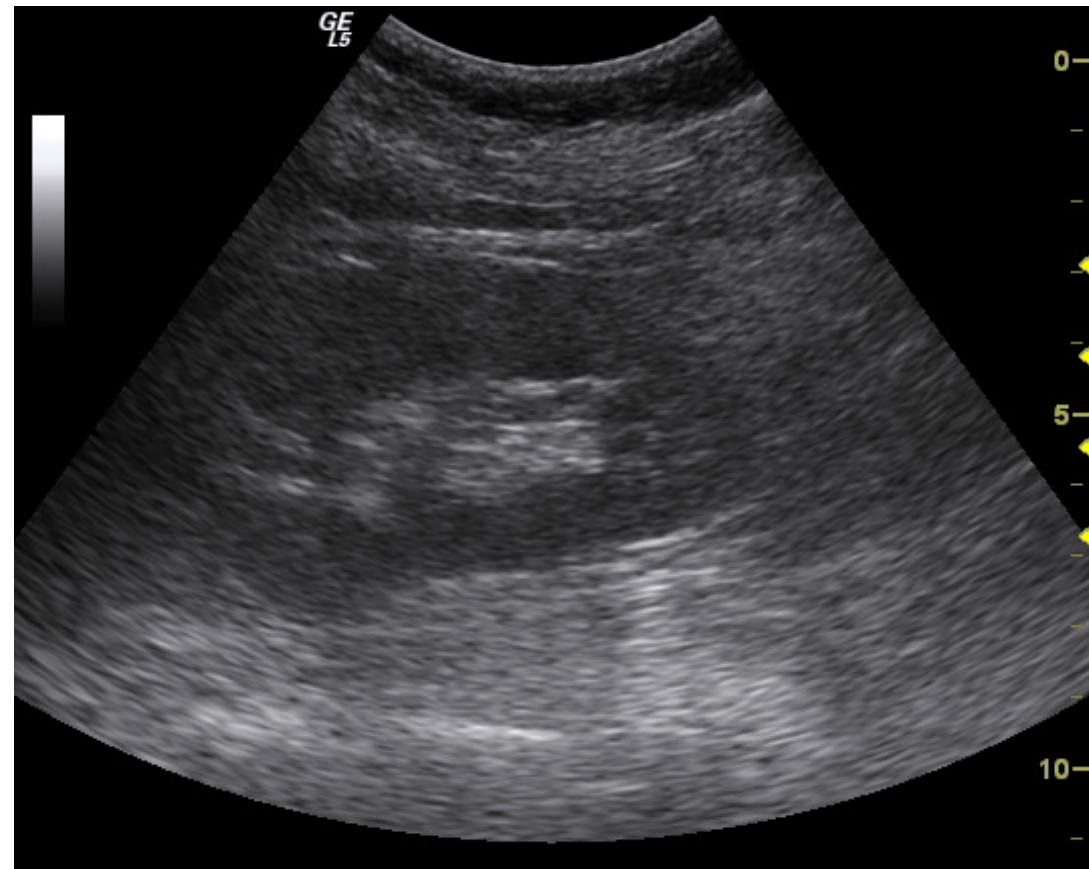


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Gain (that's right !)

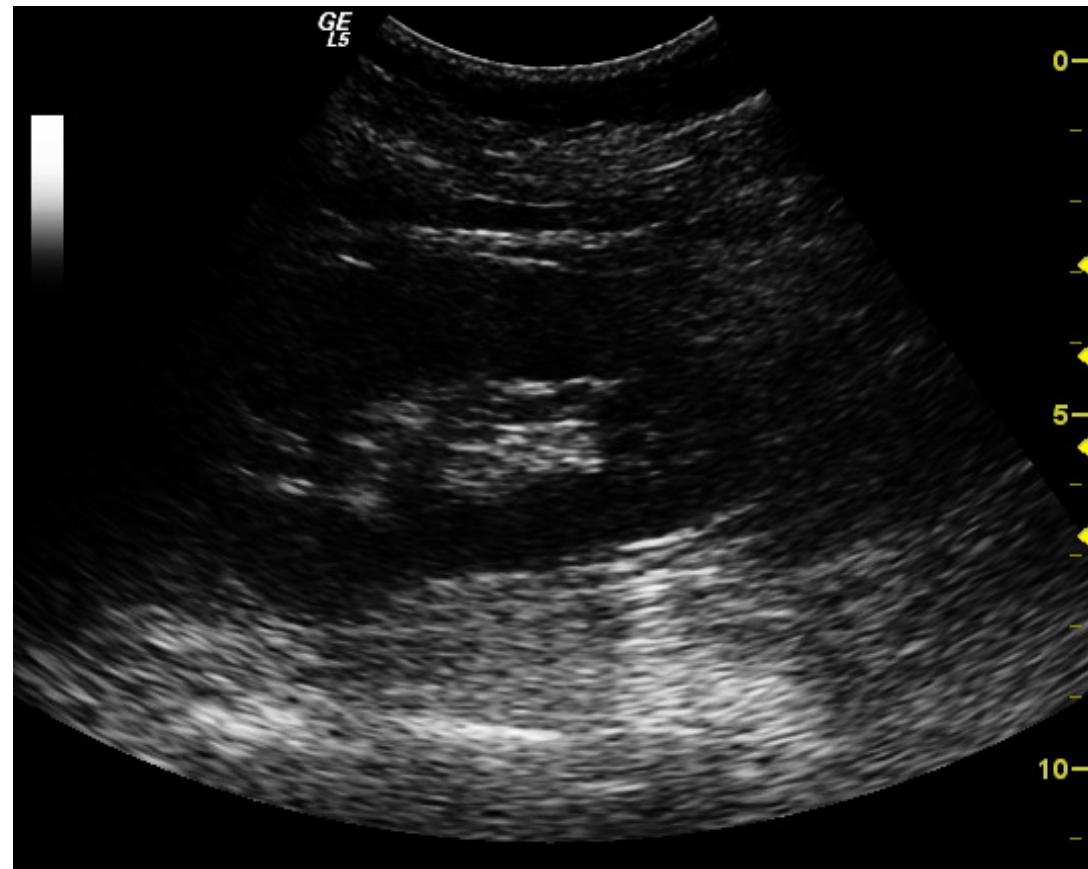




Dynamic Range

- How white is white and how black is black?
- Adjust Dynamic Range for the contrast
- High “Dynamic Range”
= Low “Contrast”

Dynamic Range (too low !)



Dynamic Range (too high !)

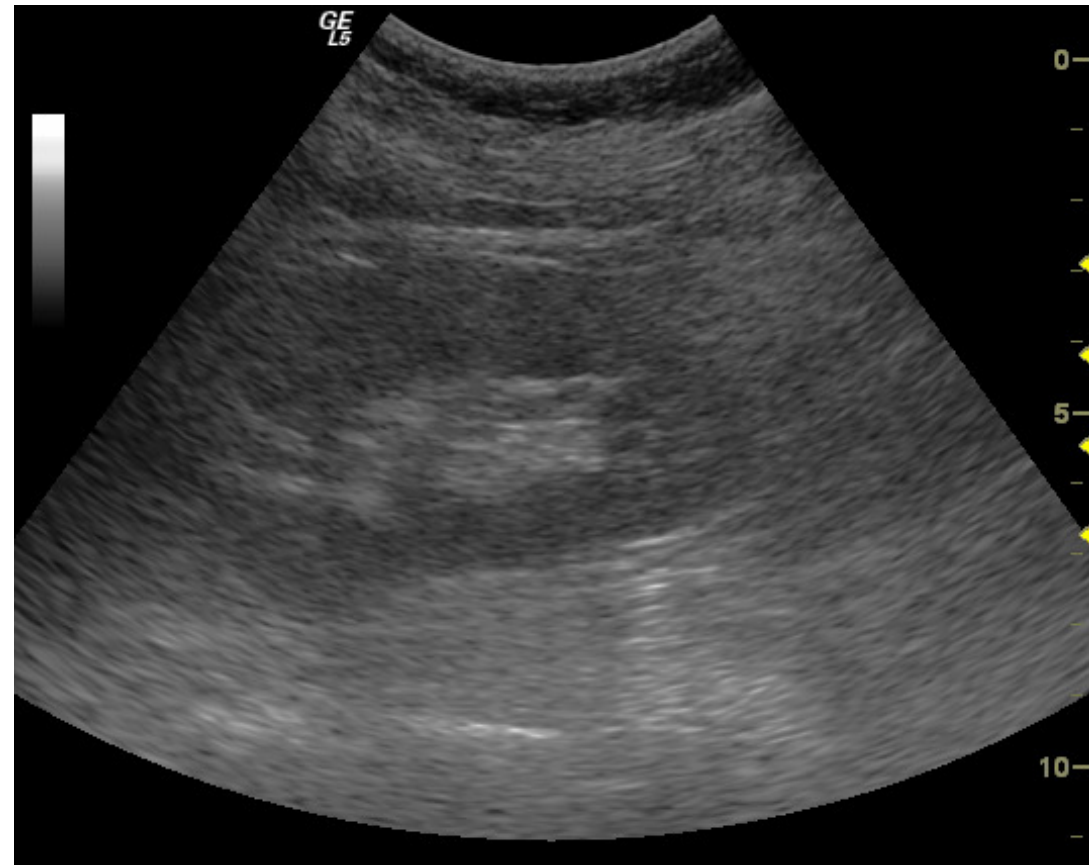




Image Descriptions

- Anechoic
- Echogenic
- Hyperechoic Vs Isoechoic Vs Hypoechoic
- Interface
- Noise
- Mirror image
- Shadow
- Cystic Vs Sonolucent



Artifacts

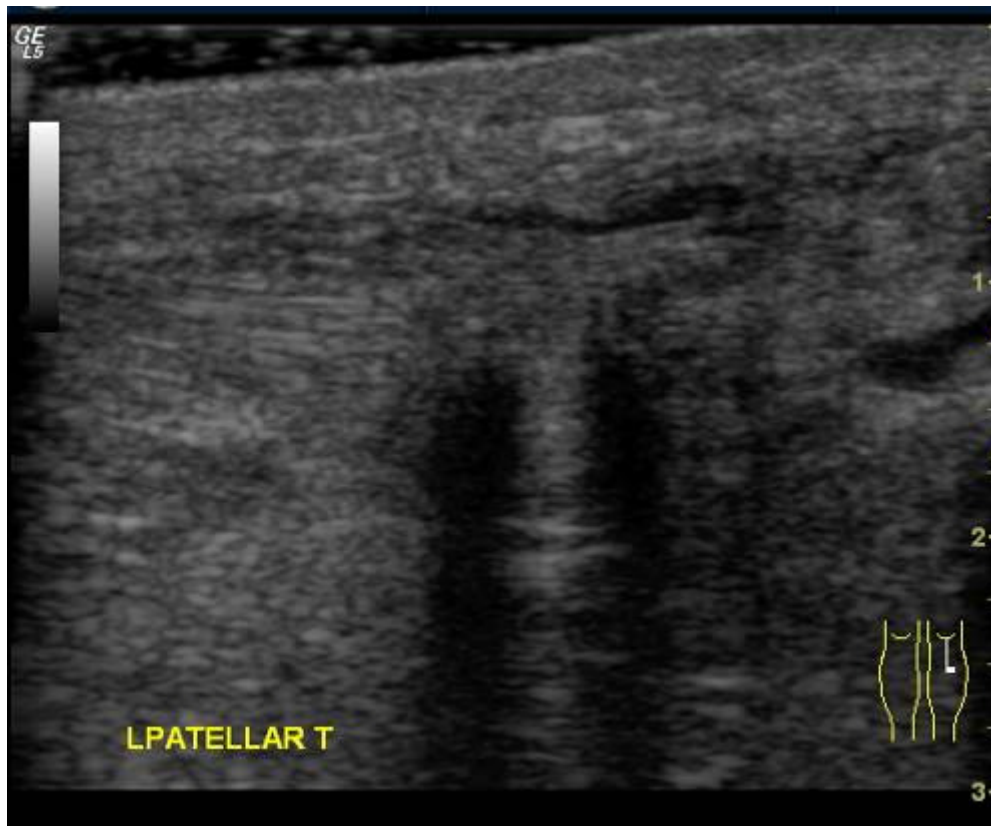
- Shadowing
- Enhancement
- Edge artifact
- Side-lobe artifact
- Reverberation
- Comet tail

Shadowing and Enhancement



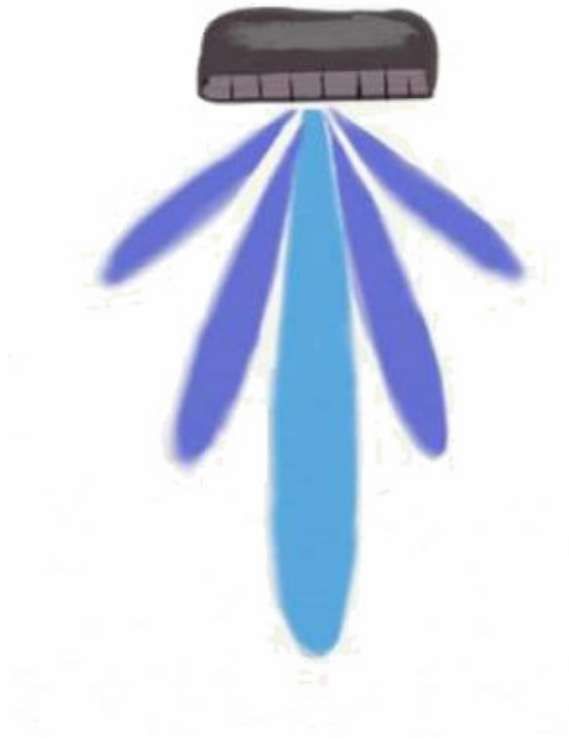
Longitudinal image of the gallbladder. Shadowing artifacts are caused by gallstones. Enhancement is seen as a result of the fluid-filled gallbladder.

Edge Artifact



Refraction artifacts at the edges of ruptured patellar tendon.

Side-lobe Artifact

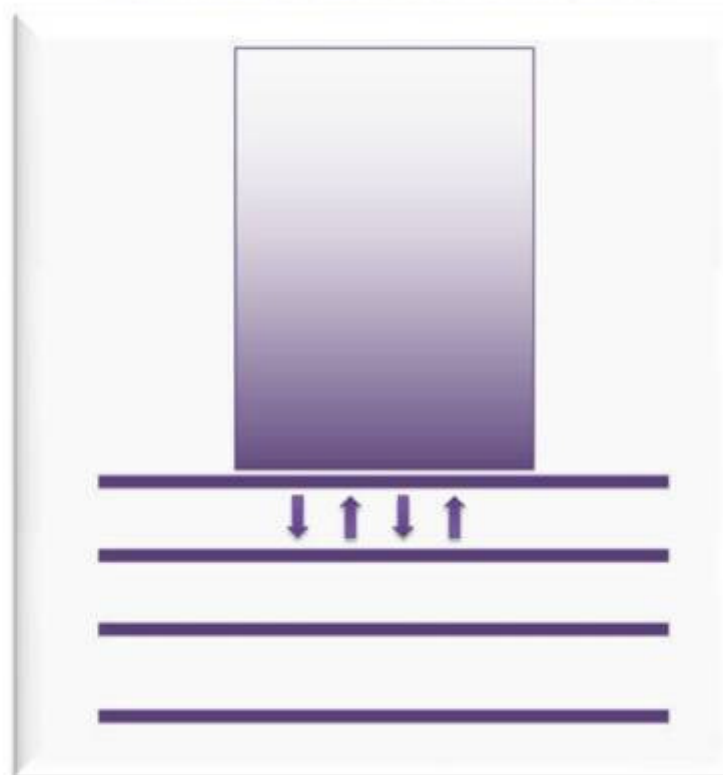


Side lobes (*shaded regions*) at various angles with respect to the main beam.

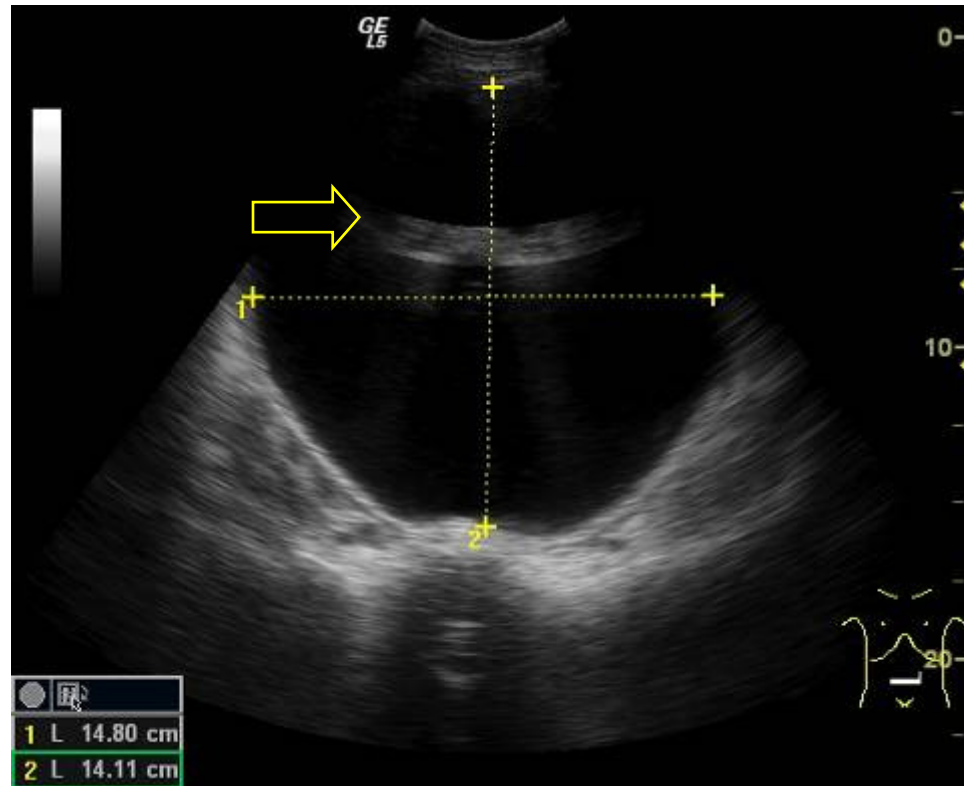


Reverberation Artifact

REVERBERATION



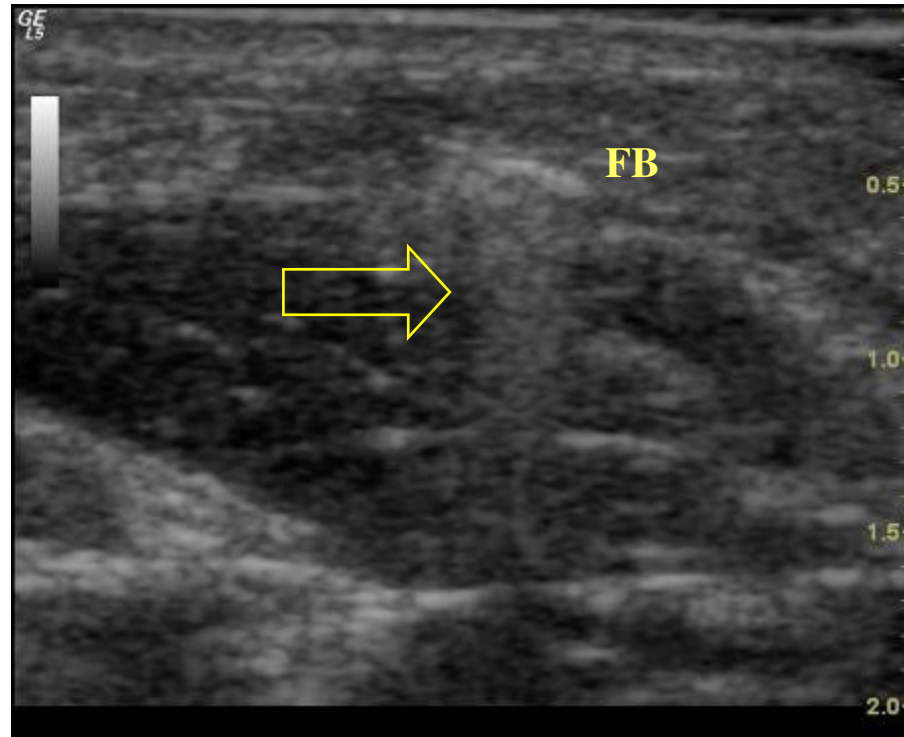
Reverberation Artifact



Reverberation artifact in the bladder



Comet Tail Artifact



Comet tail artifact (*arrow*) at the back of a metallic FB.

Guide to Image Acquisition



- Relearn anatomy
- Correct machine and transducer
- Master the gain, power, and TGC buttons
- Maximize the gain before increasing the power
- TGC should be smooth
- Boundaries of organs should be visualized
- Go from wider view and zoom in
- Acquire images in at least two planes



Infection Control

- Wipe off and disinfect the transducer after use
- Wear glove on the scan hand
- Cover TVS probe with condom
- Dispose used condom appropriately



Maintenance

■ DO

- switch off machine after use
- ‘freeze’ when not scanning
- handle transducers with care
- clean transducers after use with soft towel or tissue paper
- disinfect transducers after use



Maintenance

■ Don't

- Drop, shock or knock transducers
- Disconnect or connect transducers when power is 'on' (Hot plug is OK on some new machine)
- Leave extension cord on the floor to be rolled over by the machine
- Leave extension cord in tension or in acute angles. The connecting points will be disrupted.



Biological Effects

- Cavitation
 - rarefaction phase
 - liquid to gas
 - stable Vs collapse
- Heat production
- There is so far no firm evidence of Bio-hazard of Diagnostic Ultrasound to human

Biological Effects



■ AIUM statement on clinical safety 1983

No confirmed biological effects on patients or instrument operators caused by exposure at intensities typical of present diagnostic ultrasound instruments have ever been reported. Although the possibility exists that such biological effects may be identified in the future, current data indicate that the benefits to patients of the prudent use of diagnostic ultrasound outweigh the risks, if any, that may be present.



Biological Effects

- **ALARA** principle:

As Low As Reasonably Achievable

The End

