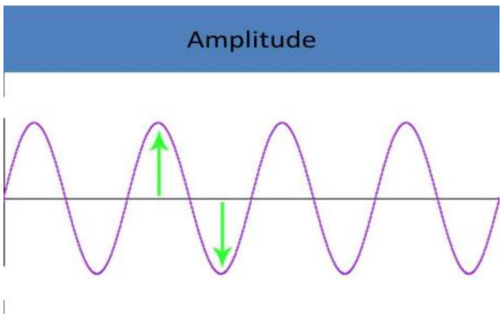
SPI Final Review

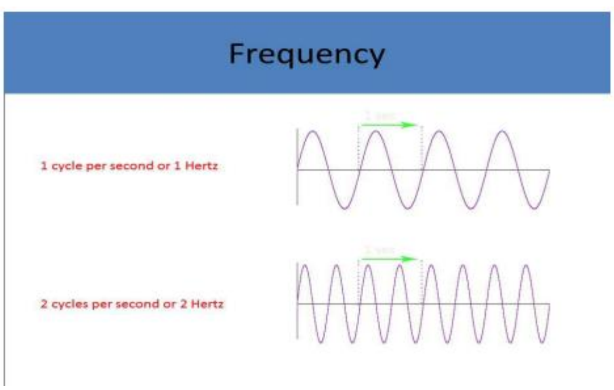
Sound Waves:

- Longitudinal: particle motion parallel to wave motion
- Mechanical: requires a medium to travel
- Cannot travel in vacuum
- Carry energy not matter
- Travel in straight lines
- Compression: positive amplitude of wave
- Rarefaction: negative amplitude of wave
- Cycle: one compression and one rarefaction



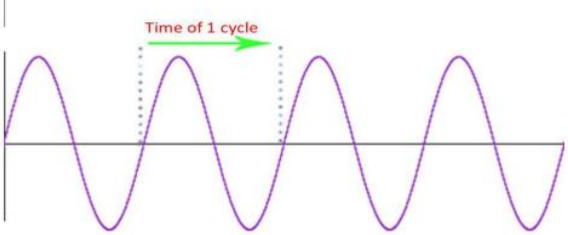
Frequency:

- Number of vibrations per second of an energy waveform
- Frequency of sound is measured in Hertz or cycles per second
- Each cycle consists of a compression and a rarefaction
- Units: Hz, kHz, MHz
- NOT operator adjustable
- Determined by the US probe
- Pulsed US frequency varies with the thickness of the element and the speed of sound in the element
- Continuous US frequency is determined by electrical frequency
- Diagnostic US 2 - 15MHz

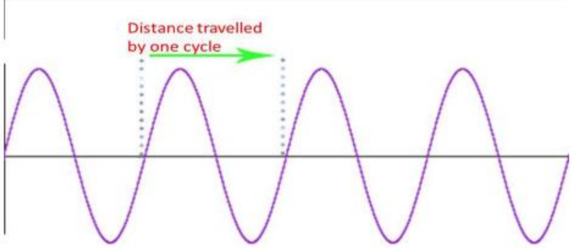


If the Frequency:	THEN Wavelength	Period	Pulse Duration	Spatial Pulse Length	Image Quality	Attenuation	Penetration Depth
↑	↓	↓	↓	↓	↑	↑	↓
↓	↑	↑	↑	↑	↓	↓	↑

Period



Wavelength



Parameter	Average Values
Amplitude	1MPa to 3MPa
Frequency	2 – 10 MHz
Intensity	0.01 – 300 mW/cm^2
Period	0.1 – 0.5 μs
Power	4 – 90 mW
Speed	1500 – 1600 m/s
Wavelength	0.15 – 0.8mm

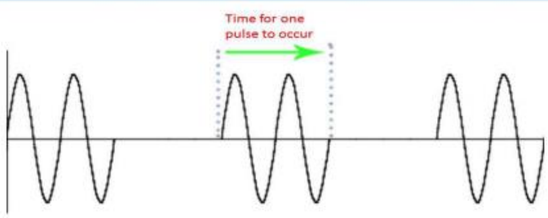
Ultrasound Imaging

Parameter	Operator Adjustable?	How?
Power	Yes	Power or Output controls
Amplitude	Yes	Power or Output controls; Increased power = increased amplitude
Intensity	Yes	Power or Output controls Increased power = increased amplitude
Propagation Velocity	No	
Frequency	No	
Wavelength	No	
Period	No	

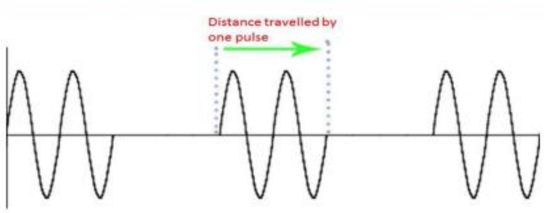
Pulsed Ultrasound

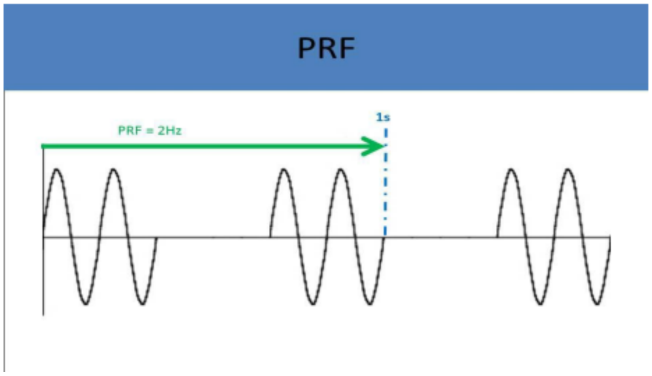
Parameter	Operator Adjustable?	How?
Pulse Duration	No	
Spatial Pulse Length	No	
Duty Factor	Yes	Depth control; Increased (deeper) imaging depth = decreased (lower) DF
Pulse Repetition Period	Yes	Depth control; Increased (deeper) imaging depth = increased (longer) PRP
Pulse Repetition Frequency	Yes	Depth control; Increased (deeper) imaging depth = decreased (lower) PRF

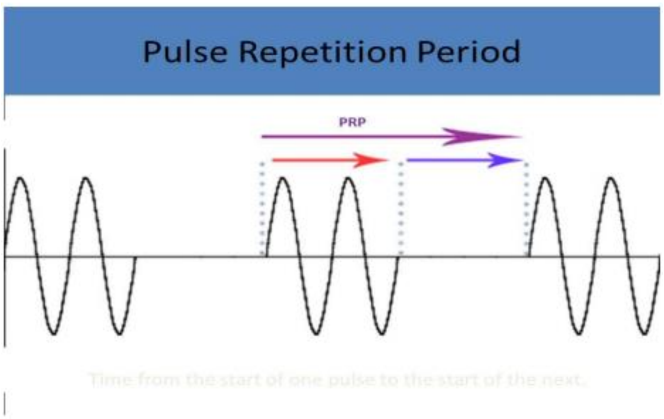
Pulse Duration



Spatial Pulse Length







Interaction of Sound with Tissue:

1. Reflection - return of the ultrasound wave to the transducer from a smooth boundary; greatest amount of reflection occurs when incident beam is perpendicular to structure and there is a significant difference in the acoustic impedance of the two media at the boundary
2. Scatter - deflection of ultrasound waves from small structures; red blood cells are non-specular reflectors that scatter sound
3. Refraction - deflection of ultrasound waves due to media with varied acoustic impedance
4. Absorption - loss of ultrasound signal due to absorption of thermal energy in tissues as it travels

- Interaction of sound with tissue leads to sound beam attenuation as it travels through the tissue
- Higher frequencies have higher attenuation rates in tissue (decreased penetration)

Acoustic Impedance (Z):

- Directly related to the density and propagation speed of the medium
- Density of Medium x Propagation Speed = Impedance
- Measured in Rayls
- The larger the difference in impedance of the two media, the greater the amount of reflection at their boundary

- If two media have the same propagation speed but one has greater impedance than the other, the media with the higher impedance must be more dense
- US gel is used to reduce the change in impedance between the probe and the skin = reduced reflection from skin barrier

Echocardiography Transducers:

- Single Element
  - requires mechanical focusing and steering
  - with only one element, electronic focusing and steering is not possible

- Phased Array
  - multiple elements used to create an image by varying timing of the electrical pulses (firing) to the different elements in the array (electronic steering and focusing)

- Transducer frequency is inversely proportional to penetration and directly related to resolution
- High frequency probes have low penetration and high resolution
- Beam width, spatial pulse length and pulse duration are inversely proportional to the transmitted frequency; these parameters decrease with increased transmit frequency
- Average transducer frequencies 2.5 - 4MHz
- Thin, easy to image patients = 5MHz
- Large habitus or patients with lung disease/COPD = 2MHz (or lower)
- Acoustic gel is used to eliminate the air between the skin and the face of the transducer
- The gel impedance is between the impedance of the matching layer and of the skin to reduce the acoustic mismatch between the matching layer and the skin = reduced reflection and improved sound transmission at the skin boundary

Sector Phased Array:

- Contains a large number of rectangular piezoelectric elements arranged in a linear pattern
- Small footprint with 100-300 elements
- Wedge-shaped sections; Pie wedge-shaped image
- Electronic steering is used to create the wedge-shaped image
- Acoustic lines are transmitted at an angle that is different from that of the previous acoustic line
- Distance between individual acoustic lines in the far field is greater than in the near field
- Allows multiple focal points at varied depths (variable focusing)
- Most limited field-of-view in the near field compared to all transducer types
- Greater field-of-view in the far field than a linear image
- Electronically focused and steered by firing groups of elements to produce one pulse at a time (Transmit Focusing)
- Used for echocardiography, abdominal, pelvic, vascular, transcranial, and neonatal brain imaging

Vector Array:

- Combine sequenced linear array and phased array techniques to provide a trapezoidal imaging format
- Slightly larger footprint than a sector phased array transducer
- Sector image has a flat top with a wider field-of-view in the near field than sector array
- Employs electronic steering and focusing
- Used for echocardiography, abdominal, pelvic, vascular, transcranial, and neonatal brain imaging

Annular Array:

- Usually constructed of 5 concentric, ring-shaped piezoelectric elements that produce a cylindrical beam
- Sector shaped image
- Mechanical wobbler can use annular array instead of single element
- Requires mechanical steering, if needed; electronic not possible with circular elements
- Can be electronically focused by timing voltages to different elements (phased annular array)
- Circular elements allow for electronic focusing in all planes at all depths to provide optimal lateral resolution at all depths on the image
- Central elements used to image more superficial structures and outer elements used to image deeper structures

Sequential Linear Array:

- AKA switched array
- Contains approximately 200 rectangular elements placed in a line across the face of the transducer
- Parallel acoustic lines are transmitted sequentially
- Each acoustic line a single sound pulse created by the transducer element
- Same size field-of-view in near and far fields (no trapezoid FOV)

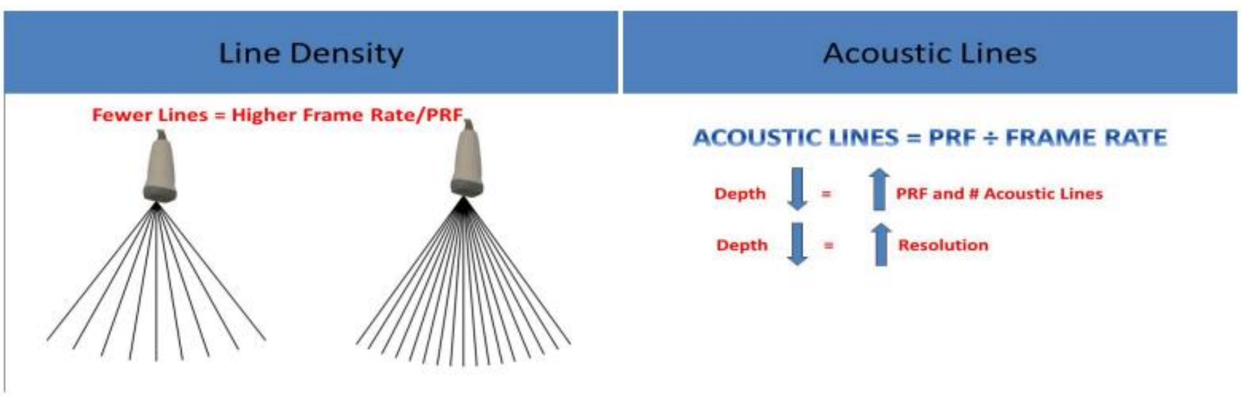
- Uses mechanical focusing (curved lens or crystal)
- Lateral resolution is improved by firing a few elements at exactly the same time to create a narrow beam
- No beam steering
- Damage to a single element will only cause the loss of the portion of the image produced by that element

Linear Phased Array:
- Contains approximately 200 elements
- Elements fired at varied times to allow for electronic focusing and beam steering; approximately 10 nanosecond delays between firing
- Phasing used to create trapezoidal FOV, steer and focus beam (electronic beam focusing and steering)
- Electronic steering allows a linear probe to produce a trapezoidal image
- Trapezoidal linear display leads to degraded lateral resolution in the far field; contrast, axial and elevational resolution are not affected
- Large footprint makes it difficult to obtain images in areas with small imaging windows
- Used for abdominal, OB, small parts, vascular, and musculoskeletal imaging

Curved Sequential Array:
- Similar construction and function as a sequential linear array
- Blunted sector FOV
- Requires mechanical focusing
- No beam steering

Curved Linear Phased Array:
- Contains a large number of linearly arranged piezoelectric elements (120-250)
- Sequentially pulsed transducer elements
- Produces curved/blunted sector image with a larger near field footprint
- Uses electronic focusing and steering
- AKA curvilinear array or convex array
- Can be used for abdominal, obstetrical, gynecological, and small parts imaging

Line Density:
- In a sector image, the number of scan lines per degree of the sector determines line density
- In a rectangular image the line density is the # of scan lines/cm
- Increasing line density (with no change in sector size)
  - Increases the # pulses per frame
  - Improves spatial resolution (axial and lateral)
  - Decreases frame rate
  - Decreases temporal resolution



Sector Angle:
- AKA Field of View (FOV) or Sector Width
- Decreasing the angle decreases the line density and increases the frame rate
- If the sector angle contains 100 scan lines and you decrease the sector to 1/2 the size, the new sector angle will contain 50 scan lines (degraded spatial resolution, improved temporal resolution)
- If the sector angle contains 100 scan lines and you increase the sector to 2X the size, the new sector angle will contain 200 scan lines (improved spatial resolution, degraded temporal resolution)
- Narrow sectors have lower line density, increased frame rate and temporal resolution, but degraded spatial resolution

Image Resolution:

1. Spatial resolution

Axial resolution

- type of spatial resolution
- ability to resolve two separate structures that lie parallel to the ultrasound beam
- improves with higher transducer frequency, wider bandwidths and shorter pulse lengths
- Axial resolution = 1/2 spatial pulse length
- usually 1mm for 3MHz probe and 0.5mm for 7.5MHz probe

Lateral resolution

type of spatial resolution
- ability to resolve two separate structures that lie perpendicular to the ultrasound beam
- improves with higher transducer frequency, harmonic imaging, beam focusing, wider bandwidths and more superficial structures

2. Contrast resolution

- ability to differentiate two structures with varied echogenicity
- a larger image matrix on the monitor will offer the ability to display more pixels of information and more shades of grey which improves contrast resolution
- The more bits per pixel, the more shades of grey on the image and contrast resolution improves
- compression, rejection and monitor contrast controls will change the contrast resolution on the image

3. Elevational resolution

- AKA slice thickness resolution
- improves with thinner image slices
- usually set by manufacturer
- slight improvement with increased transducer frequency and focusing
- Curved elements and lenses will improve focusing and decrease slice thickness
- This will improve lateral and slice thickness resolution

4. Temporal Resolution

- the ability to detect that an object has moved over time
- higher frame rates = improved temporal resolution
- decreased temporal resolution will cause the image to "drag" with a visible difference in the motion of the probe and the display of the structure
- improves with decreased number of focal zones, smaller field of view, decreased image depth and decreased line density
- PW Doppler and M-mode have better temporal resolution than 2D and color Doppler

Temporal Resolution

Increases With	Decreases With
Shallow imaging	Deep imaging
Single focal zone	Multiple focal zones
Decreased number of pulses per scan line	Increased number of pulses per scan line
Narrow sector angle	Wide sector angle
Decreased line density	Increased line density

Factors That Determine Image Resolution	
Axial Resolution	Pulse length Transducer frequency Transducer bandwidth
Lateral Resolution	Beam width Transducer frequency Transducer bandwidth Grating lobes
Temporal Resolution	Pulse repetition frequency/image depth Focal zone number Field of view size Line density
Elevational Resolution	Transducer frequency Width of the beam in the elevation plane
Contrast Resolution	Monitor matrix (number of pixels)

Image Resolution:

1. *Axial Resolution*

- Type of spatial resolution
- Ability to resolve two separate structures that lie parallel to the ultrasound beam; useful in evaluating wall thickness of a vessel
- Improves with higher transducer frequency, wider bandwidths and shorter pulse lengths
- Usually 1mm for 3MHz probe and 0.5mm for 7.5MHz probe

2. *Lateral Resolution*

- Type of spatial resolution
- Ability to resolve two separate structures that lie perpendicular to the ultrasound beam; useful for differentiating two atheroma that are side by side in the vessel
- Improves with higher transducer frequency, beam focusing, wider bandwidths and more superficial structures

3. *Contrast Resolution*

- Ability to differentiate two structures with varied echogenicity
- Compression will change the contrast resolution on the image
- Monitor contrast setting can also adjust image contrast

4. *Elevational Resolution*

- AKA slice thickness resolution
- Improves with thinner image slices
- Most difficult to adjust
- Slight improvement with increased transducer frequency and focusing

5. *Temporal Resolution*

- The ability to detect that an object has moved over time
- Decreased temporal resolution will cause the image to "drag" with a visible difference in the motion of the probe and the display of the structure
- Improves with decreased number of focal zones, smaller field of view, decreased image depth and decreased line density

Frame Rate:

- Minimum frame rate should be at least 30 Hz to avoid flicker visible to the human eye
- Fixed, automatic or operator-adjustable
- Frame rates that vary change with transducer frequency, display depth, and focal-zone settings
- As the # scan lines increases, the frame rate decreases
- Low frame rates allow an increased number of acoustic lines and improves image quality (spatial resolution) with increased line density; good for non-mobile structures
- Higher frame rates (higher temporal resolution) must be used for echocardiography due to movement of cardiac structures in the heart BUT higher frame rates cause reduced image quality (spatial resolution)
- Frame rates can be improved by the use of parallel processing; refers to processing multiple lines of signals at the same time

Image Depth and the Range Equation:

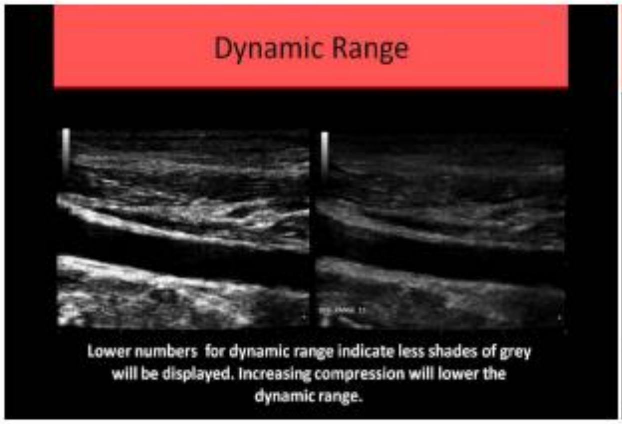
- Pulse repetition frequency = # pulses emitted per second
- Pulse repetition period = time from the beginning of one pulse to the beginning of the next pulse
- PRF is inversely related to the PRP
- Image depth is inversely related to pulse repetition frequency
- As the pulse travels deeper into the patient, it takes a longer time to reach the intended structure; less pulses per second can be emitted due to the increased distance and travel time for the pulses
- Range equation used to calculate the time of flight or go-return time; the time sound travels TO and FROM the transducer
- Used to calculate distance to reflector
- US system uses this information to locate pixel placement on the screen
- Range Equation: distance to reflector = 1/2 speed of sound x time of flight

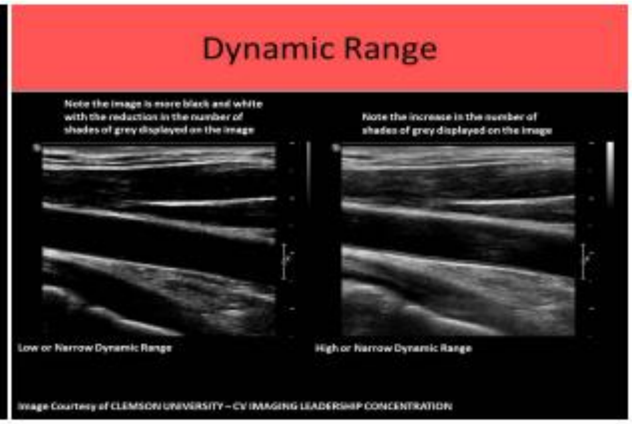
2D Operator Controls:

1. Power Output - adjusts the electrical voltage applied to the PE elements in the transducer; changes the energy of the beam; use as a last resort to increase penetration and reflected sound wave amplitude
2. Overall Gain - adjusts the displayed amplitude of the reflected sound waves on the entire image
3. Time Gain Compensation - allows varied levels of amplification of the reflected sound waves across the image; near field gain is usually set lower to suppress reflections and the far field gain is usually set higher to enhance reflections; compensates for beam attenuation
4. Depth - the deeper the structure being evaluated, the lower the PRF and frame rate (PRF = pulse repetition frequency and refers to the number of ultrasound pulses emitted per second); axial resolution is constant at a set depth but the lateral resolution varies with shape of the beam
5. Dynamic Range/Compression - adjusts the range of grays displayed on the image; changes the contrast level of the image; increased/larger dynamic range = decreased image contrast
6. Focal Zone - used to improve lateral resolution; increased focal zone number causes decreased temporal resolution; activating beam focusing will increase the intensity of the beam at the focal zone
7. Gray Map - changes the shades of gray assigned to the reflected echo amplitudes; used to adjust spatial and contrast resolution; change map before image is frozen = pre-processing; change map on stored image = post-processing

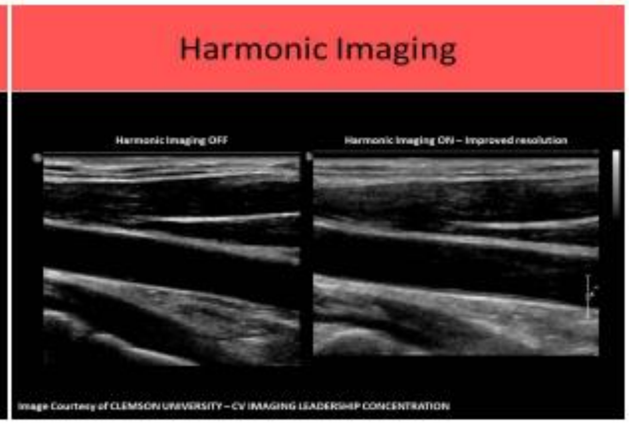
2D Image Optimization Hints:

- Adjust probe position to obtain images of the vessel with the beam perpendicular to the vessel walls; 2D imaging improves with perpendicular incidence
- Adjust compression to vary the "black & white" appearance of the image to improve visualization of vessel walls and to see soft atheroma formation
- If the reverberation artifact is prevalent in superficial vessels, adjust probe position to create more distance between the probe face and the vessel
- Adjust the gray scale map (pre- and post-processing) to improve lumen characteristics and identify plaque/thrombus
- Adjust gain settings, monitor brightness and contrast


Dynamic Range
Lower numbers for dynamic range indicate less shades of grey will be displayed. Increasing compression will lower the dynamic range.


Dynamic Range
Note the image is more black and white with the reduction in the number of shades of grey displayed on the image
Note the increase in the number of shades of grey displayed on the image
Low or Narrow Dynamic Range
High or Narrow Dynamic Range
Image Courtesy of CLEMSON UNIVERSITY – CV IMAGING LEADERSHIP CONCENTRATION


Focal Zone Placement
FOCUS NEAR FIELD
FOCUS OPTIMIZED
Image Courtesy of CLEMSON UNIVERSITY – CV IMAGING LEADERSHIP CONCENTRATION


Harmonic Imaging
Harmonic Imaging OFF
Harmonic Imaging ON – Improved resolution
Image Courtesy of CLEMSON UNIVERSITY – CV IMAGING LEADERSHIP CONCENTRATION

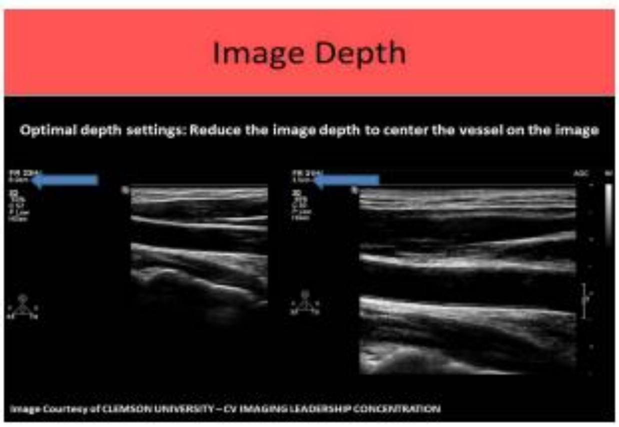
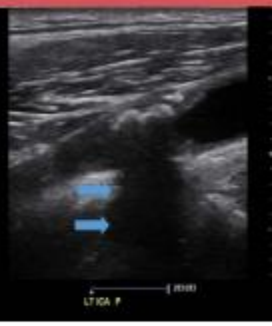


Image Depth
Optimal depth settings: Reduce the image depth to center the vessel on the image
Image Courtesy of CLEMSON UNIVERSITY – CV IMAGING LEADERSHIP CONCENTRATION

Posterior Shadowing

Occurs posterior to highly attenuating structures. Plaque in the arterial wall is highly reflective. The posterior shadowing can limit color and PW Doppler evaluation of the arterial segment posterior to the plaque.

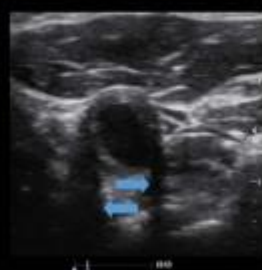


Posterior Enhancement

Occurs posterior to poorly attenuating structures. Fluid filled structures are non-reflective. The structures located deep to the fluid filled structure will demonstrate increased echogenicity.

Edge Shadowing

When the ultrasound beam strikes a rounded structure, sound waves are scattered and refracted, leading to energy loss and the formation of a shadow. It causes linear posterior shadowing on each side of the structure.



Mirror Image Artifact

Occurs when there is a highly reflective surface in the path of the primary beam. Places a second copy of the structure deeper on the image.

DOPPLER FLOW EVALUATION TECHNIQUES

Doppler Ultrasound Physics

- Johann Christian Doppler first identified the physical principles involved in Doppler evaluation
- Doppler shift: the mathematical difference between the transmitted and received frequencies, occurs when structures are moving toward or away from the "listener"
- Train whistle blows as it moves toward you at the station, as it gets closer to the station the approaching train whistle has a higher pitch (frequency); the departing train whistle has a different, lower pitch (frequency)
- Tissues and other non-mobile structures do not exhibit a Doppler shift
- Reflected sound has the same frequency as the transmitted sound if the blood is stationary
- If the blood is moving away from the transducer, the reflected sound has a lower frequency
- If the blood is moving toward the transducer, the reflected sound has a higher frequency
- Fast fourier transformer processes Doppler shifts into Doppler tracing displayed on screen
- Doppler shift frequencies are displayed on a tracing as a function of time; x axis = time, y axis = Doppler shift

The ultrasound system calculates VELOCITY, not SPEED!

Speed – measure of magnitude, any distance divided by unit time, 30 m/s
Velocity – measure of magnitude & direction, positive or negative direction related to starting point, + 30m/s or - 30m/s

Doppler Calculations:

- The Doppler shift is directly proportional to the transducer frequency and blood flow velocity
- As blood flow velocity increases, the Doppler shift increases
- As the transducer frequency increases, the Doppler shift increases BUT the calculated velocity is unchanged because the ultrasound system is programmed to "disregard" the change in transducer frequency
- As the cursor angle increases, the angle between the beam and the flow decreases
- As the angle between the beam and the flow decreases, the Doppler shift increases (the more aligned the cursor is to the flow direction, the higher the Doppler shift)
- EX: Increasing the cursor angle from 45 to 60 degrees = decreased angle between the beam and the flow = increased Doppler shift and velocity
- EX: Decreasing the cursor angle from 60 to 45 degrees = increased angle between the beam and the flow = decreased Doppler shift and velocity
- Overestimating the angle between the beam and the blood flow = overestimated flow velocity
- Underestimating the angle between the beam and the blood flow = underestimated flow velocity
- The greater the Doppler angle, the greater the amount if error in the calculated velocity

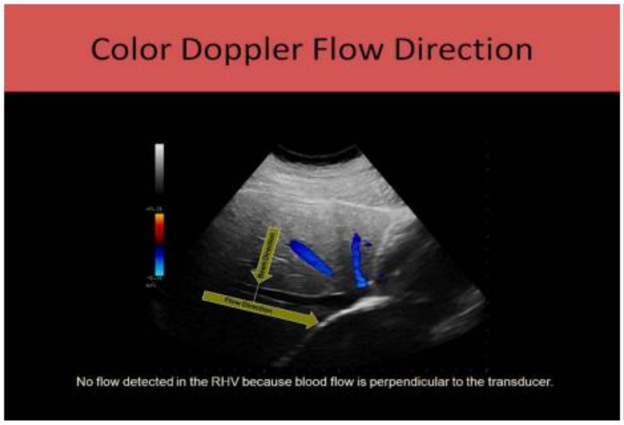
Doppler Operator Controls:

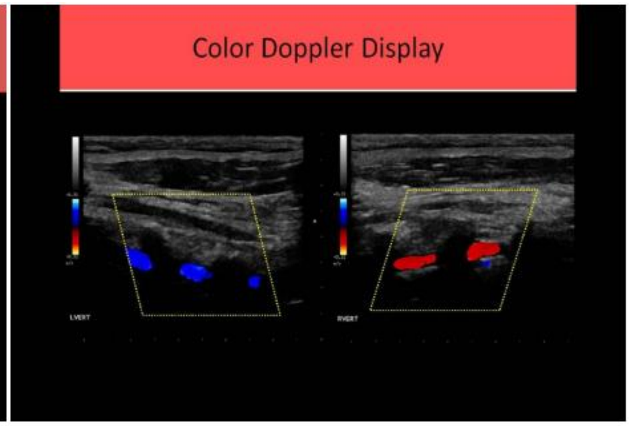
1. Doppler Gain - adjusts the displayed amplitude of the reflected sound waves from the flowing blood
2. Cursor Angle - the optimum angle between the cursor and the blood flow is 0-degrees or parallel to the flow; standard setting for most vascular evaluations is a 60-degree cursor angle; changing the cursor angle changes the velocity calculated from the frequency shift detected
3. Sample Volume Size - adjusts the amount of flow evaluated in a specific location; smaller sample sizes produce more accurate Doppler information with improved evaluation of laminar flow and appearance of the spectral window; average size of 1-1.5mm for arterial evaluations; larger sample sizes helpful for evaluating venous flow and performing volume flow calculations for dialysis access grafts
4. Sample Volume Depth - used to evaluate flow in specific locations; necessary for evaluating arterial stenosis; deeper vessels require lower frequency transducers to obtain samples at increased depths
5. Wall Filter - AKA high pass filter; eliminates low frequency Doppler shifts and high amplitude signals from display; lower settings used for venous evaluation compared to arterial evaluations
6. Baseline - used to demonstrate positive and negative shifts appropriately without aliasing
7. Velocity Scale or PRF - increasing the scale allows the display of higher velocities without aliasing; lower settings used for venous evaluation compared to arterial evaluations
8. Sweep Speed - speed of the spectral Doppler display; 50mm/s is the standard setting; High sweep speed (100mm/s) is recommended for precise measurements of acceleration time; Slower sweep speeds (25mm/s) can be useful for evaluating venous reflux time

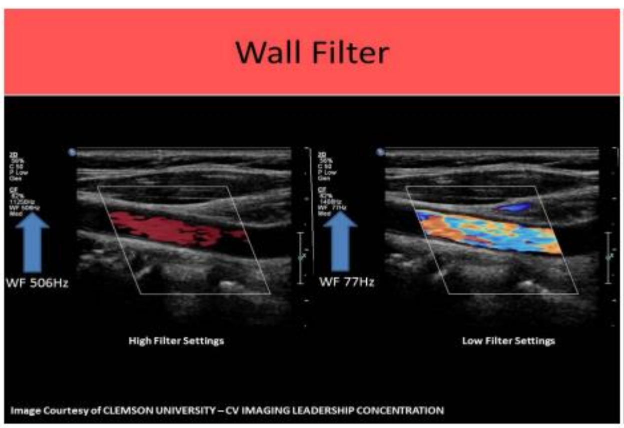
Color Doppler Operator Controls:

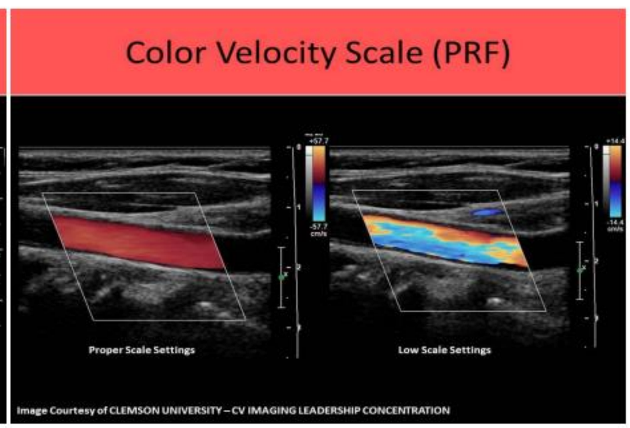
1. Color Gain - adjusts the displayed amplitude of the reflected sound waves from the flowing blood; over-gaining can lead to noise artifact
2. Color Sample Angle - the optimum angle between the sample box and the blood flow is 0 degrees or parallel to the flow
3. Sample Volume Width - adjusts the amount of flow evaluated in a specific location; smaller sample sizes produce more accurate color Doppler information with faster frame rates and improved temporal resolution
4. Sample Volume Depth - used to evaluate flow in specific locations; more superficial structures provide better color display with faster frame rates and improved temporal resolution
5. Color Packet Size - refers to the number of samples taken during evaluation; larger packets have higher line density but lower frame rates and decreased temporal resolution

6. Wall Filter - eliminates low frequency Doppler shifts from display; used to reduce color ghosting
7. Baseline - used to demonstrate positive and negative shifts appropriately without aliasing; can be used to eliminate aliasing
8. Velocity Scale or PRF - increasing the scale allows the display of higher velocities without aliasing
9. Color Map - varied color assignments to Doppler shifts; pre- or post-processing function
10. Variance - degree of variability of mean velocity at different depths in the sample; typically displayed as a GREEN scale superimposed on the red/blue display; used to highlight flow turbulence
11. Color Priority - determines if a pixel is displayed as shade of black and white or as a color; lower threshold settings display less color (lower color priority); higher threshold settings display more color (higher color priority)



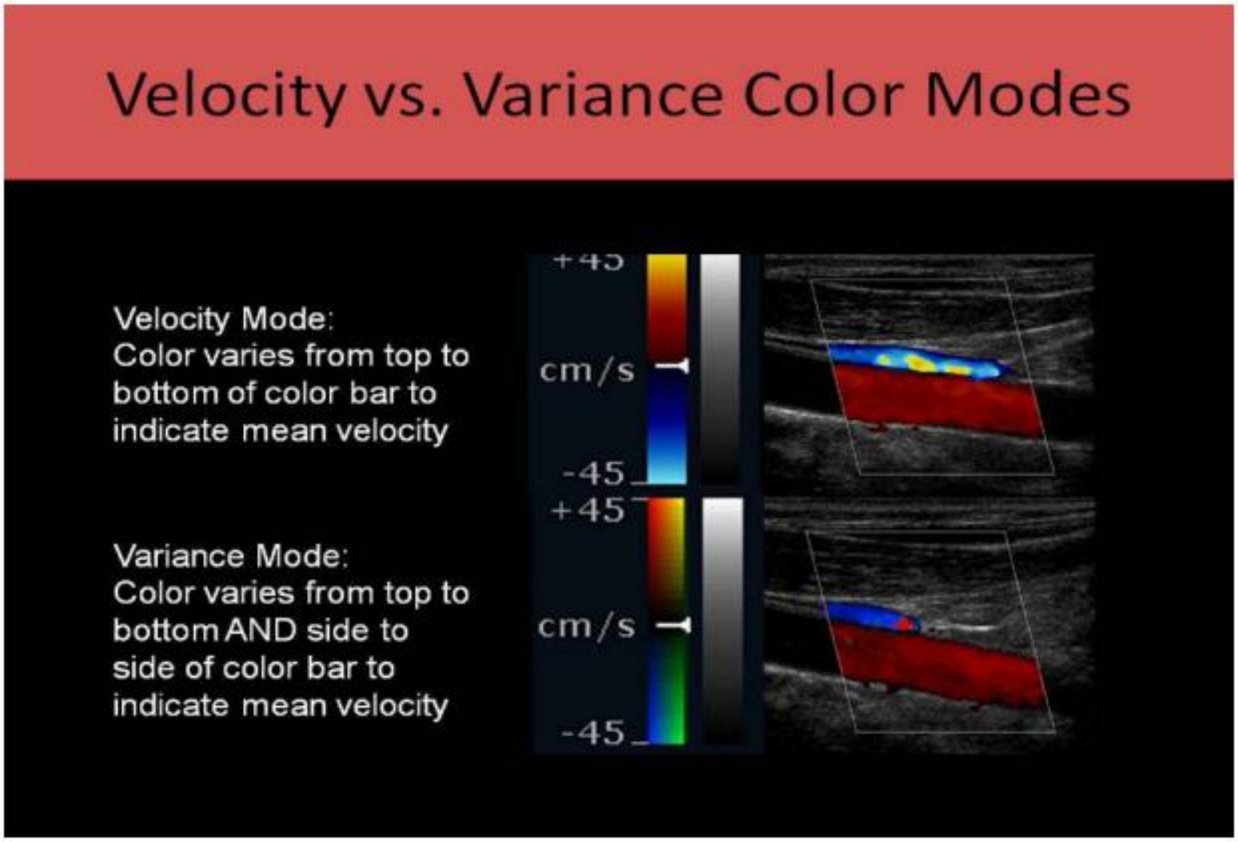






Velocity vs Variance Mode:
Velocity – colors on top of the stripe indicate blood flow toward the probe and colors on the bottom of the stripe indicate blood flow away from the probe; color change with velocity variation demonstrated as varied colors up and down the stripe; aliasing causes flow to be displayed incorrectly; high velocity antegrade flow that exceeds the Nyquist limit will be incorrectly displayed as the color on the on the bottom of the color stripe and shades of white and yellow (depends on the map); color image looks the same as variance map with laminar flow; display of turbulent flow demonstrates a different color image than with the variance map

Variance – used to determine turbulence and represent velocity; Turbulent flow displayed as GREEN color; colors on top of the stripe indicate blood flow toward the probe and colors on the bottom of the stripe indicate blood flow away from the probe AND colors on the left side of the stripe represent laminar flow and colors on the right side of the stripe indicate turbulent flow; color change with velocity variation always seen up and down the stripe AND from left to right; color image looks the same as velocity map with laminar flow; display of turbulent flow demonstrates a different color image than with the velocity map

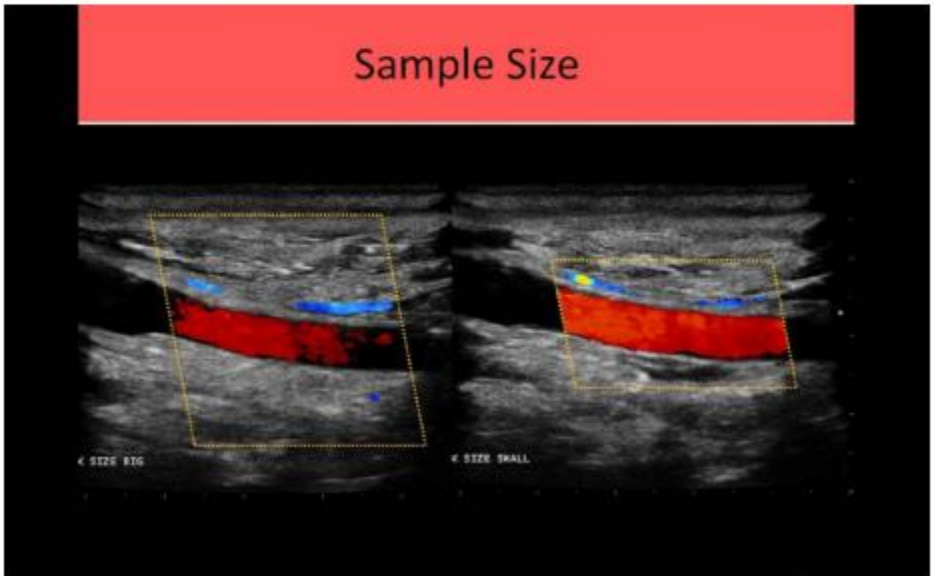


Autocorrelation:
- Used to process Doppler shift information for color Doppler
- Automatically correlates data from multiple sampling sites
- At least three pulses per scan line necessary to generate a single frame of color Doppler information
- Displays average Doppler shift frequencies as varied hues
- Velocity measurement accuracy is limited because angle correction is not utilized

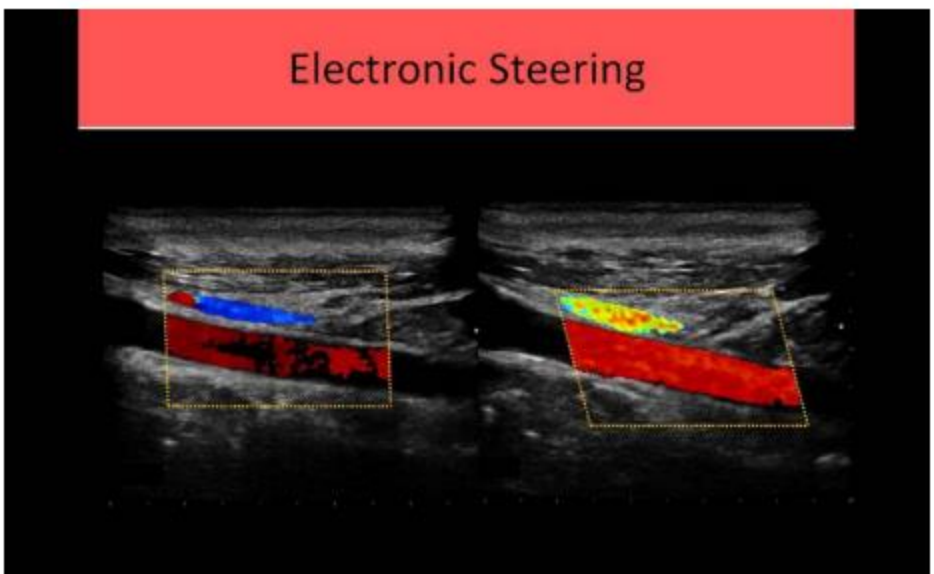
Advantages of Color Doppler:
- “Triplex” capabilities
- Permits instantaneous identification of areas of abnormal blood flow
- Easier placement of the single line cursor that is used for spectral Doppler

Potential Errors:
- Box position
- Box size
- Gain too low/high
- Filter too high/low
- Scale set too low/high

Color Doppler Hints:
- Adjust scale, gain, and baseline
- Adjust color threshold
- Decrease size of sample for improved flow visualization
- Create angle of vessel across the screen, NO flow will be detected when it moves at 90º to the US beam



The smaller the area of color evaluation, the better the color display will be on the image. A smaller color Doppler FOV offers a faster frame rate for improved flow evaluation and display.



The transducer will detect blood from that is moving toward or away from the probe. Steering the color box will make the flow in the vessel less perpendicular to the US beam, therefore improving the detection and display of the flow.

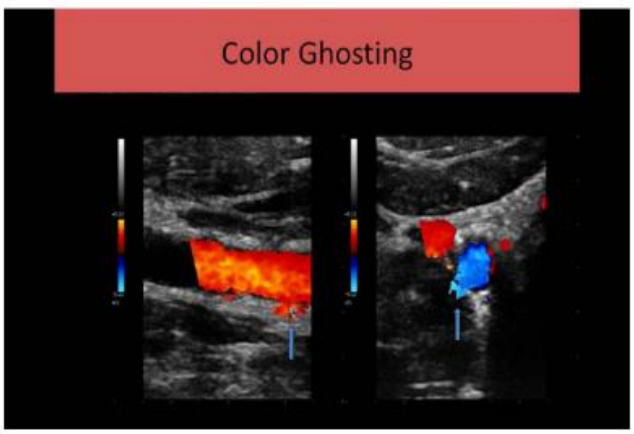
Color Doppler	Spectral Doppler
Imaging representation of flow	Graphic representation of flow
Demonstrates presence/absence of flow	Demonstrates presence/absence of flow
Demonstrates direction of flow	Demonstrates direction of flow
Average flow velocity	Peak flow velocity

Pulsed Wave	Continuous Wave
One crystal transmits and receives sound waves, very low duty factor	Two crystals used, one to transmit and one to receive the sound wave, 100% duty factor
Used to localize points of stenosis	Cannot locate exact area of obstruction
Nyquist Limit imposes limitations on the depth of vessels that can be evaluated	Not limited by PRF(Nyquist Limit), good for deep or superficial evaluations
Aliasing possible	No aliasing

DOPPLER ARTIFACTS:

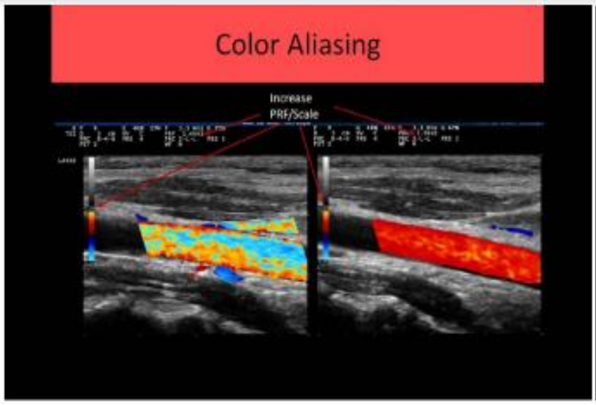
Clutter:
- Unwanted Doppler display patterns typically caused by a vessel's wall motion
- Called ghosting for color Doppler
- Filters used to correct the issue

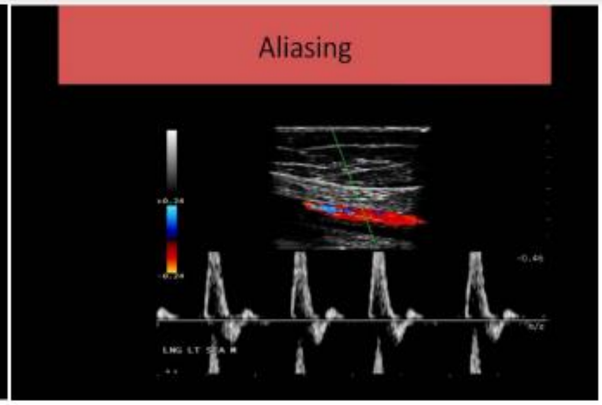
1. Filter: an electronic circuit designed to allow signals to pass while stopping signals of other frequencies
2. High-pass: a filter that allows high, but not low, frequencies to pass through
3. Low-pass: a filter that allows low, but not high, frequencies to pass through



Aliasing:
- Misrepresentation of the Doppler signal due to PRF limitations
- Causes colors/waveform to "wrap around" from top to bottom on the baseline

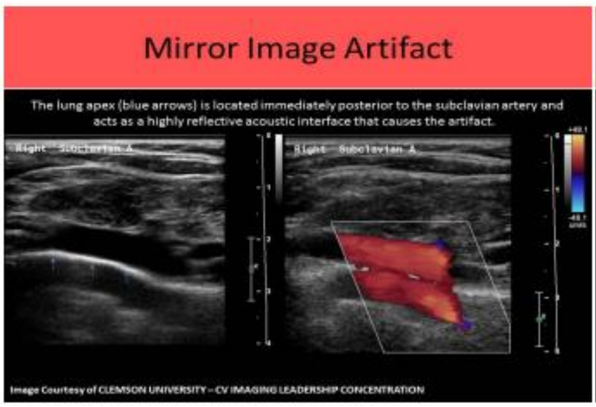
SOLUTIONS
1. Increase scale
2. Lower freq. probe
3. Change angle°
4. Adjust approach to decrease distance to vessel
5. Switch to CW

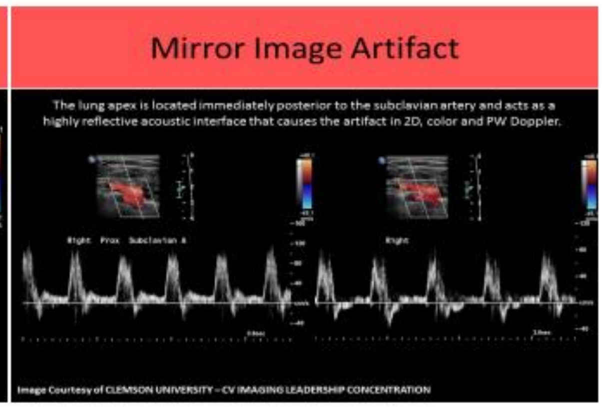


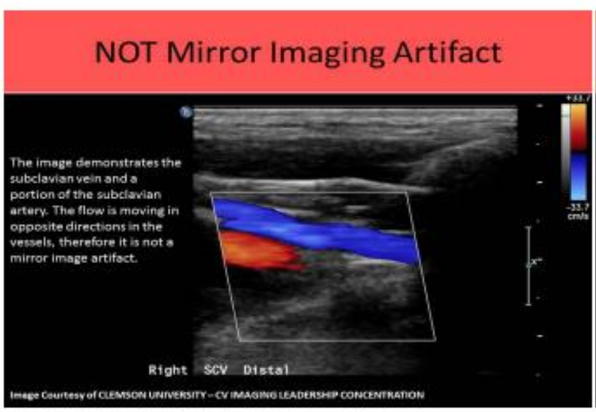


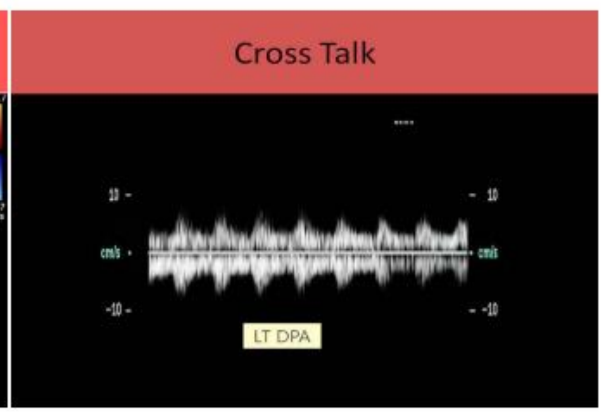
Cross Talk:

- Type of mirror imaging
- Caused by adjacent highly reflective structures, receiver gain too high or incident Doppler angle near 90°



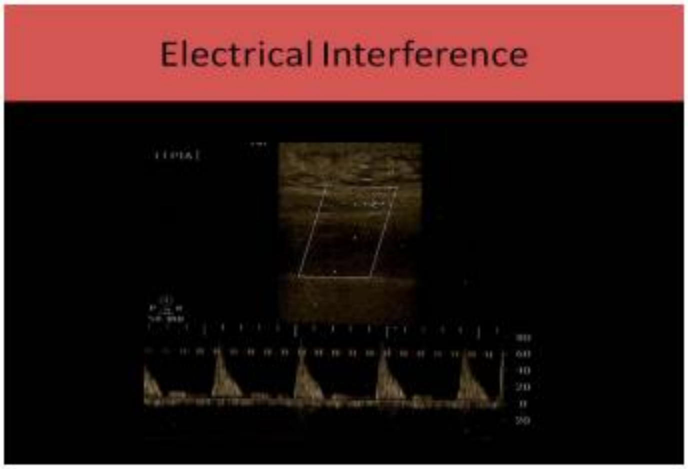






Electrical Interference/Noise:

- Appears as repetitive, consistent artifactual echoes demonstrated on the Doppler tracing
- The frequency of the electrical signal is directly related to the number of artifact echoes demonstrated in one second
- Reduced by decreasing Doppler gain, increasing wall filter settings, try another wall outlet

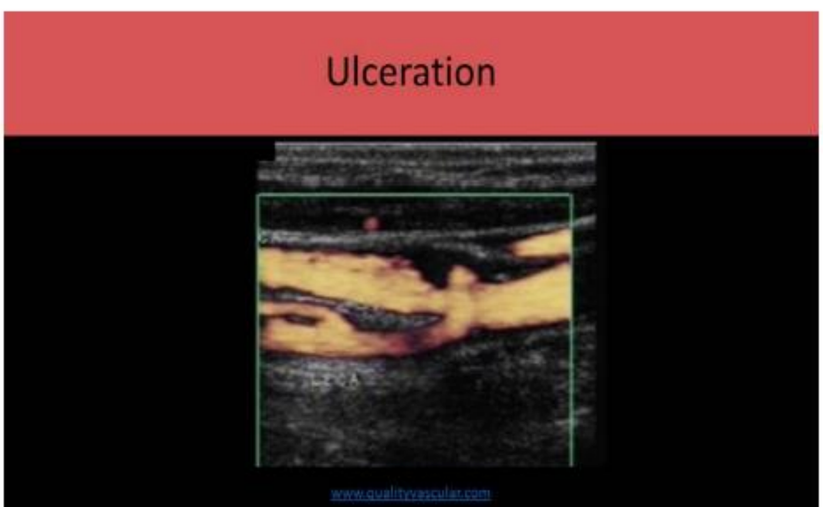


Reynold's Number:

- # expressing the balance of inertial and viscous forces acting on the blood flowing
- Used to discuss color Doppler turbulence
- Average flow speed X vessel diameter X density
- < 1500 for laminar flow
- > 2000 abnormal

Power Doppler Imaging:

- AKA Color Angio or Energy Mode
- Displays an approximation of lower echo amplitudes
- More sensitive to lower Doppler shifts than normal color-flow Doppler
- Demonstrates very low velocity blood flow with no aliasing
- Disadvantages: Low frame rates and more susceptible to tissue-motion artifacts



Power Doppler is much more sensitive to low velocity flow movement than color Doppler but in most US systems the direction of flow is not displayed with Power Doppler.

Color Doppler vs. Power Doppler

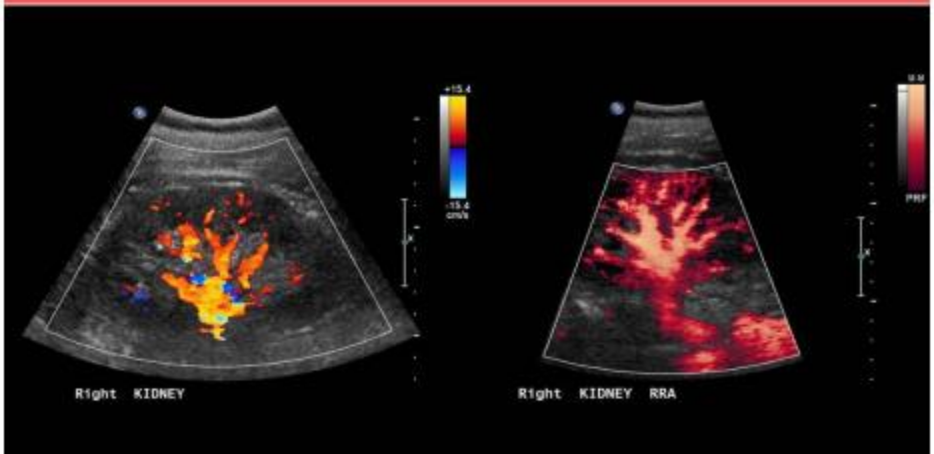


Image Courtesy of CLEMSON UNIVERSITY – CV IMAGING LEADERSHIP CONCENTRATION

EVALUATING TEST RESULTS:

1. Sensitivity-The ability of a test to detect disease when it IS present. The number of truly positive tests performed in the current modality is compared to the positive tests diagnosed by the gold standard test
 # True Positive Tests / Total # Positive Tests proven positive by the gold standard test

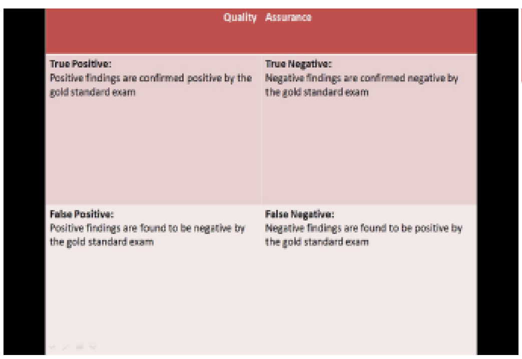
2. Specificity-The ability of a test to rule out disease when it IS NOT present. The number of truly negative tests performed in the current modality is compared to the negative tests diagnosed by the gold standard test
 # True Negative Tests / Total # Negative Tests proven negative by the gold standard test

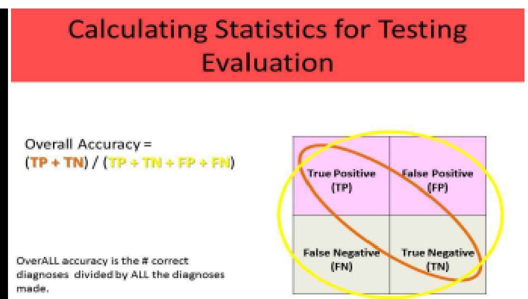
3. Positive Predictive Value-Calculates how often a positive study is correctly diagnosed; ability of an exam to predict the presence of disease
 # True Positive Tests / Total # Positive Tests

4. Negative Predictive Value-Calculates how often a negative study is correctly diagnosed; ability of the exam to predict the absence of the disease
 # True Negative Tests / Total # Negative Tests

5. Accuracy-ability of test to correctly identify disease or lack of disease; total number of correct diagnoses compared to the total number of tests;
 # True Positive Tests + # True Negative Tests / Total # Tests Performed

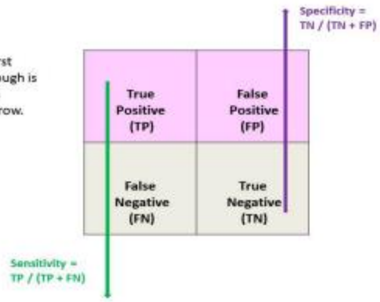
Overall accuracy value is always between sensitivity and specificity AND between PPV and NPV
EX: sensitivity 80%, specificity 92%, PPV 94%, NPV 88%
Accuracy must be between 80 - 92% AND between 88 - 94%
To meet all requirements the accuracy must be between 89 -91%
89% is greater than 80% sensitivity and greater than 88% NPV
91% is less than 92% specificity and less than 94% PPV





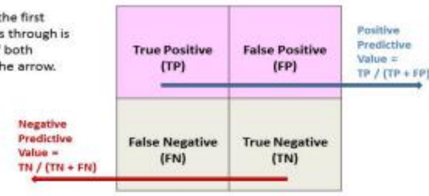
Calculating Statistics for Testing Evaluation

For each calculation, the first square the arrow goes through is divided by the sum of both numbers crossed by the arrow.



Calculating Statistics for Testing Evaluation

For each calculation, the first square the arrow goes through is divided by the sum of both numbers crossed by the arrow.



Quality Assurance

In order to validate test results, 450 patients underwent Ascending Venography and a Lower Extremity Venous Doppler Ultrasound to evaluate patients for DVT. 300 Veins were correctly diagnosed as having a normal flow or negative for DVT. 100 Veins were correctly diagnosed as having a thrombus present or positive for DVT. 35 Veins were incorrectly diagnosed with DVT by ultrasound and 15 Veins were incorrectly diagnosed as negative for DVT by ultrasound.

100 TP	35 FP
15 FN	300 TN

Sensitivity 100/ (100 + 15) = 87%

Specificity 300/ (300 + 35) = 90%

Positive Predictive Value 100/ (100 + 35) = 74%

Negative Predictive Value 300/ (300 + 15) = 95%

Accuracy 100 + 300/ (100 + 300 + 35 + 15) = 89%

Phantom Testing:

- A phantom is used as the standard for testing US system functionality
- Required for system calibration and to satisfy medical/legal needs for the facility

Uniformity:
- Evaluating the compensation controls
- Image taken with TGC set to display an even echogenicity from the top to bottom of the image
- TGC is then turned off to compare the images
- Normal results demonstrate a reduction in amplitude in the echoes in the far field on the second image

Dead Zone:
- Area closest to the transducer that cannot produce an accurate image due to reverberation
- Caused by the time it takes for the PE crystal and receiver to switch from transmit to receive
- Measured from the top of the phantom to the depth that uniform tissue is identified
- The dead zone depth should be as thin as possible with recommendations for normal depth set by manufacturer
- In normal scanning, a standoff pad is used to eliminate the dead zone and visualize superficial structures

Sensitivity:
- Ability to detect low level echoes accurately
- Turn the gain all the way down and then slowly increase it until the far field rods are visible on the image = minimum sensitivity
- Normal overall sensitivity is indicated when all rods are displayed on the image
- Number of visible rods on the image should be consistent between semi-annual assessments
- If less rods are visible on the current sensitivity test compared to the last sensitivity test = decreased system sensitivity, system service is needed

Registration Accuracy:
- Accuracy of the placement of the echoes on the screen as related to the structure placement in the body when the structure is scanned from different windows

Vertical Depth Accuracy:

- AKA range accuracy
- Reported in cm
- Accuracy of depth assessment of structures within the phantom
- A reflector is placed at a specific depth in the phantom
- A transducer is placed on the phantom and the distance to the reflector is measured
- The depth measured should correlate with the known depth of the reflector

Horizontal Calibration:
- Accuracy of the placement of echoes in the correct position along the horizontal axis of the image
- Evaluates the position of echoes along a line that is perpendicular to the beam
- Reported in cm

Spatial Resolution:
- Evaluates the minimum resolution capability of the system
- Determines minimum axial and lateral resolution capability
- Reported in mm
- Axial resolution refers to the smallest distance between two pins located parallel to the beam that are properly displayed as two separate echoes
  - 6 or more rods are placed in a row at different millimeter intervals from top to bottom in the phantom
  - The ability to resolve the pins as separate structures and the minimum distance visible between those pins is used to assess the minimum axial resolution
  - Axial resolution should be constant across the image

- Lateral resolution refers to the smallest distance between two pins located side by side (perpendicular to the beam) that are properly displayed as two separate echoes on the image
  - 6 or more rods are placed at specific depths on the image
  - The vertical depth calibration rods can be used to assess the width of the reflector rods
  - Rod width is constant and they are placed at specified depths within the phantom
  - The transducer is tested for proper display of an expected width measurement of the rods at each depth
  - Lateral resolution is degraded as the beam gets farther from the transducer and the rods appear widest in the far field

Contrast Resolution:
- Structures of different densities are placed within the phantom
- Tissue background is the reference point at 0dB
- Negative values indicate a less echogenic or anechoic structure
- Positive values indicate a more echogenic structure