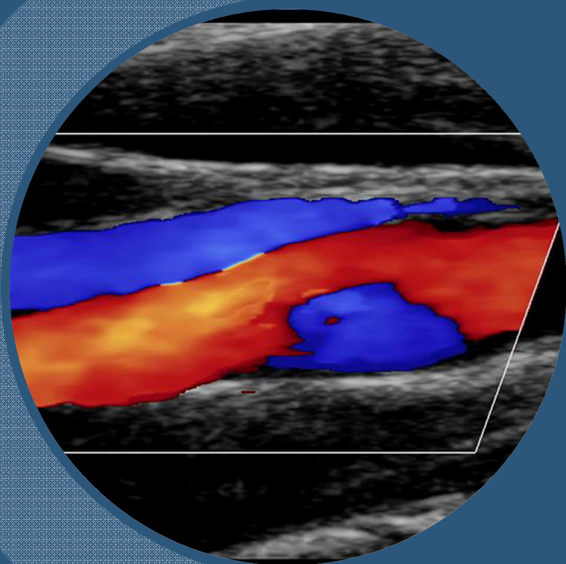

Basics of Physics in Vascular Imaging

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OBJECTIVES

- By the end of this presentation, you will be able to
  - Describe the basic principles of ultrasound (US) physics, including parameters of sound, pulsed-wave and continuous-wave operation, and transducers
  - Describe spectral and color Doppler controls and optimization, and recognize characteristics of spectral Doppler waveforms
  - Identify artifacts in the US image
  - Describe the principles of ALARA and bioeffects of US imaging

FINANCIAL DISCLOSURES

- Royalties from Wolters Kluwer, Davies Publishing, and McGraw-Hill Publishing

BASIC PRINCIPLES OF SOUND

Current ("old") principles of ultrasound
Pulse-echo principle

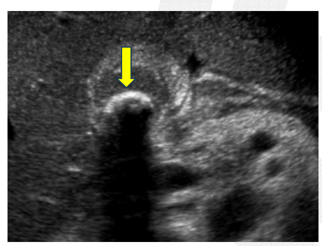
- **Pulse echo principle** of sound
  - Send out a pulse and wait for echoes to return before sending out next pulse
  - Creates one scan line
  - Scan lines make one image called a **frame**

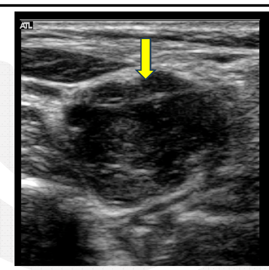
TERMINOLOGY

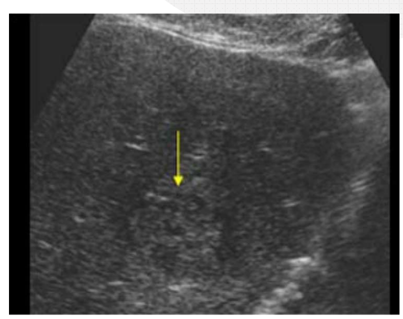
- **Grayscale** – also called 2D or B-mode
  - Presents anatomic information in shades of gray
- **Doppler**
  - **Pulsed-wave (PW) spectral Doppler** – allows you to select a vessel to sample and obtain flow velocity measurements
  - **Color Doppler** – PW technique that shows direction of flow as a color
  - **Power Doppler** – Color technique used for very slow flow or hard to find vessels
  - **Continuous-wave (CW) spectral Doppler** – non-imaging technique for measuring high velocities or used to obtain pulse in peripheral pressure studies

US TERMINOLOGY

- **Echogenic** – something that produces echoes*
- **Hyperechoic** - Relatively brighter than surrounding tissue
  - Note: **hyperechoic** and **echogenic** are frequently used as synonyms, but the official AIUM definition is listed here
- **Hypoechoic** – Relative darker than surrounding tissue
- **Isoechoic** – identical to surrounding tissue







* Often used synonymously with hyperechoic

PARAMETERS OF SOUND

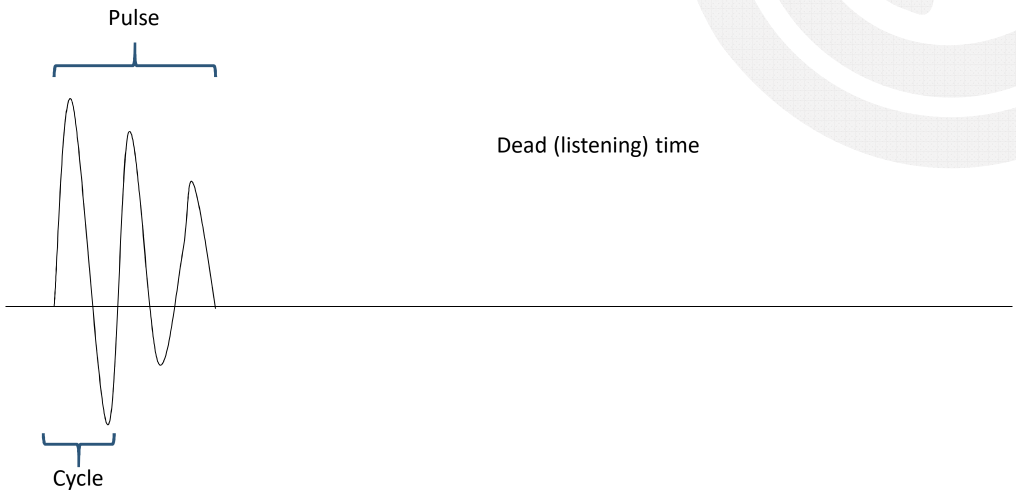
- **Operating frequency** (f) – number of cycles per second
  - Higher frequencies = better spatial resolution but worse penetration
  - Lower frequencies = worse spatial resolution but better penetration
  - Typical frequencies in diagnostic ultrasound 2 – 20 MHz
- **Propagation speed** (c) – speed of sound through medium
  - Although each tissue has its own propagation speed, US machines are all programmed with only one: **1,540 m/s**
- **Wavelength** (λ) – length of one cycle of sound; propagation speed divided by frequency (λ=c/f)

PARAMETERS OF SOUND

- **Acoustic impedance** (Z) – acoustic resistance to sound
  - The bigger the difference in impedance between two tissues, the stronger the return echo, and therefore the brighter the dot on the screen
- **Pulse repetition frequency** (PRF) – number of pulses per second
  - Determined by depth of image for grayscale
  - For Doppler, also called **scale**, and is adjusted for fast vs. slow flow
- **Intensity** – Strength of beam (power) divided by area over which it is spread (area); units W/cm^2
  - Smaller area of insonation at same power = higher intensity (increases potential risk for bioeffects)

ANATOMY OF ONE PW PULSE

- Pulses are made of cycles
- PW has period of transmission and listening
- CW transmits 100% with no listening time



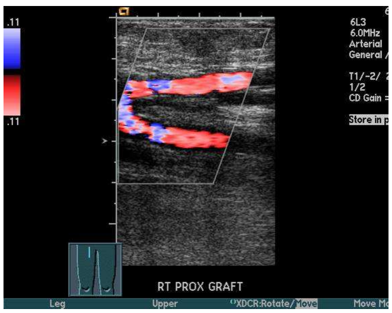
TRANSDUCER TYPES

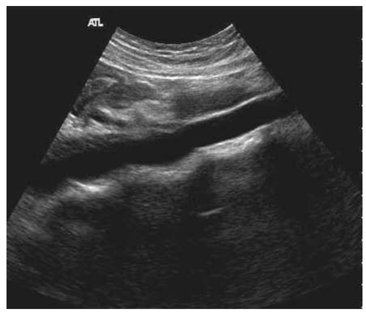
Linear array transducer
Most vascular studies
(extracranial, peripheral
arterial & venous)
Low- vs. high-frequencies

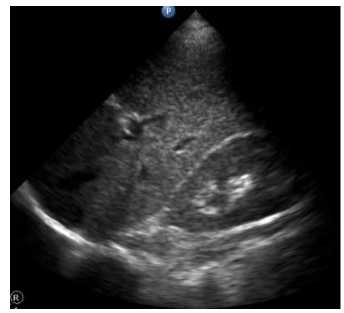
Curvilinear array transducer
Abdominal vascular studies
Morbidly obese patients

Phased array transducer
Small footprint, used for TCD at
low frequency (2 MHz)
Good for going between ribs

TRANSDUCER TYPES

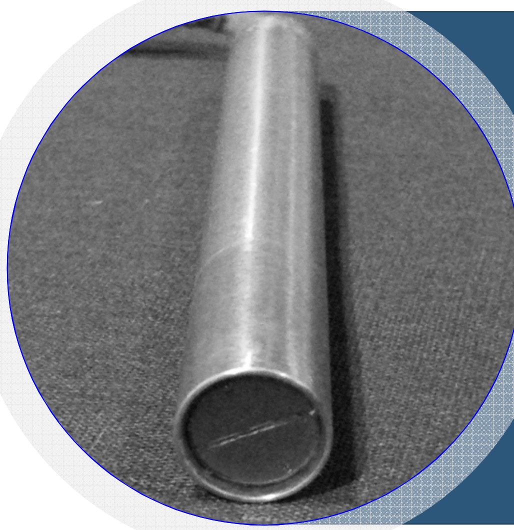






CW (DEDICATED) TRANSDUCER

- Continuously transmits sound and continuously receives sound
  - Two elements in probe
- No depth measurement possible so no grayscale image provided
- **Only output is spectral CW Doppler**
- Can be built into PW probe but still operates off of two elements for spectral Doppler
- Cannot choose specific vessel to sample



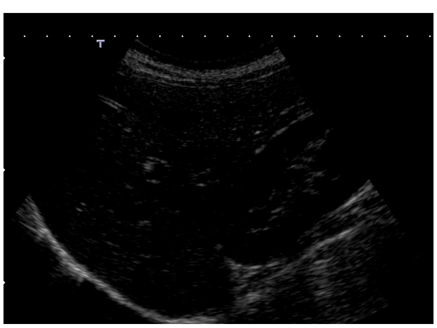
SAFETY MESSAGE

- Ultrasound (in 60 years of testing) appears to be safe, but…
  - **Doppler** does put more energy into the patient, potentially increasing the risk of bioeffects
  - **Transducers** that are damaged can present an unsafe situation, in addition to degrading the image

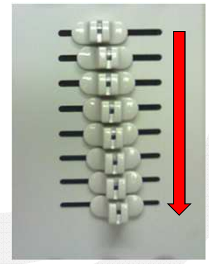
"As low as reasonably achievable"

GRAYSCALE CHARACTERISTICS AND KNOBOLOGY

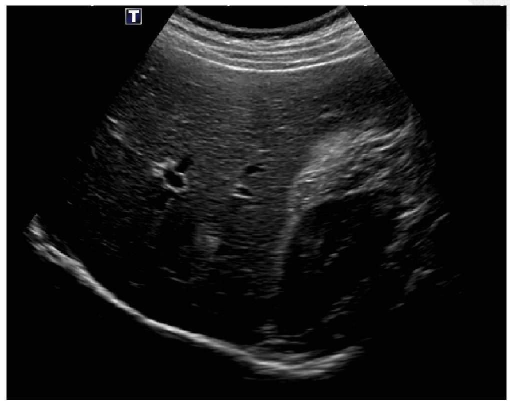
- **Overall gain**
  - Button/knob labeled **B-mode** or **2D**
  - Whole image gets brighter or darker



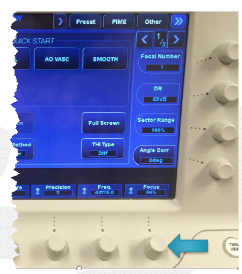
GRAYSCALE CHARACTERISTICS AND KNOBOLOGY



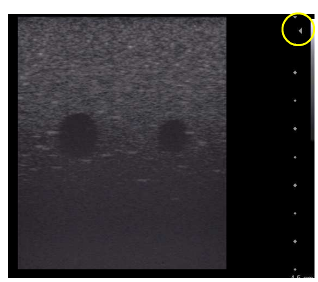
- **TGC**
  - Slider pods to compensate for attenuation
  - Shallow to deep



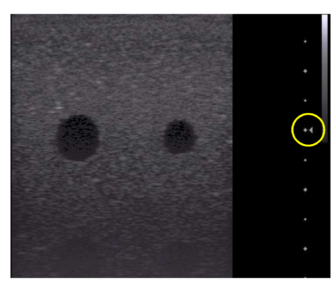
GRAYSCALE CHARACTERISTICS AND KNOBOLOGY



- **Focal Zones**
  - Place at or below area of interest
  - Especially important for Doppler
  - More focal zones = better grayscale but worse frame rate



Focus too high



Focus correct location

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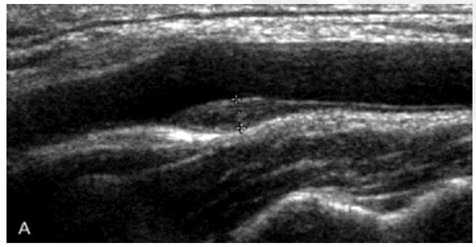
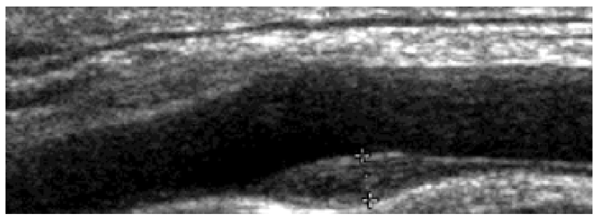
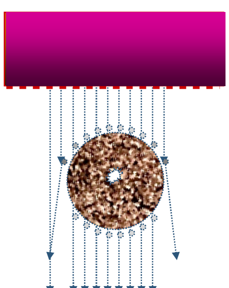
GRAYSCALE CHARACTERISTICS AND KNOBOLOGY

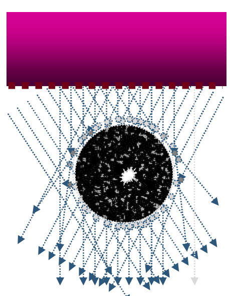
- **Depth**
  - Not too much, not too little
  - No wasted space
  - No cutting off pertinent anatomy
  - Zoom focal area as needed





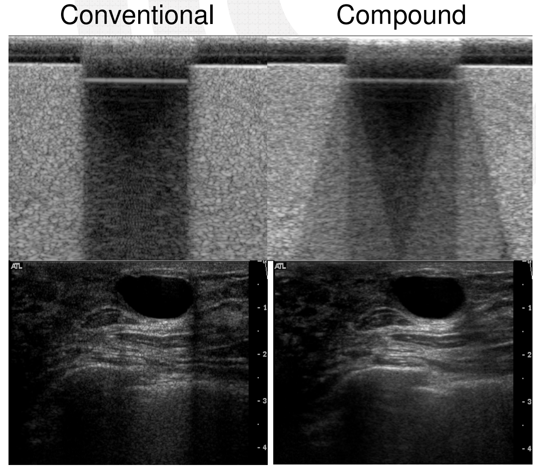
SPATIAL COMPOUNDING





- SonoCT
- ApliPure
- Cross-Beam
- SieClear
- iBeam

Conventional Compound

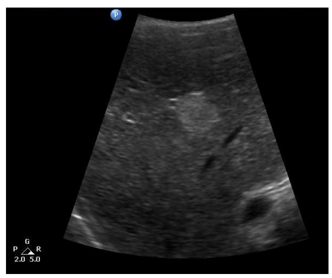


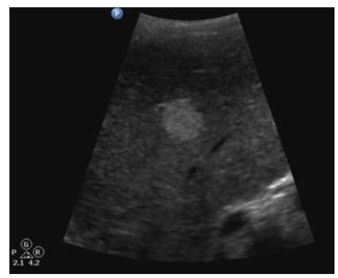
Eliminate edge shadows and reduce speckle

Images courtesy of F. Forsberg, PhD

TISSUE HARMONIC IMAGING (THI)

- Sound traveling through tissue causes a vibration in the tissue
- The tissue sends its own sound wave back to the transducer at **double** the fundamental (transmitted) frequency
  - This sound is called the **2nd harmo**nic frequency
- Imaging with **tissue harmonic imaging** (THI) allows for better lateral resolution reduction in superficial artifacts



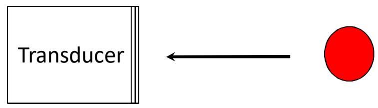


DOPPLER PRINCIPLES

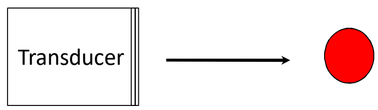
- **Doppler effect** – change in frequency of sound of a reflector compared to stationary observer (transducer)
- **Doppler shift** – difference between transmitted frequency and received frequency
  - As a reflector moves **toward** a source, the frequency of the returning echo **increases**
    - This is called a **positive shift**
  - Likewise, the frequency of the echo **decreases** when a reflector is moving **away** from the source
    - This is called a **negative shift**

DOPPLER

- **Positive Doppler Shift**
  - **TOWARDS** the transducer



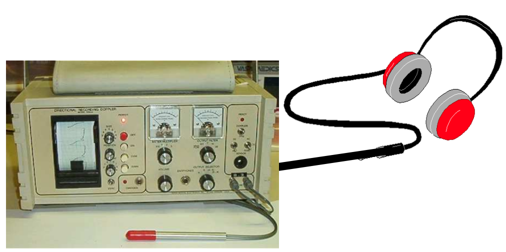
- **Negative Doppler shift**
  - **AWAY** from the transducer



- **No Doppler shift**
  - No movement of reflector

DOPPLER

- These differences are typically 1/1000th of the operating frequency, which is in the audible range of sound
  - (Audible sound = 20-20,000 Hz) Therefore, if we subtract the incident frequency from the reflected frequency, we get a number in the audible range of sound
  - We only need to hook up a speaker or headphones to the Doppler instrument



DOPPLER

- The Doppler shift depends on several factors:
  - the speed of sound in soft tissue
  - the incident frequency
  - the velocity of the blood moving through the vessel
  - and the angle between the beam and the direction of motion
- All summed up in one fabulous equation $$F_D = \frac{2fv\cos\theta}{c}$$
- But…we're not interested in the frequency shift…

DOPPLER

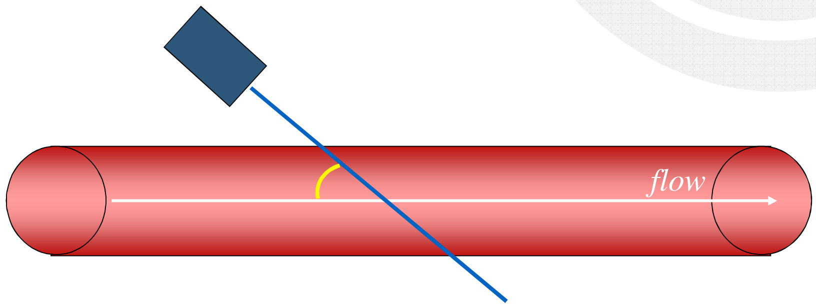
- The machine measures the frequency shift, but calculates the velocity of the blood, which is what we want

$$v = \frac{cF_D}{2f\cos\theta}$$

- **Key**
- F_D = Doppler shift (kHz)
- f = operating frequency
- v = velocity of blood
- cosθ = angle between flow and beam
- c = propagation speed of sound

DOPPLER ANGLE

- The Doppler angle is the angle between the flow and the beam



SHIFT HAPPENS – THE DOPPLER ANGLE

- The smaller the Doppler angle, the more accurate the velocities
  - We don't use the angle itself, but the *cosine* of the angle
  - 0° is the most accurate angle
- Never use an angle > 60°
  - At angles > 60° the degree of error is too high to be reliable
- At 90°, the Doppler shift is 0
  - Cannot be perpendicular to flow

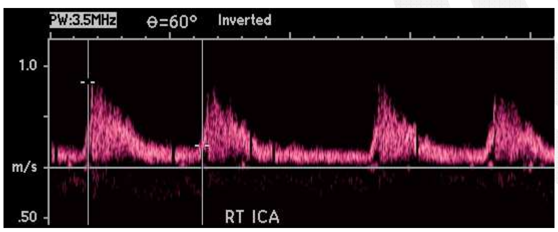
Note: cardiac sonographers assume 0° angle

DOPPLER TERMINOLOGY

- **PW Doppler**
  - Spectral and Color Doppler
- **CW Doppler**
  - Non-imaging; dedicated pencil probe
- **Spectral Doppler**
  - Waveform plot of velocity over time
    - Or frequency shift over time
- **Color Doppler**
  - Or color-shift Doppler, color Doppler imaging (CDI)
- **Power Doppler**
  - Or amplitude Doppler, color power angio, color Doppler energy

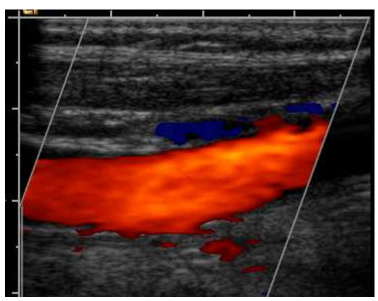
DOPPLER TERMINOLOGY

- Spectral Doppler



PW
CW

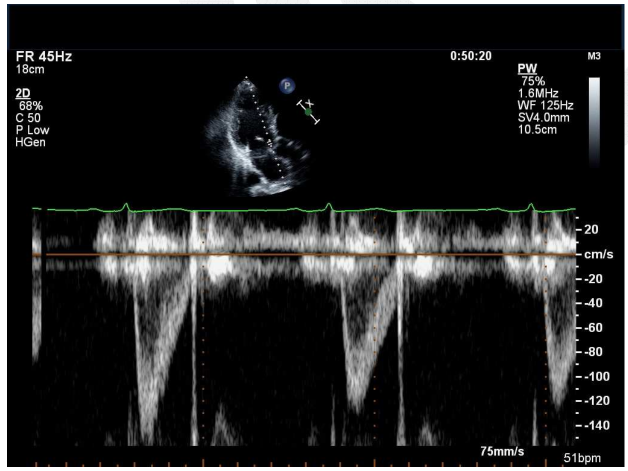
- Color Doppler



PW

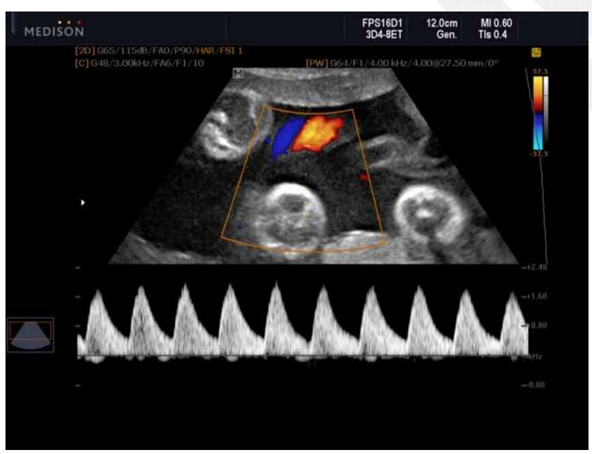
DOPPLER TERMINOLOGY

- Duplex Doppler
  - B-mode (grayscale) plus spectral waveform



DOPPLER TERMINOLOGY

- Triplex Doppler
  - B-mode + spectral waveform +color Doppler



Very slow frame rates…pause the live image while recording spectral

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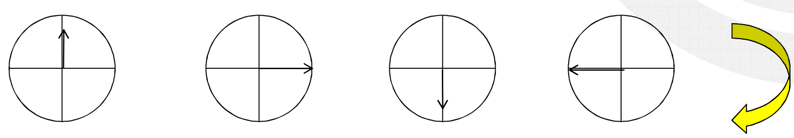
PRINCIPLES OF PW DOPPLER

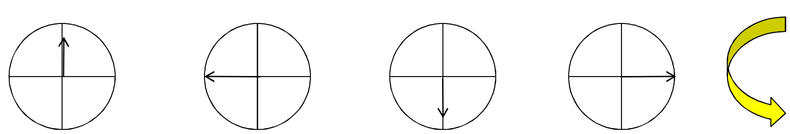
- **Aliasing** – PW Doppler artifact
  - As with 2D imaging, a new pulse cannot be sent before next one is received
  - PW Doppler is limited by aliasing
    - You must sample at a fast enough rate, or aliasing occurs
    - The maximum **Doppler frequency shift** that can be measured without aliasing is one that is **less than one-half the PRF**
    - **Nyquist limit – ½ PRF**
    - Note: Doppler has its own PRF, called **scale**

ALIASING – A PW PROBLEM

- What happens if you don't sample often enough?



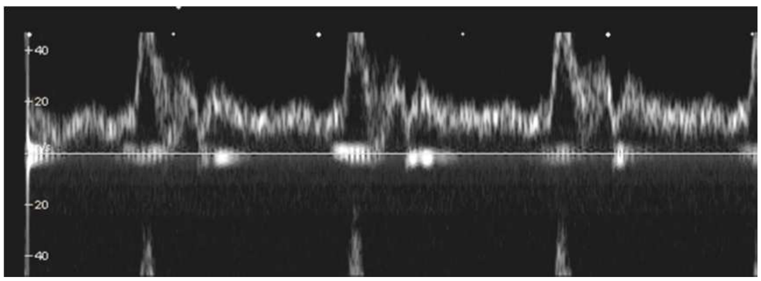
Sample every 15 sec



Sample every 45 sec

PW DOPPLER - ALIASING

- The signal “wraps around” because the PRF is too low
- The lower the PRF, the lower the Nyquist limit
  - Increase Nyquist limit by increasing **scale**



PW DOPPLER - ALIASING

- **How to reduce/eliminate aliasing:**
  - **Increase the PRF**
    - Increase “PRF” or “scale” setting
    - Decrease depth if possible
  - **Increase the angle of the Doppler beam**
  - **Decrease the frequency**
  - **Use a CW probe**
    - CW does not have aliasing

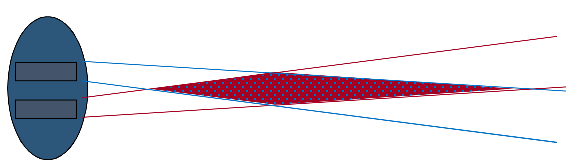
$$F_d = \frac{2fv\cos\theta}{c}$$

PW DOPPLER - ALIASING

- Why do we use PW Doppler if there is aliasing?
  - **Range resolution** – we can choose what vessel to sample and angle correct to flow
- This advantage outweighs all of the disadvantages, as we can also tell the machine the angle the blood is flowing, and therefore obtain more accurate velocity measurements

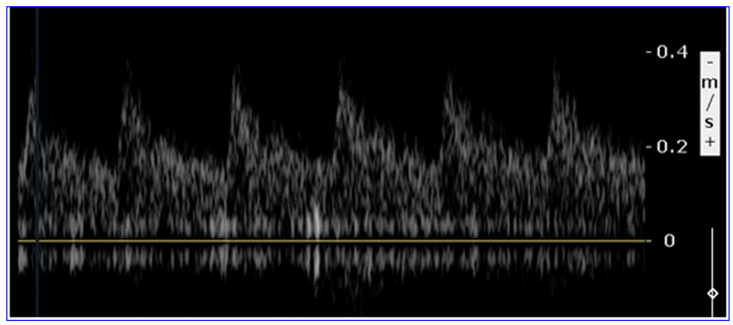
CW DOPPLER

- Sample volume of a CW transducer is where the transmit & receive beams overlap
- Large sample volume with CW Doppler
- No user-selectable sample volume
  - All vessels with sample volume are in waveform



CW DOPPLER

- CW can measure very high velocities, but there is depth (range) ambiguity
  - The transducer does not know what depth the sound is coming from
    - BUT, no aliasing!
    - There will be spectral broadening



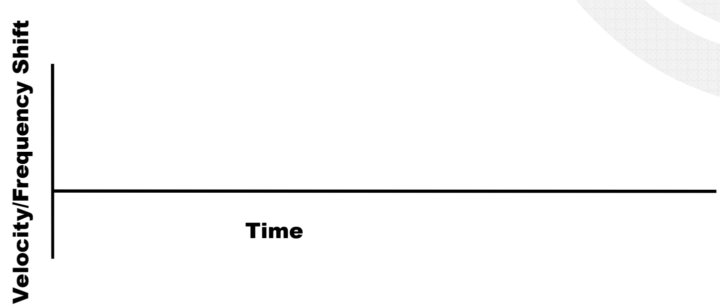
SPECTRAL ANALYSIS

- Spectral analysis allows us to identify the individual components that make up the returned signal
  - Graph of the frequency shift(s) or velocities vs. time
- Done by **Fast Fourier Transform (FFT)**
  - Slow
  - Accurate

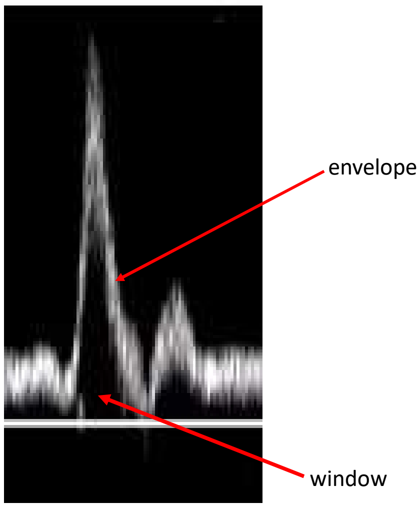
SPECTRAL ANALYSIS

- Parts of the spectrum
  - **Time** – the phase of the cardiac cycle the spectrum appears in (systole, diastole)
  - **Duration** – How long does the event occur?
  - **Direction** – is blood flowing toward or away from the transducer?
  - **Amplitude** – How many RBCs are there?
  - **Broadening** – range of frequencies present
    - Window and envelope

TIME-VELOCITY SPECTRUM (SPECTRAL ANALYSIS)



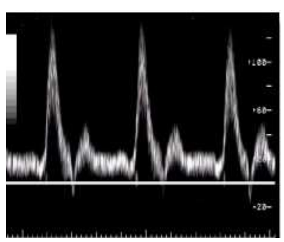
SPECTRAL ANALYSIS



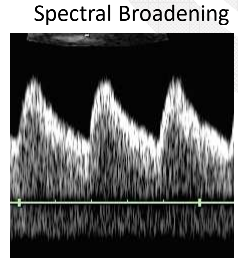
- The envelope is made up of different velocities
- Single-velocity flow will have a thin, clean envelope
- **Spectral Broadening**: presence of many different velocities cause a thickened envelope
- Brightness of the dots of the spectral display represent the amplitude of the Doppler shift

SPECTRAL ANALYSIS

Laminar flow



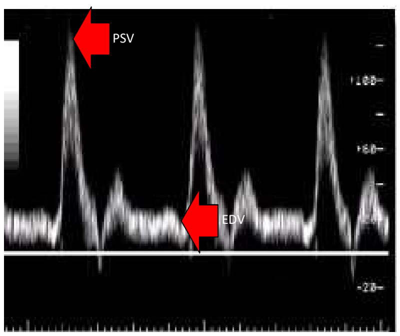
Spectral Broadening

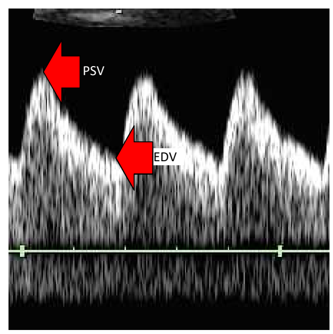


-The envelope is made up of different frequency shifts or velocities.
-Smooth, laminar flow will have a thin, clean envelope
-Turbulent flow (with its many different velocities) will have a broadened envelope. This is called spectral broadening. Not all spectral broadening is turbulent or abnormal.

SPECTRAL WAVEFORM

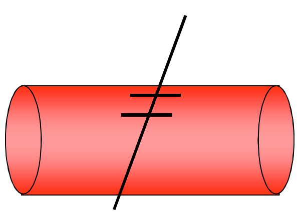
- Peak systolic velocity
  - Highest velocity during systole
- End diastolic velocity
  - Usually measured just before beginning of next systole. Not always the lowest velocity

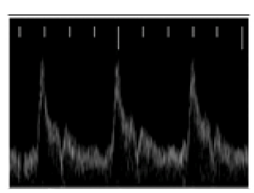




DOPPLER CONTROLS

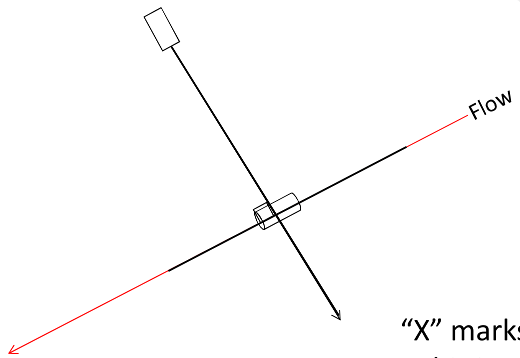
- **Range Gate**
  - Controls size of the sample gate - use smallest possible gate unless searching for slow flow
  - Keep gate in center of vessel to reduce spectral broadening





DOPPLER CONTROLS

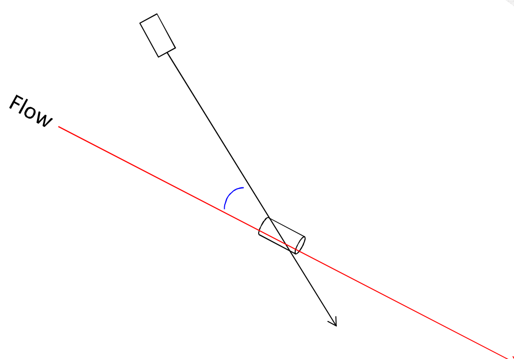
- We need to change the steer of the cursor to avoid being perpendicular to flow (the dreaded 90° angle)



"X" marks the spot –
This is a 90° angle!

DOPPLER CONTROLS

- We need to change the steer of the cursor to avoid being perpendicular to flow (the dreaded 90° angle)

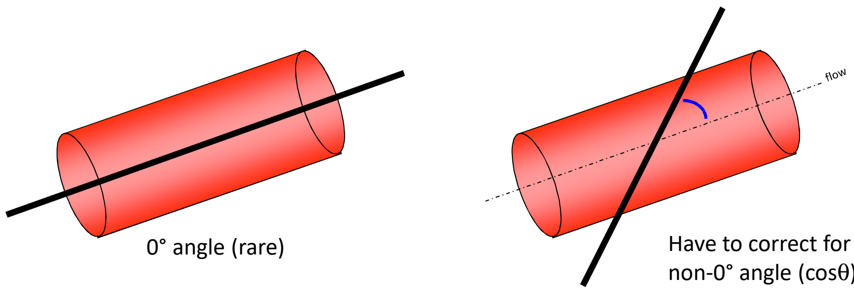


< 90° here – this is okay

DOPPLER CONTROLS

- Because we are rarely parallel to the flow (angle = 0°), we have to correct for the portion of the signal that is not parallel

Exceptions:
- TCD
- Echocardiography



0° angle (rare)

Have to correct for non-0° angle (cosθ)

DOPPLER CONTROLS

- **Doppler angle to flow must be ≤ 60°**
    - Most vascular US typically 30-60°
- Machine needs to know the *angle to flow* in order to calculate the velocities
    - Angle correction should be **parallel to back wall of vessel**
    - If using parallel to flow, be sure to be consistent on all studies and mention in report which technique was used
    - Review prior ultrasounds

DOPPLER CONTROLS

- **Doppler Angle Correction**
  - At angles > 60°, the slightest error in angle estimation causes even more significant errors in velocity
  - In vascular ultrasound, Doppler angle correction is critical
    - It is always needed when velocities are needed
  - **The lower the angle, the more accurate the velocity estimation**
    - Remember: 0° most accurate angle
      - 0° is the highest Doppler shift
      - 90° is the lowest Doppler shift

DOPPLER CONTROLS

- **Scale/PRF**
  - **Flow sensitivity**
    - Use low scale/PRF for slow flow
    - Use higher scale/PRF settings for fast flow
  - **Increase PRF in presence of aliasing**
    - Aliasing means that your sampling rate is too slow for the flow speed
  - Flow really fast? **Increase PRF**
  - Having trouble finding flow? **Decrease PRF**

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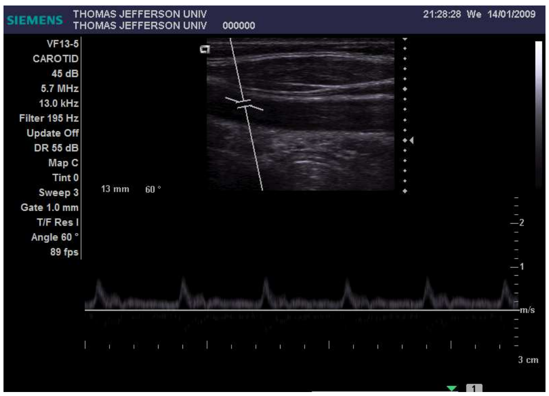
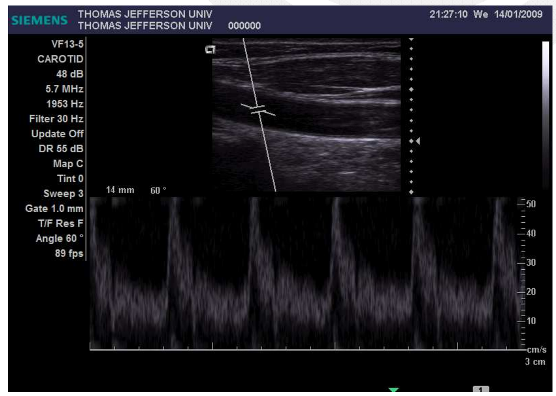
DOPPLER CONTROLS

Scale too high

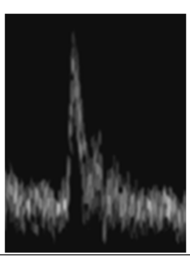


Scale too low

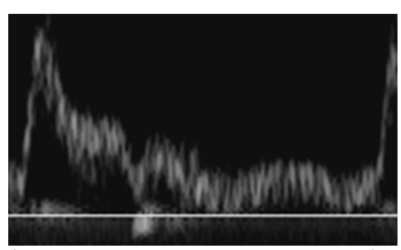


DOPPLER CONTROLS

- **Sweep Speed**
  - How many waveforms will be displayed on the screen at one time
  - Stretch out waveform for more accurate measurements
    - Ex.: use fast sweep speed for renal art. Studies



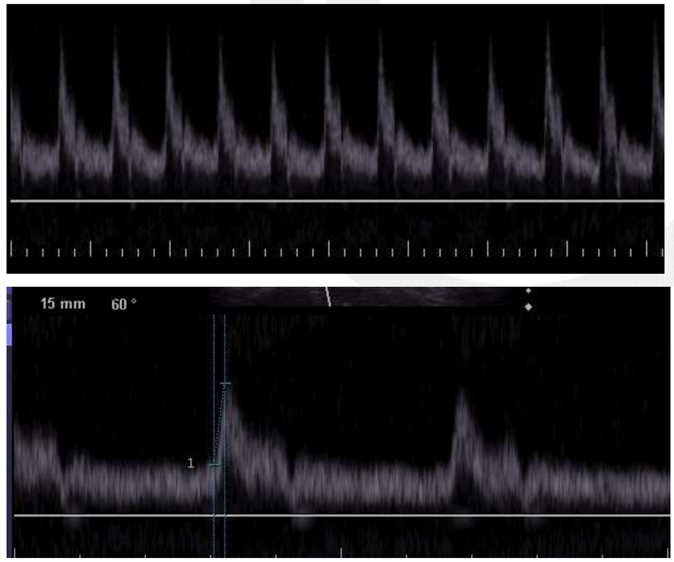
1 second



1 second

DOPPLER CONTROLS

Sweep Speed

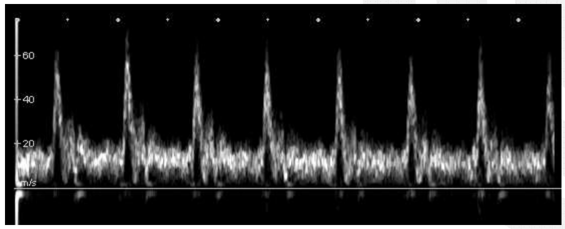


Number of waveforms displayed on screen

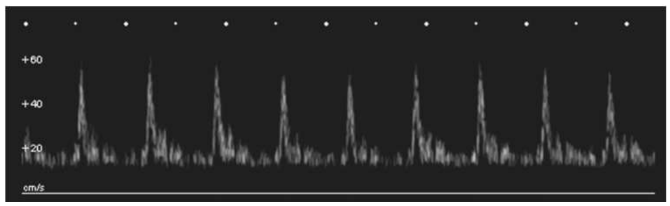
WALL FILTER

- **Wall Filter**
  - Used to eliminate the low frequency signals in the spectral signal that appear from wall or valve motion
  - Causes artifact called **clutter**
    - Cardiac applications – use high wall filter
    - Vascular/abdominal imaging – use low wall filter
  - Less noise from wall motion
  - Also called *wall-thump* or *high-pass* filter
  - Caution: too-high a wall filter can eliminate useful spectral information

WALL FILTER



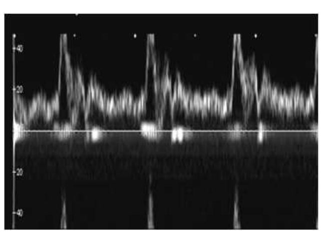
Filter set appropriately

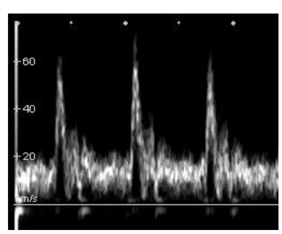


Filter set too high – missing info

DOPPLER CONTROLS

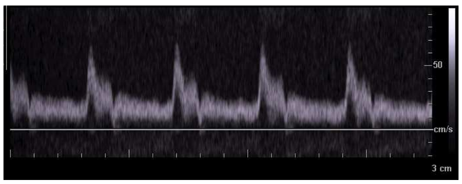
- **Baseline** (new term: *zero-flow baseline*)
  - Controls where the bottom of the waveform will be displayed
  - The baseline can be lowered in the presence of aliasing
    - Doppler shift must be < ½ PRF



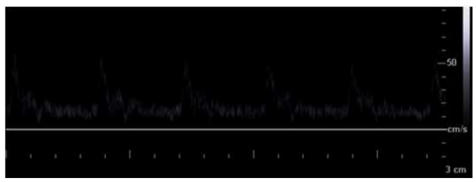


SPECTRAL GAIN

- **Spectral Gain**
  - Overall brightness of the dots
  - Proper gain settings essential
  - **Avoid over- or under-measurement of spectral waveform velocities**



Spectral gain too high
Fills in window and may cause over-measurement of velocities



Spectral gain too low
Waveform too hard to see
May cause under-measurement of velocities

COLOR DOPPLER

- Superimposes Doppler shift information onto a 2D image by using color
  - The color represents direction of flow
    - The shade of the color (light red, dark blue, etc.) signifies lower versus higher velocities
  - The color represents the **mean** of the velocities in the waveform, not the maximum as in spectral Doppler

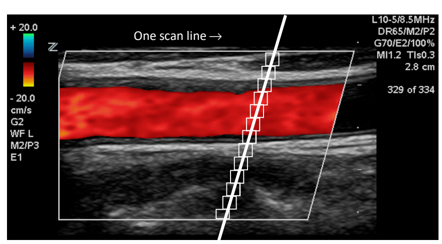
COLOR DOPPLER

- Color Doppler Imaging (CDI) is a **PW technique**, and is therefore bound by the same limitations
  - Aliasing, etc.
- Size and angle of the gate controlled by the operator (same as spectral)

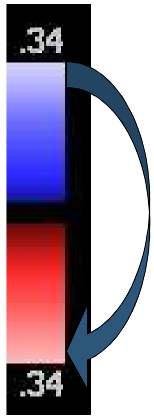
COLOR DOPPLER

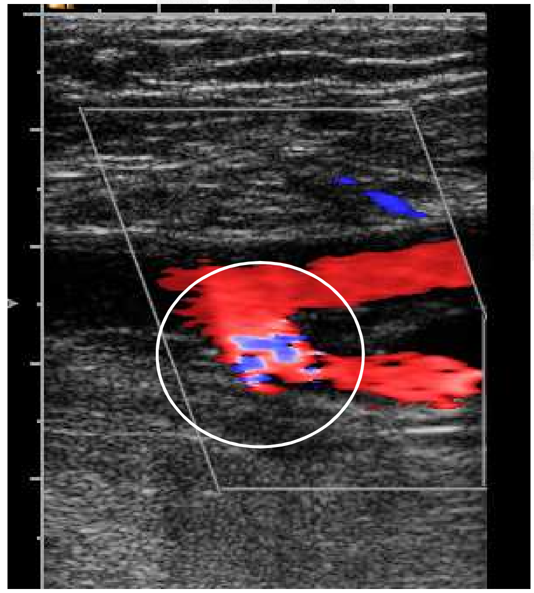
- Color Doppler sends multiple pulses down 1 scan line to make the color image
  - # pulses is called **packet size**, or **ensemble length**
- **Autocorrelation** – technique used by color Doppler to decide (correlate) if there's flow or not, and in what direction?

Use the smallest color box possible for better frame rates

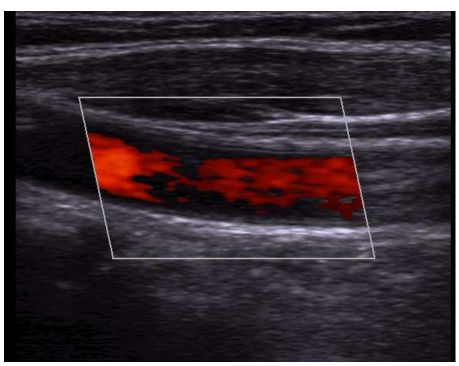


COLOR DOPPLER ALIASING

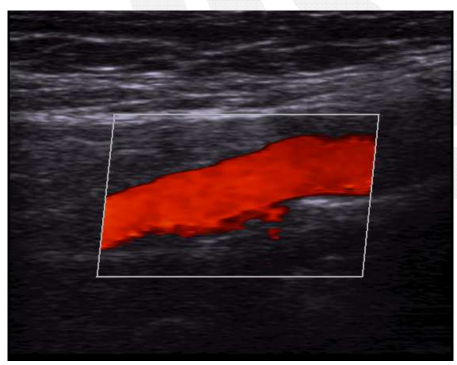




COLOR GAIN

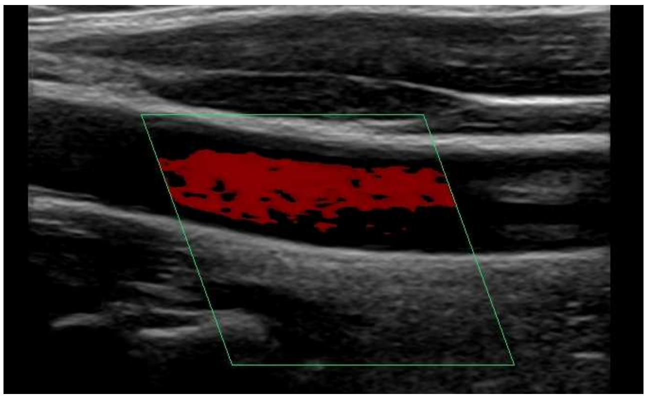


Gain too low



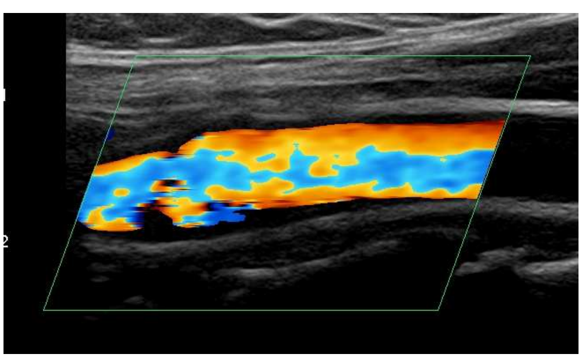
Gain too high

SCALE TOO HIGH



- The vessel is not filling with color
- With scale too high, low flow states will not be displayed appropriately
- Slowest flow towards the walls of the vessels not displayed
  - Notice the only flow is towards the center
- High scale settings should be used for fast flow
- Lowering the scale would cause this vessel to fill better

SCALE /PRF TOO LOW



- See the aliasing? Aliasing occurs when the scale (PRF) is too low
- Increase the scale (PRF) until the aliasing goes away
  - Although if there is a stenosis, a focal area of aliasing may indicate an elevated flow velocity

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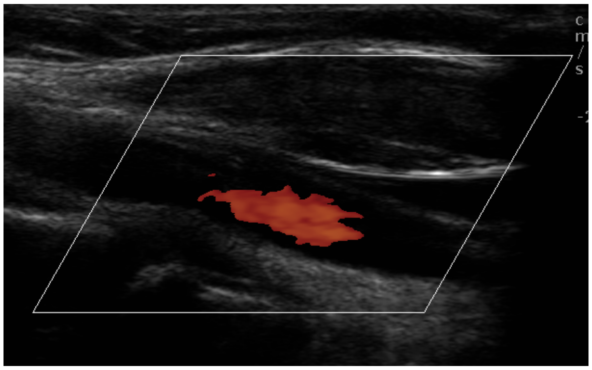
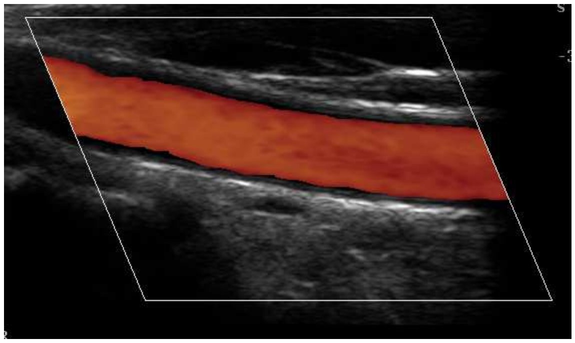
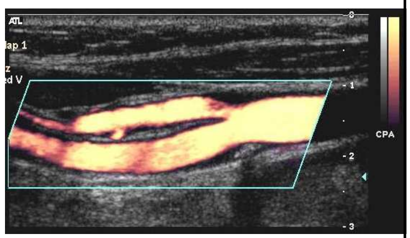
PROPER COLOR BOX STEERING





POWER DOPPLER IMAGING (PDI)

- PDI Evaluates the <u>strength</u> (amplitude) of the shift, not the velocity
  - Depends on the # of scatterers (RBCs)
- Can detect very slow flow
- Very sensitive
- Relatively independent of angle
  - PDI is NOT dependent on frequency shift but # of RBCs
  - But, 90° vessels have very small frequency shifts, so these signals will be very weak and may be filtered out

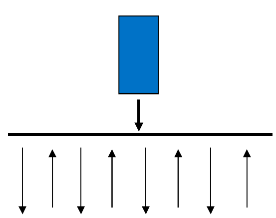


ARTIFACTS

- The machines makes some basic assumptions about the medium the sound is traveling through:
  - **Sound beams travel in a straight line**
  - **Reflections that are produced lie in the path of the beam**
  - **Sound travels at exactly 1,540m/s**
  - **Sound travels directly to the reflector and back**

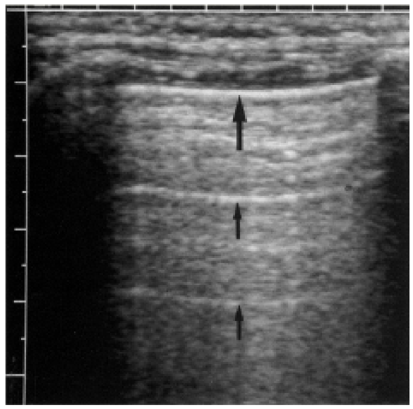
ERRORS OF PROPAGATION

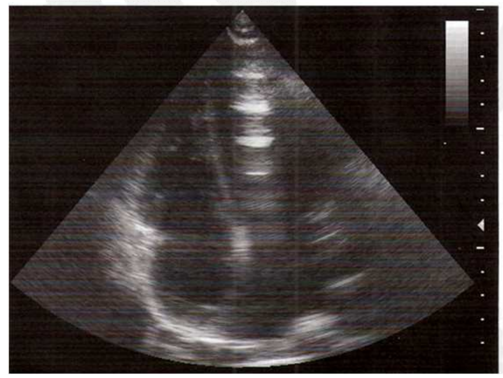
- **Reverberation**
  - Appears as multiple, equally spaced reflections on an image
  - Caused by sound bouncing back and forth between two strong reflectors and then returning to the transducer



ERRORS OF PROPAGATION

- Reverberation



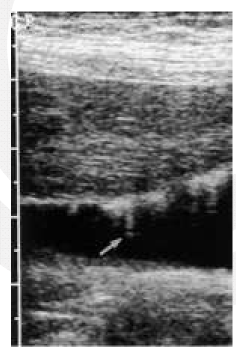


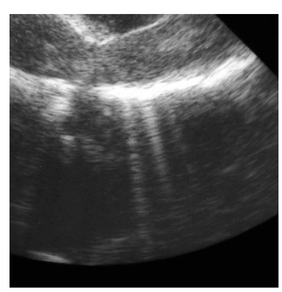
“Step-ladder” appearance

Miele, F. (2006) *Ultrasound Physics & Instrumentation.*

ERRORS OF PROPAGATION

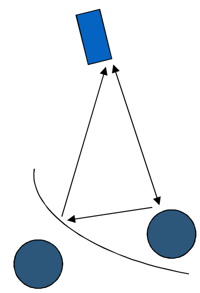
- **Comet Tail**
  - Form of reverberation
  - Closely spaced parallel echoes
    - Appears as solid white line, unlike reverb
  - Caused by surgical clips, cholesterol crystals, etc.
- **Ring-down**
  - Caused by vibration of foci of air
  - Looks like a comet tail
  - Potentially useful artifact because it indicates presence of air (e.g.,abscess or pneumobilia)





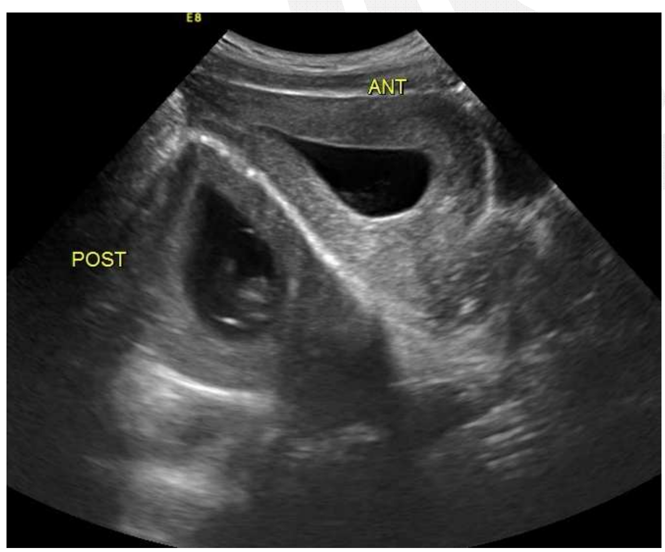
ERRORS OF PROPAGATION

- **Mirror Image Artifact**
  - Sound beam bounces off of a strong reflector, such as the diaphragm, which acts like a mirror, and reflects the sound toward another reflector
  - Causes an image of the original reflector to be displayed at the wrong location on the display
  - Duplicate object always appear deeper than original object



ERRORS OF PROPAGATION

- Mirror Image Artifact



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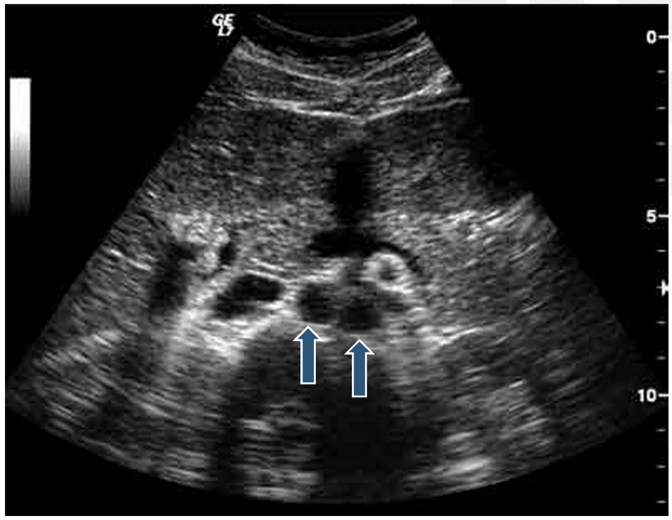
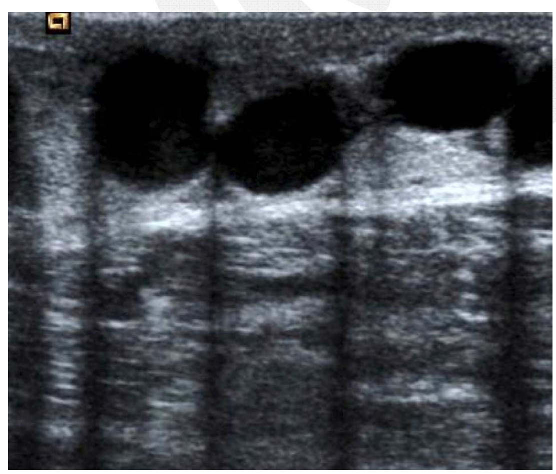
GHOST IMAGE/REFRACTION ARTIFACT



Refraction from rectus muscles cause duplication of aorta

ERRORS OF PROPAGATION

- **Edge Shadowing**
  - Caused by refraction
  - Beam hits a curved specular reflector (such as the GB) and is sent off in another direction
  - The area that the beam was supposed to image is represented by a shadow
  - Reduced with spatial compounding

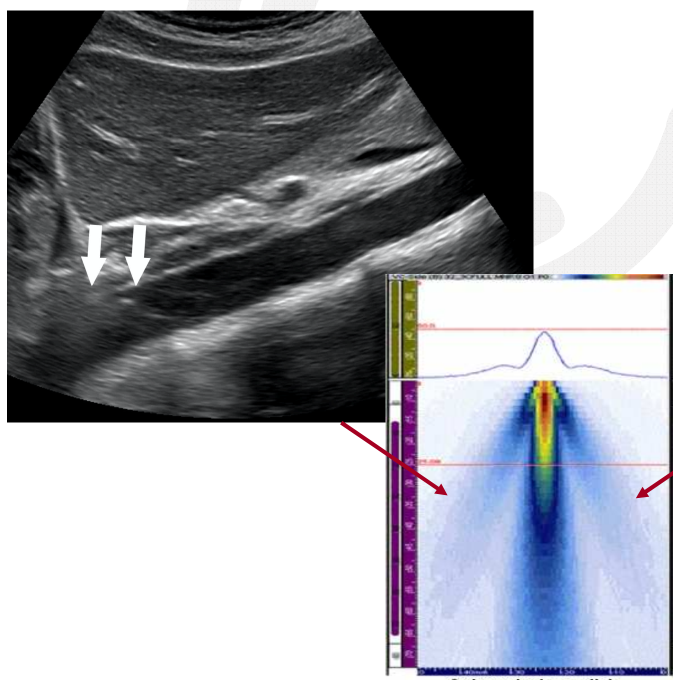


ERRORS OF PROPAGATION

- **Propagation Speed Errors**
  - The US machine assumes the sound is traveling at 1,540m/s
    - If the actual propagation speed is **> 1,540 m/s** it will be **displayed too close** to the transducer
    - If the actual propagation speed is **< 1,540 m/s** it will be **displayed too far away** from the transducer
    - Also called a "registration error"

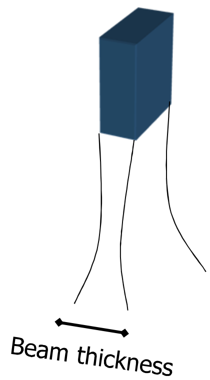
ERRORS OF PROPAGATION

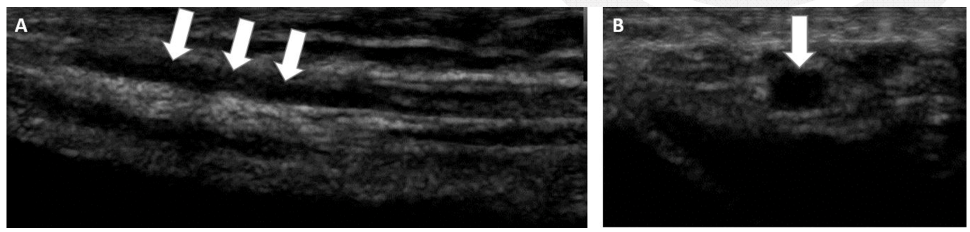
- **Side lobes/Grating lobes**
  - Acoustic energy emitted in a different direction than the primary beam
  - Reflectors can appear in the wrong place or multiple locations
    - Side Lobes –single element transducers
    - Grating Lobes –arrays (not common with advanced electronics due to apodization, which alters the voltages sent to individual elements)



3 elements, 1 mm pitch

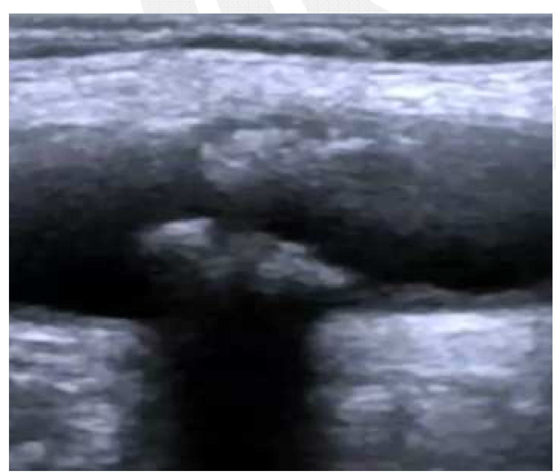
SLICE-THICKNESS ARTIFACT (PARTIAL-VOLUME THICKNESS ARTIFACT)





ERRORS OF ATTENUATION

- **Shadowing**
  - Beam travels through an area of high attenuation (such as a gallstone)
  - Black shadow appears deep to the attenuating structure



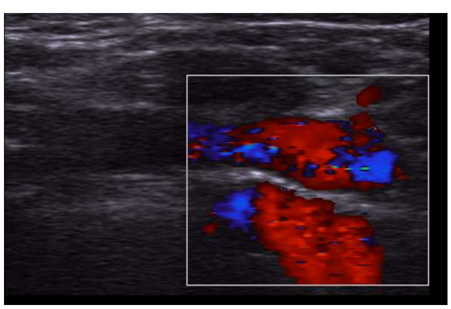
ERRORS OF ATTENUATION

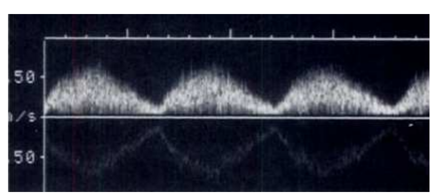
- **Enhancement**
  - Occurs when sound travels through a medium with a *lower* attenuation rate than the surrounding tissue
  - Cystic structures cause enhancement
  - Solid masses may also have enhancement though

https://radiopaedia.org/articles/acoustic-enhancement?lang=us

Doppler Artifacts

- **Mirror image**
  - Occurs with spectral and color Doppler
  - Can be caused by **too-high Doppler gain** or **angle too close to 90°**

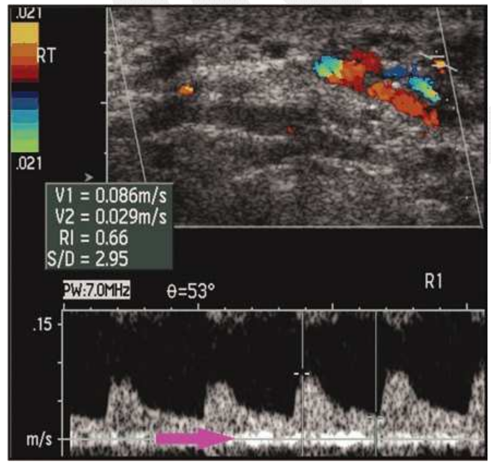




Mirror image artifact

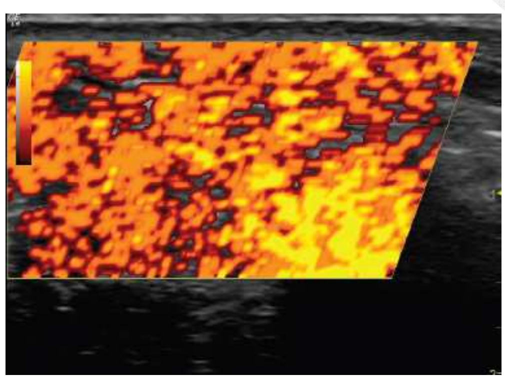
DOPPLER ARTIFACTS

- **Clutter**
  - Tissue motion also causes a Doppler shift (not just from the RBCs)
  - This appears on screen as color not related to blood flow
  - **Eliminated by wall filters**



DOPPLER ARTIFACTS

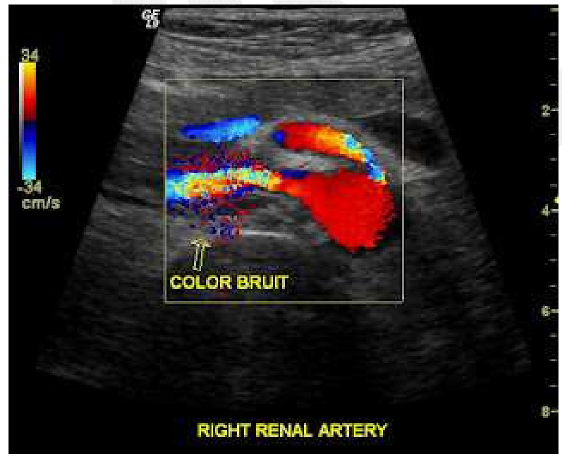
- **Flash artifact**
  - Motion artifact seen with power Doppler (CDE)



https://radiologykey.com/doppler-imaging-2/

DOPPLER ARTIFACTS

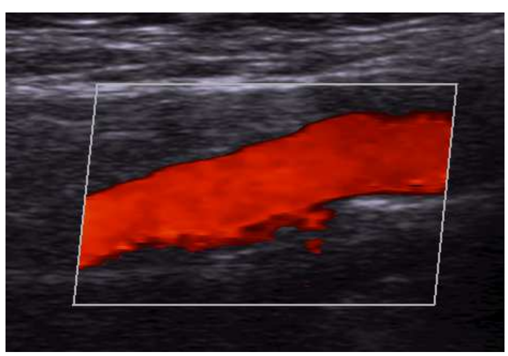
- **Color Bruit**
  - A high-grade stenosis, AV fistula or pseudoaneurysm can cause a thrill in the tissue
  - This tissue vibration is picked up by color Doppler
  - Potential valuable clue to occult pathology



http://radiologyspirit.blogspot.com/2010/07/color-bruit.html

DOPPLER ARTIFACTS

- **Color Bleed (blossoming)**
  - Color that extends beyond the vessel walls
  - Decrease color gain if there is color bleed



BIOEFFECTS

- **Two types:**
  - **Mechanical (nonthermal)**
    - Mechanical index (MI) – likelihood of having mechanical bioeffects
  - **Thermal**
    - Thermal index (TI) – not an actual temperature reading, it's a relative measure of the increase in temperature

BIOEFFECTS

- **Mechanical bioeffects**
  - **Radiation force, streaming, cavitation**
    - **Cavitation** – creation of bubbles in tissue. Potential for tissue damage,
  - No adverse non-thermal bioeffects have been reported below **0.4 MPa (≈ MI < 0.4)** in tissues with existing gas bodies
    - Cavitation typically only occurs in tissues with existing gas bodies, such as bowel gas, lung air, or injected contrast agents
  - In tissues without existing gas bodies, no adverse non-thermal bioeffects have been reported with
    MI < 1.9 (this number is the FDA maximum for MI except for ophthalmic US, which is 0.23)
  - With ultrasound contrast, no adverse non-thermal bioeffects have been reported with **MI < 0.4**

BIOEFFECTS

- **Thermal bioeffects**
  - **Heat** – acoustic energy is converted to heat as it travels through the body (see: attenuation, absorption)
  - A temperature increase of **≤ 2.0°C** appears to be safe (up to 50 hours)
  - Thermal effects not only dependent upon rate of heat deposition (how fast heat is put into the tissue), but also heat dissipation (how fast heat is removed by blood flow, etc.)
  - **Scanned modes** (B-mode, color Doppler) sweep the beam so energy is distributed over large volume
  - **Unscanned modes** (M-mode, spectral Doppler) keeps the beam in one place, increasing dwell time over a smaller volume (thereby depositing more heat)

BIOEFFECTS

- **Thermal bioeffects**
  - Dwell time
  - The longer you spend on one area, the more energy you deposit into that tissue
- In order of worsening thermal effects (from not as bad to worse):
  - B-mode < Color Doppler < Spectral Doppler
- **To minimize thermal bioeffects:**
  - **Decrease output power**
  - **Decrease dwell time**
  - **Avoid bone when possible**

The benefit of performing a study must outweigh the risk

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AIUM STATEMENTS

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In Vitro Biological Effects

It is often difficult to evaluate reports of ultrasonically induced in vitro biological effects with respect to their clinical significance. An in vitro effect can be regarded as a real biological effect. However, acoustic exposures[1,2] and predominant physical and biological interactions and mechanisms involved in an in vitro effect may not pertain to the in vivo situation. Results from in vitro experiments suggest new end points and serve as a basis for design of in vivo experiments. In vitro studies provide the capability to control experimental variables that may not be controllable in vivo and thus offer a means to explore and evaluate specific mechanisms and test hypotheses. Although they may have limited applicability to in vivo biological effects, such studies can disclose fundamental cellular or extracellular effects of ultrasound. Although it is valid for authors to place their results in context and to suggest further relevant investigations, extrapolations to clinical practice should be viewed with caution.

References

1. Edmonds PD, Abramowicz JS, Carson PL, Carstensen EL, Sandstrom KL. Guidelines for *Journal of Ultrasound in Medicine* authors and reviewers on measurement and reporting of acoustic output and exposure. *J Ultrasound Med* 2005; 24:1171–1179.

2. ter Haar G, Shaw A, Pye S, et al. Guidance on reporting ultrasound exposure conditions for bioeffects studies. *Ultrasound Med Biol* 2011; 37:177–183.

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AIUM STATEMENTS

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Prudent Clinical Use and Safety of Diagnostic Ultrasound

Diagnostic ultrasound has been in use since the late 1950s. Given its known benefits and recognized efficacy for medical diagnosis, including use during human pregnancy, the American Institute of Ultrasound in Medicine herein addresses the clinical safety of such use: No independently confirmed adverse effects caused by exposure from present diagnostic ultrasound instruments have been reported in human patients in the absence of contrast agents. Biological effects (such as localized pulmonary bleeding) have been reported in experimental mammalian systems at diagnostically relevant exposures, but the clinical relevance of such effects is either not significant or is not yet known. Increased outputs and time of exposure can increase the likelihood of bioeffects. Ultrasound should be used only by qualified health professionals to provide medical benefit to the patient. Ultrasound exposures during examinations should be as low as reasonably achievable (ALARA).[1,2]

References

1. American Institute of Ultrasound in Medicine. Official Statements: As Low As Reasonably Achievable (ALARA) Principle. American Institute of Ultrasound in Medicine website. https://www.aium.org/officialStatements/39. Reapproved April 2, 2014.

2. American Institute of Ultrasound in Medicine. Official Statements: Recommended Maximum Scanning Times for Displayed Thermal Index (TI) Values. American Institute of Ultrasound in Medicine website. https://www.aium.org/officialStatements/65. Approved October 30, 2016.

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As Low As Reasonably Achievable (ALARA) Principle

The potential benefits and risks of each examination should be considered. The as low as reasonably achievable (ALARA) principle should be observed when adjusting controls that affect the acoustic output and by considering both the transducer dwell time and overall scanning time. Practicing ALARA requires that users do all of the following:

1. Apply correct examination presets if built into the diagnostic ultrasound device. The review of manufacturer default presets for appropriateness is encouraged.
2. Adjust the power to the lowest available setting that provides diagnostic-quality images. If appropriate, reduce power at the end of each examination so the next user will start with the lowest acoustic output setting.
3. Monitor the mechanical index (MI) and thermal index (TI). Know the recommended upper limit of the MI, TI, and related duration limitations for the type of examination being performed.[1,2]
4. Move/lift the transducer when stationary imaging is not necessary to reduce the dwell time on a particular anatomic structure. When possible, avoid fields of view that include sensitive tissues such as the eye, gas-filled tissues (lung and intestines), and fetal calcified structures (skull and spine).
5. Minimize the overall scanning time to that needed to obtain the required diagnostic information.

References

1. American Institute of Ultrasound in Medicine. Recommended maximum scanning times for displayed thermal index (TI) values. American Institute of Ultrasound in Medicine website. https://www.aium.org/resources/statements.aspx. Approved October 30, 2016.

2. American Institute of Ultrasound in Medicine. *Medical Ultrasound Safety*. 3rd ed. Laurel, MD: American Institute of Ultrasound in Medicine; 2014.

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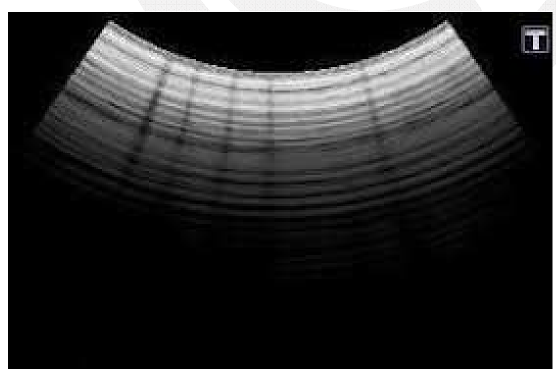
IMPLEMENTING A PREVENTATIVE MAINTENANCE PROGRAM

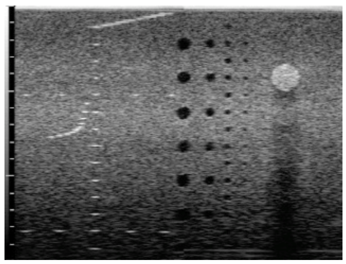
- **Lab accreditation** – ACR or IAC
  - https://www.acraccreditation.org/
  - Intersocietal.org
- Need a **quality assurance (QA)** program that includes preventative maintenance
- Sonographers perform routine evaluation of equipment and image status
  - E.g., broken transducers, dropout on images, etc.

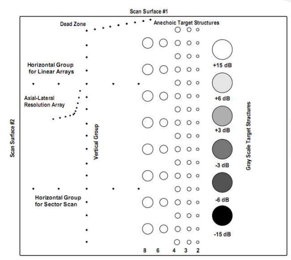


https://www.bmus.org/media/resources/files/10.15_PP.pdf

QUALITY ASSURANCE

- Biomedical engineer uses ultrasound **tissue mimicking phantoms** and/or **Doppler phantoms** to ensure equipment safe and accurate
- Pressure machines need routine calibration





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