

PRINCIPLES OF DOPPLER ULTRASOUND

Definitions

- **Frame rate:**
 - “real-time” ultrasound is generated by a series of still frames that are displayed in rapid succession, creating motion
 - Frame rate is expressed as the number of frames per second (FPS)
 - Motion pictures use upwards of 24 FPS

Definitions

- **Temporal resolution**

- Ability to detect an object has moved over time
- Related to frame rate

- **Spatial resolution**

- Ability to distinguish two points as separate in space in any direction

- **Artifact**

- Structure not naturally present
- Formed by artificial means

Definitions

- **Spectral Broadening**
 - Filling-in and widening of spectral waveform
- **Range gate**
 - Same as sample volume (sv) or sample gate
- **Bi-directional**
 - Ability to display forward and reverse flow directions

Definitions

- **Cosine θ (theta)**

- In Doppler ultrasound, the numeric value of the angle (theta) at which the ultrasound beam intersects with the axis of flow

- **B-mode ultrasound**

- Brightness mode ultrasound, aka, 2-D in cardiac ultrasound nomenclature
- Image is created by pixels of different shades of grey or “brightness”
- Based on the strength (amplitude) of reflected energy

Definitions

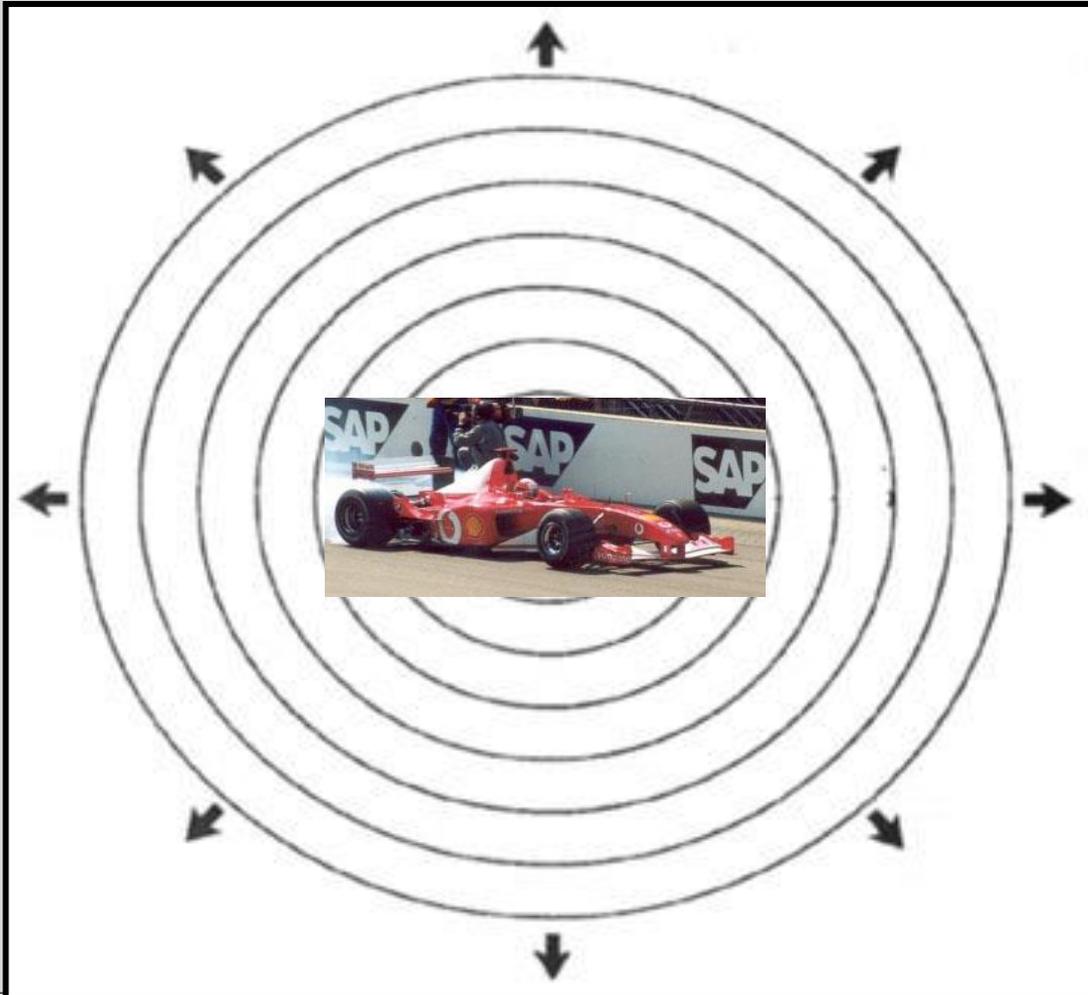
- **Scanline**

- Line or path of ultrasound beam, and subsequent echo
- Multiple scanlines, generated by multiple piezo elements, are used to create an image “frame”

Doppler Shift

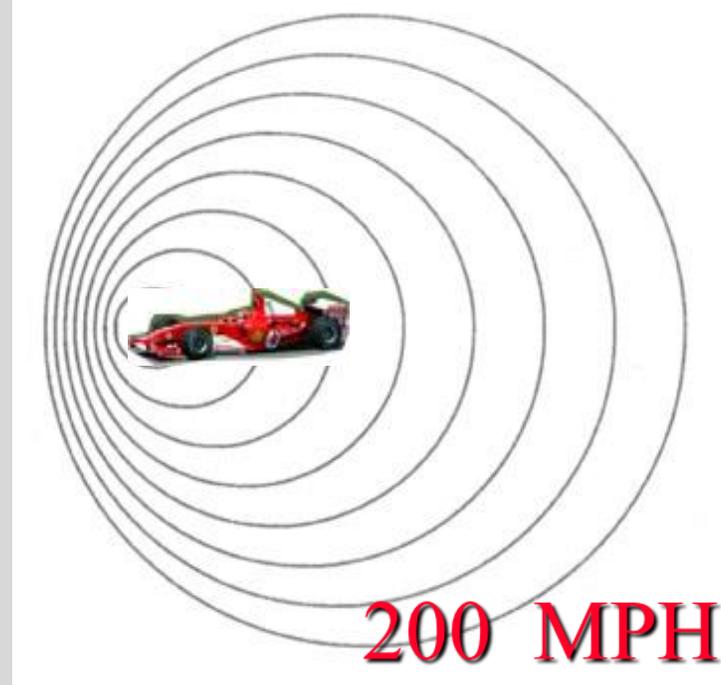
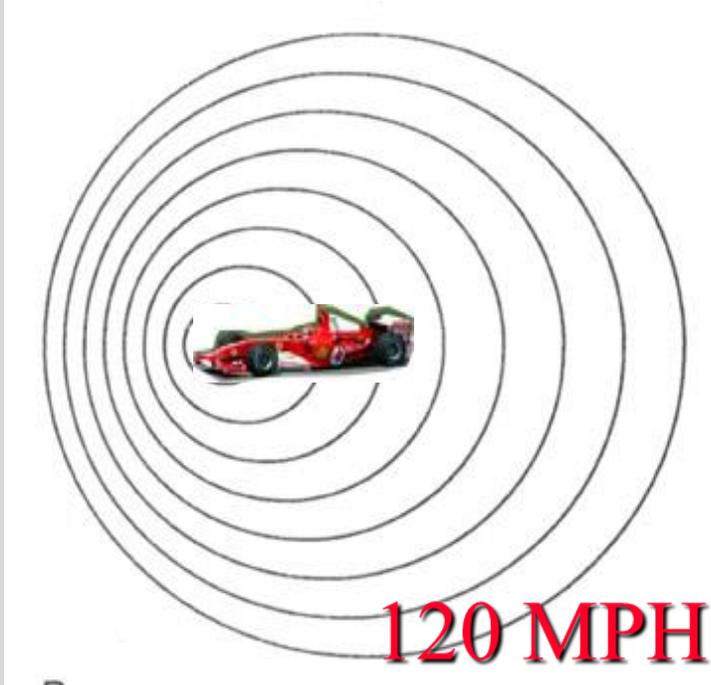
- Light or sound from moving objects will appear to have different wavelengths depending on the relative motion of the source and the observer.
 - If sound source moves rapidly towards the observer, the audible frequency will increase
 - If sound source moves away rapidly, frequency will decrease
 - Same goes for light waves/frequency

Doppler Shift



- Formula 1 race start:
- No movement = no Doppler shift
- Sound is emitted in all directions and frequency is similar in all directions

Doppler Shift



- Frequency increases in front of car, decreases as it moves away
- Faster the car goes, the greater the frequency “shift”

Doppler in Vascular

- Blood cells don't emit a sound
 - We transmit a sound, and evaluate the echo
- Difference between the transmitted frequency and the reflected frequency (the echo) is called the Doppler shift
- Imaging and Doppler ultrasound use piezoelectric effect

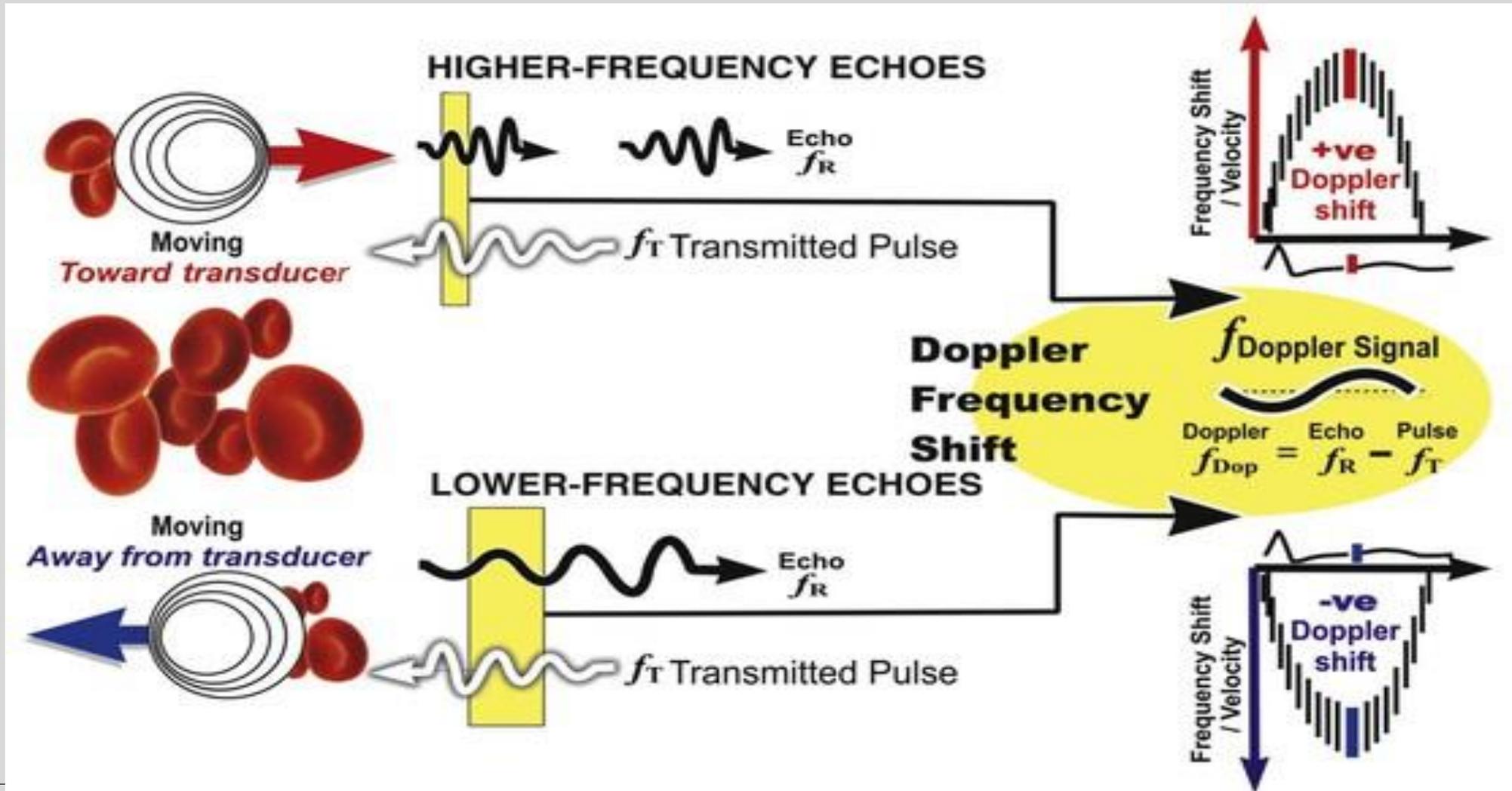
Frequency

- Frequency of the transmitted signal depends on the size of the elements
 - Thinner crystals = higher frequency
 - Thicker crystals = lower frequency
- Units: 1 sound wave/cycle per second, or Hz
- For diagnostic ultrasound, Doppler frequency is between 2.0 – 12 MHz

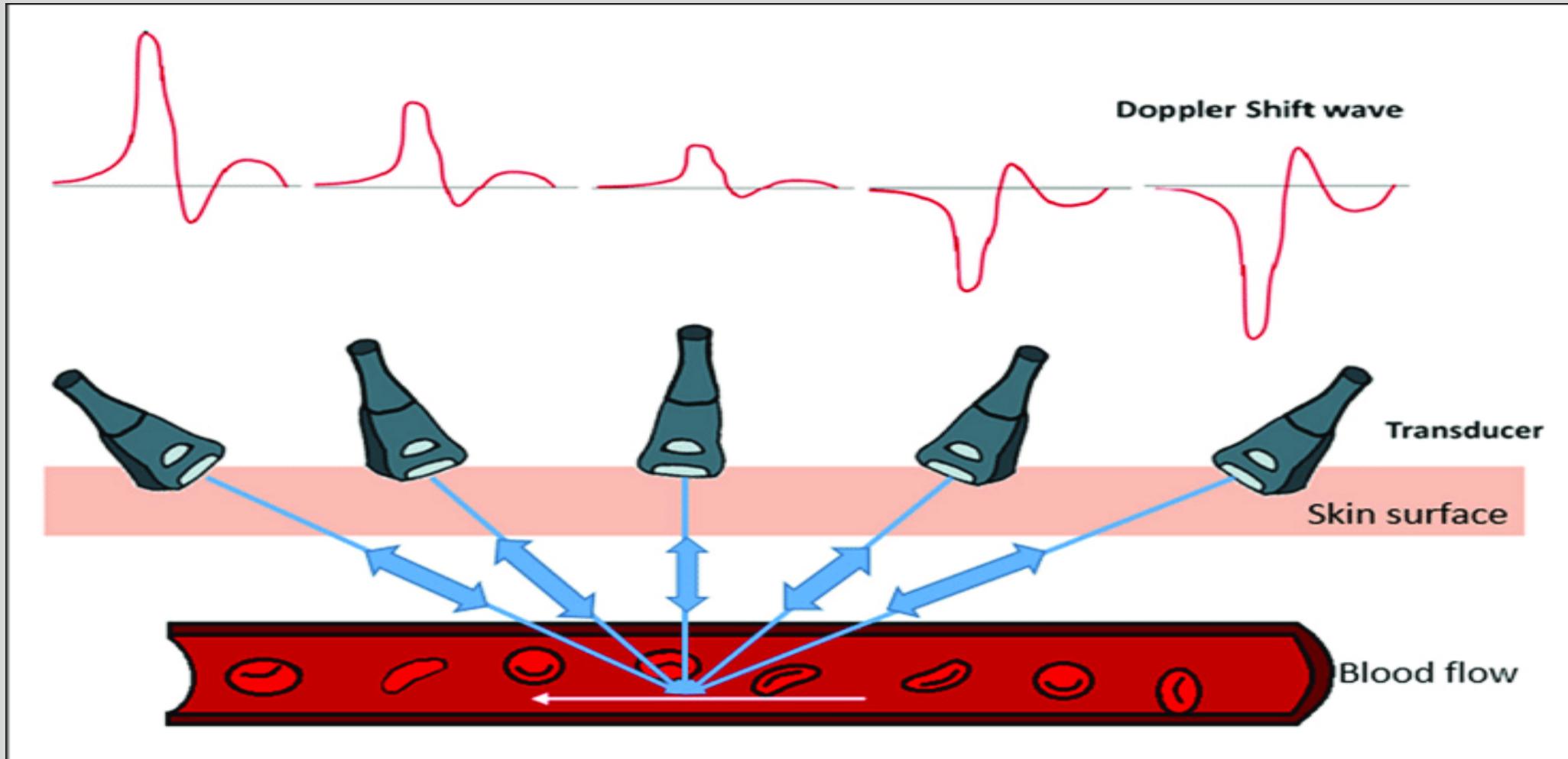
Bi-directional Doppler

- Quadrature detection and processing allows “directionality”
 - Transmitted frequency is subtracted from the returning frequency
 - If the returning frequency is higher, the Doppler shift is “positive” (+)
 - If the returning frequency is lower, the Doppler shift is “negative” (-)

Frequency Shift

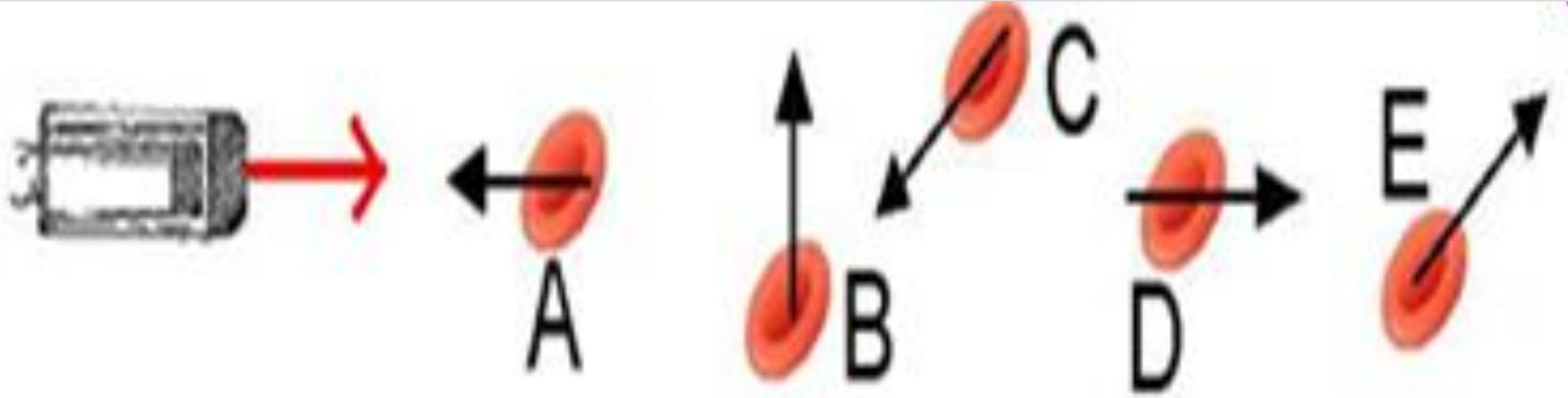


Doppler Angle vs Freq. Shift

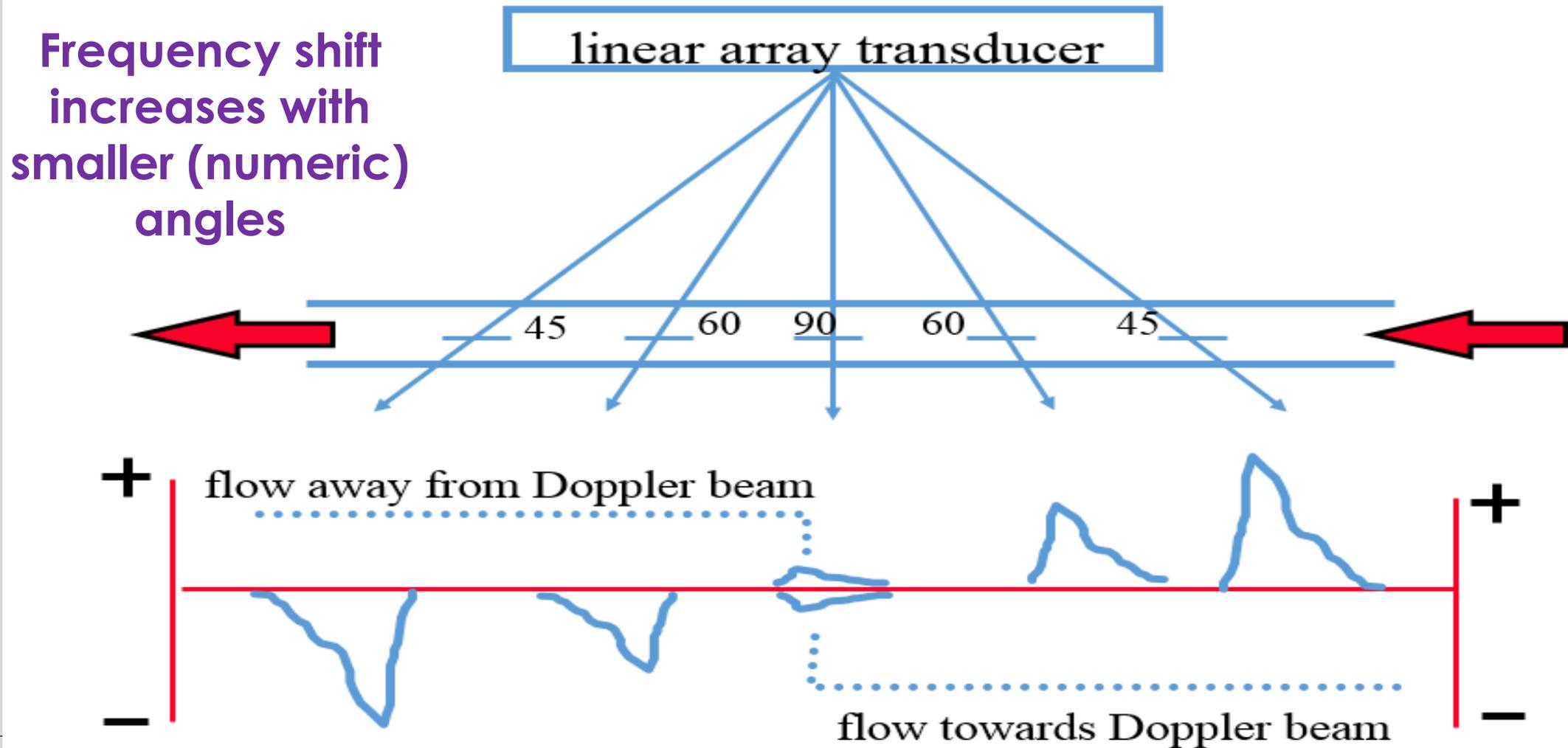


Frequency Shift is Related to:

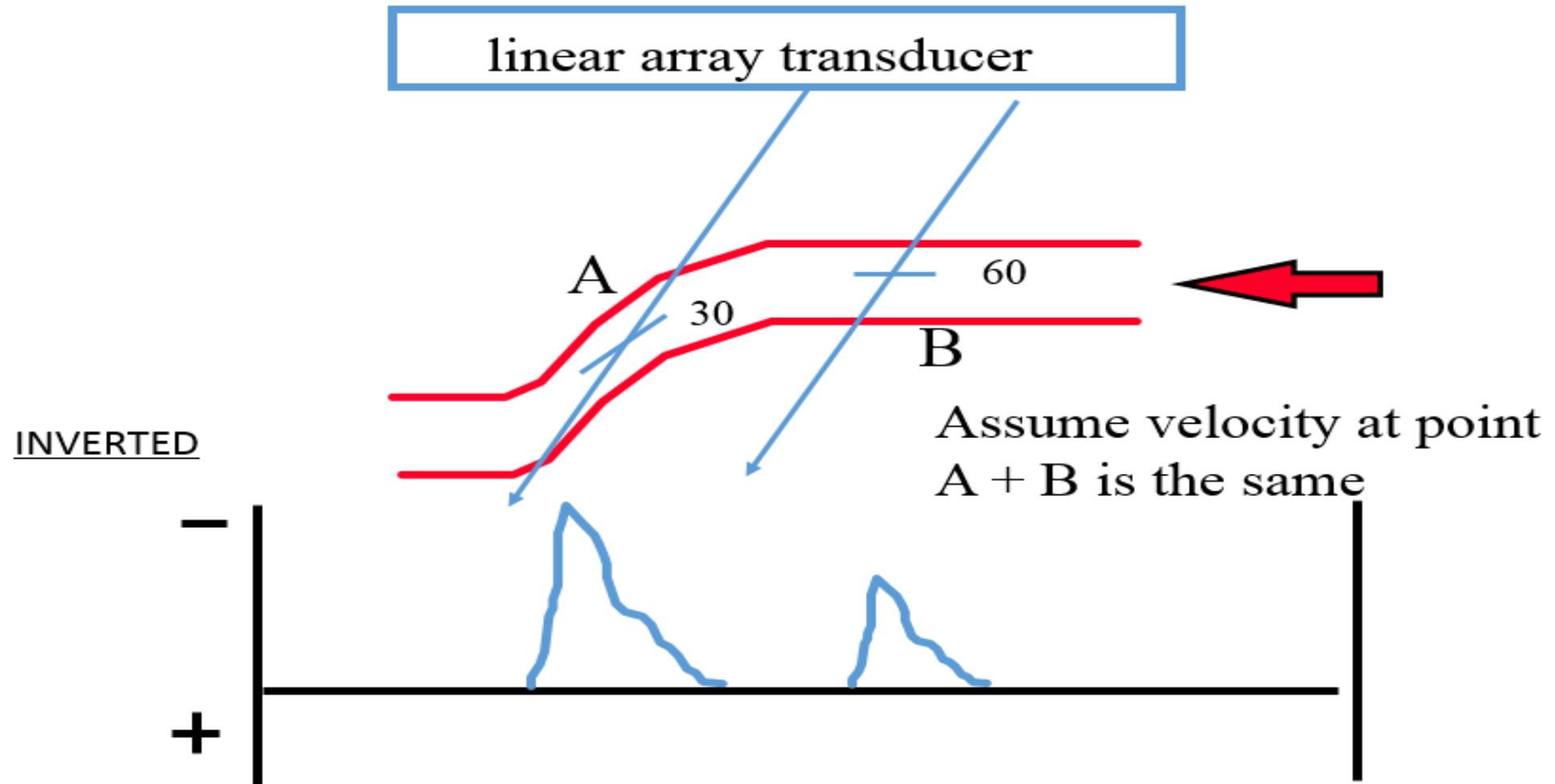
- Transmitted Doppler frequency
- Velocity of blood cells
- Angle of Doppler beam to flow
 - 0° = highest frequency shift
 - 90° = lowest frequency shift (worst Doppler angle)
 - 45 -**60** $^\circ$ = most attainable angle for our scanning purposes



Doppler Angle vs. Freq. Shift



Frequency Increase Due to Angle



Doppler Equation

$$\Delta f = \frac{2 f_t V \cos\theta}{C}$$

- Δf = frequency shift
- $2f_t$ = 2 x transmitted frequency
- V = velocity
- $\cos \theta$ = Cosine theta – Doppler angle of incidence
- C = average speed of sound in tissue

Mnemonic tip...



= 3 other things

$$C \Delta F = v \ 2f_t \ \text{Cos}\theta$$

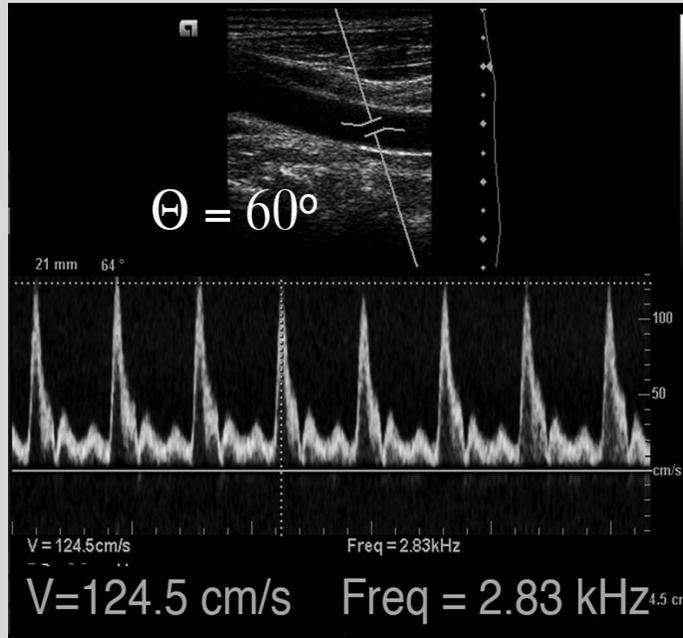


Figure A - 60°

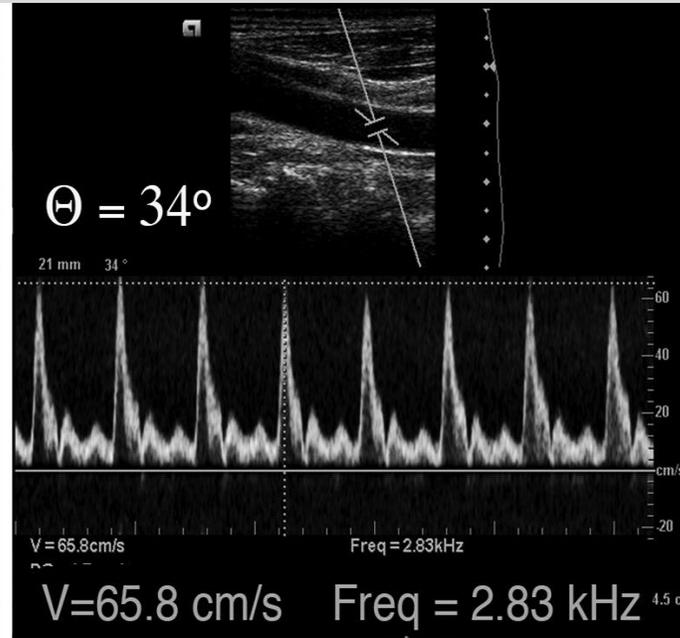


Figure B - 34°

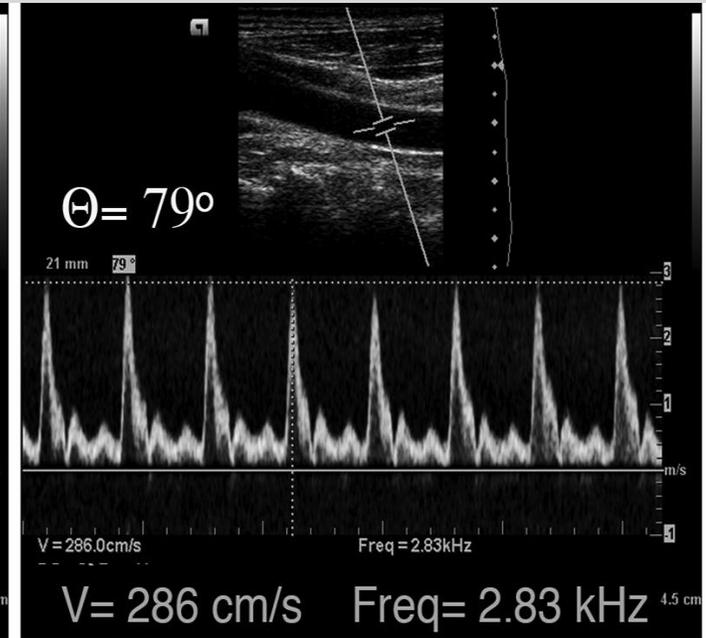
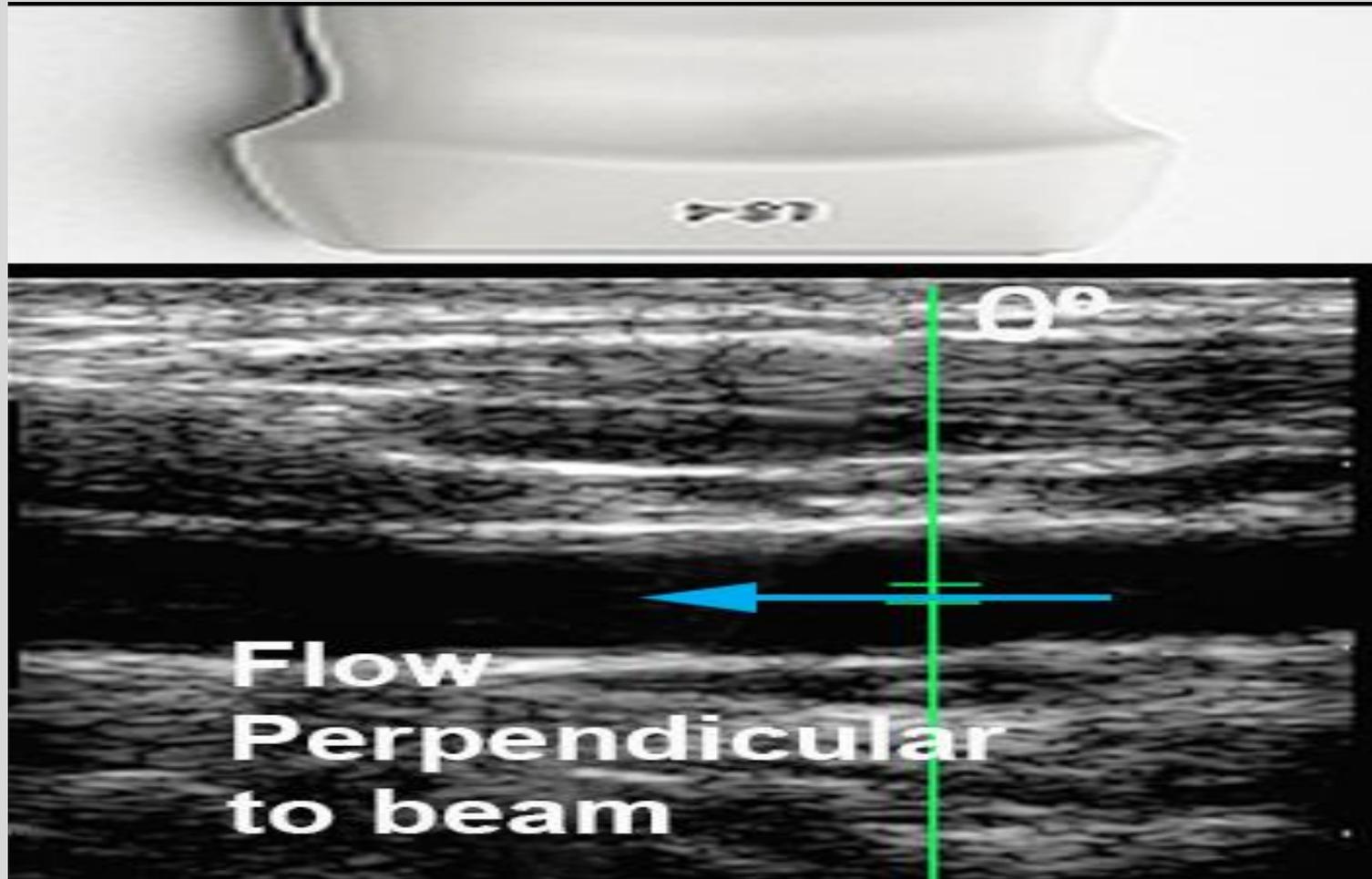


Figure C - 79°

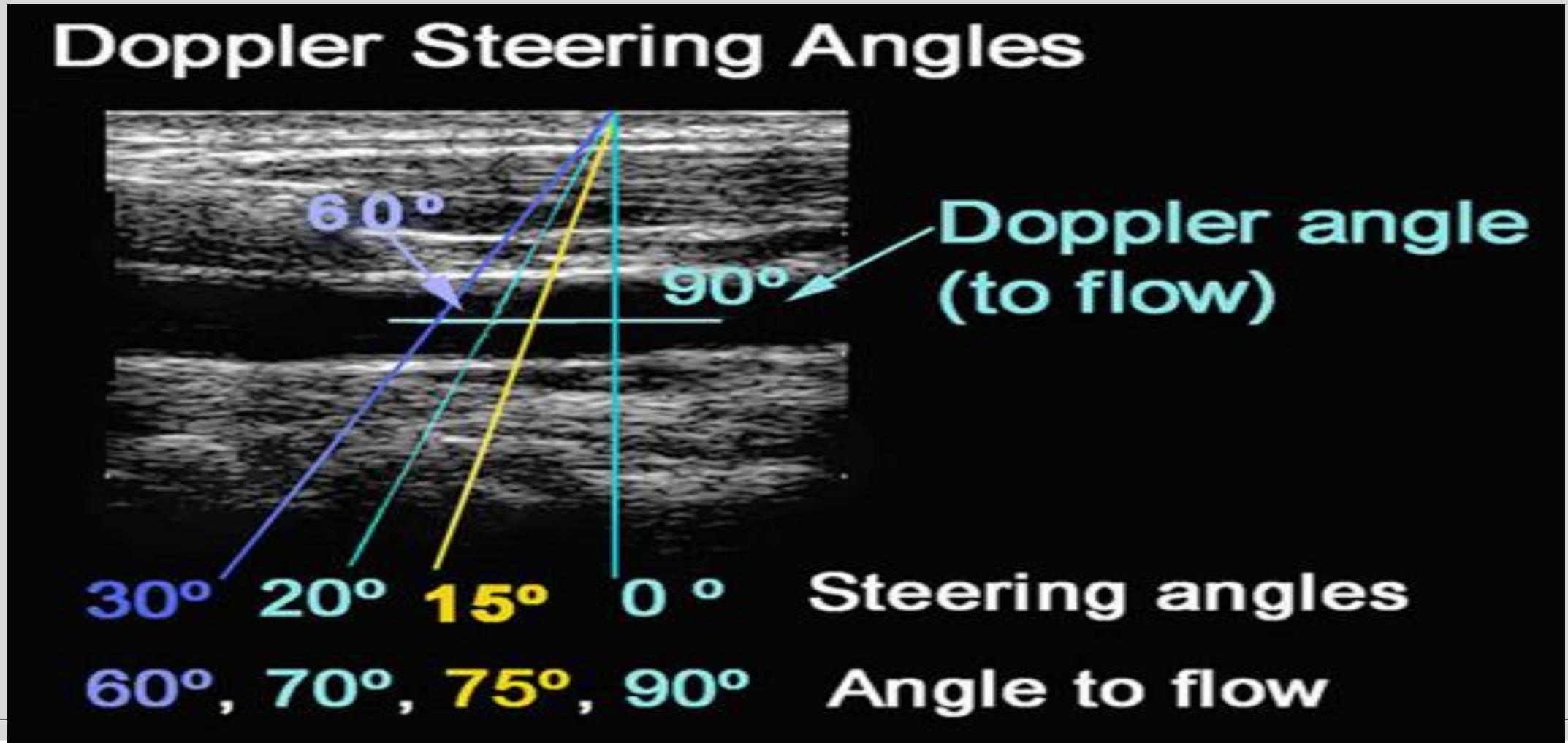
Frequency is the same in A, B, and C. Notice how the **velocities** are different due to different cosine θ angles!!!!

$$V = \frac{\Delta F}{\text{Cos } \theta}$$

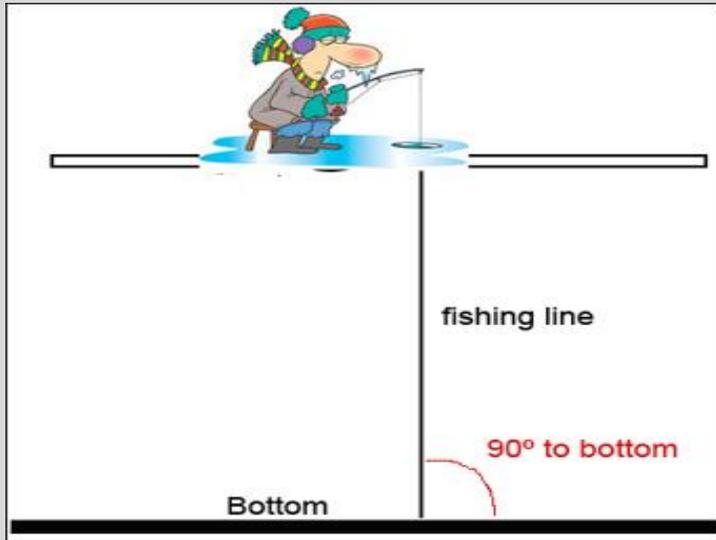
Vascular is a horizontal world



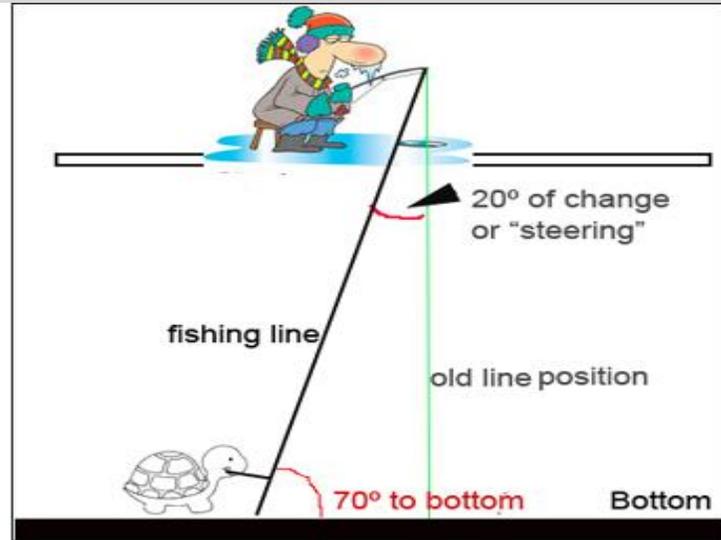
Steering Angle vs. Angle of Incidence



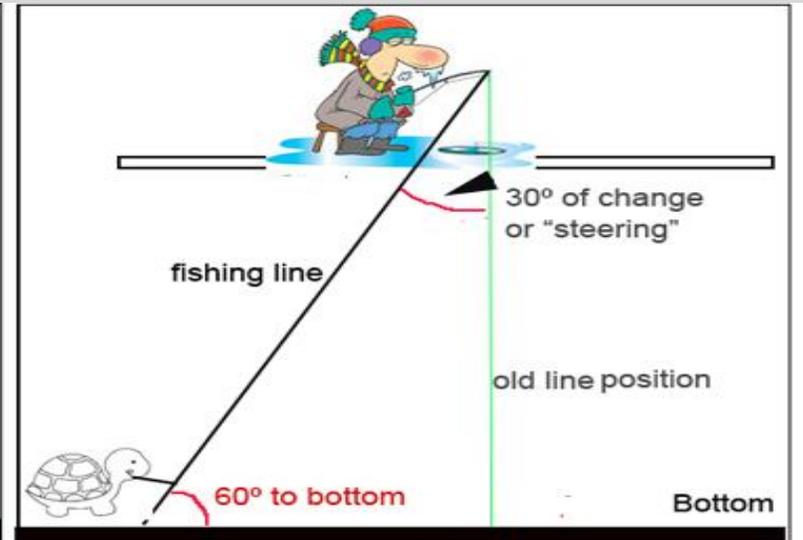
Steering Angle Explained



Ice fisherman with his fish line dropped straight down through the hole (zero degrees of line angle). The bottom angle is 90 degrees.



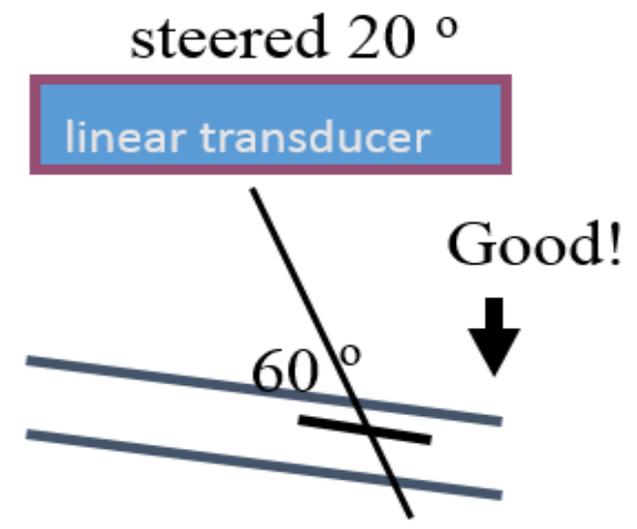
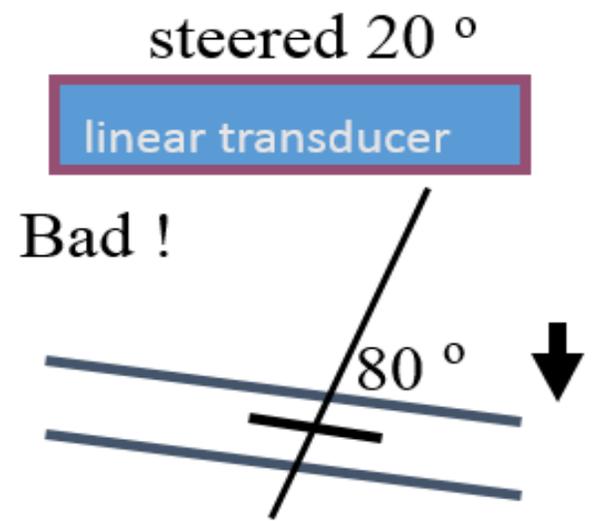
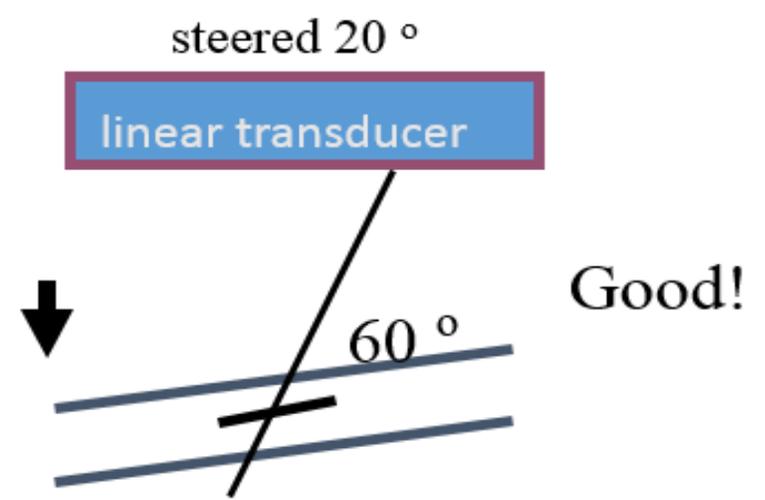
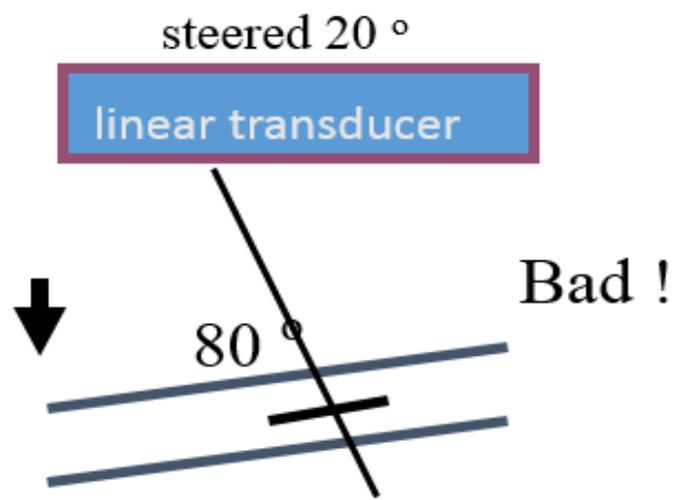
A turtle grabs the bait and walks a few feet along the bottom. The line angle has changed by 20° from where it was. The bottom angle is now 70 degrees.



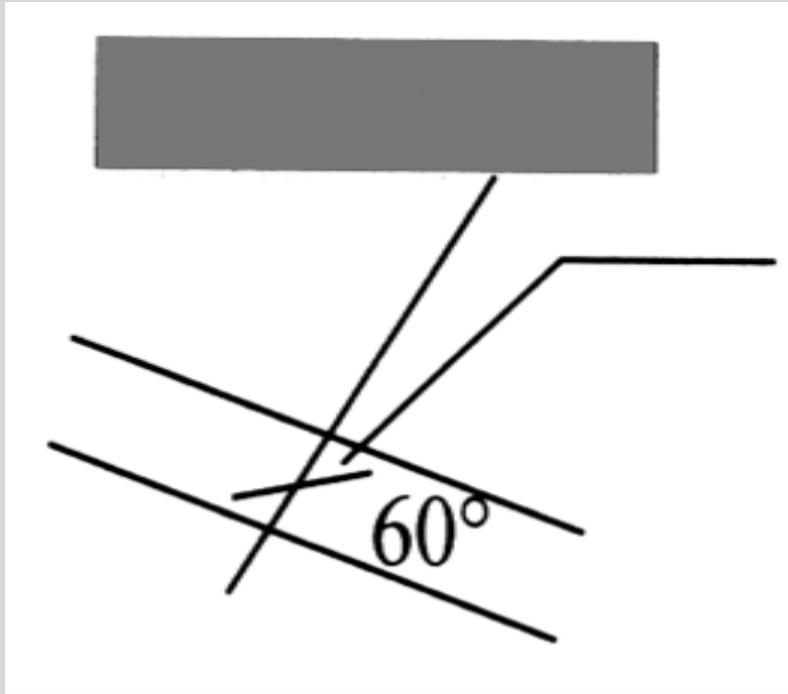
Turtle pulls the bait several more feet along the bottom. The line angle is now 30° from where it was originally at zero. The bottom angle is now 60 degrees.

Doppler Beam Steering

- Purpose: to achieve a 60° angle to flow (or less)
 - AKA “angle theta”
 - AKA the Doppler angle
- To obtain Doppler angles of 60° or less, steer your box to the side that is deeper!!
- Phased array transducers use electronic steering technology



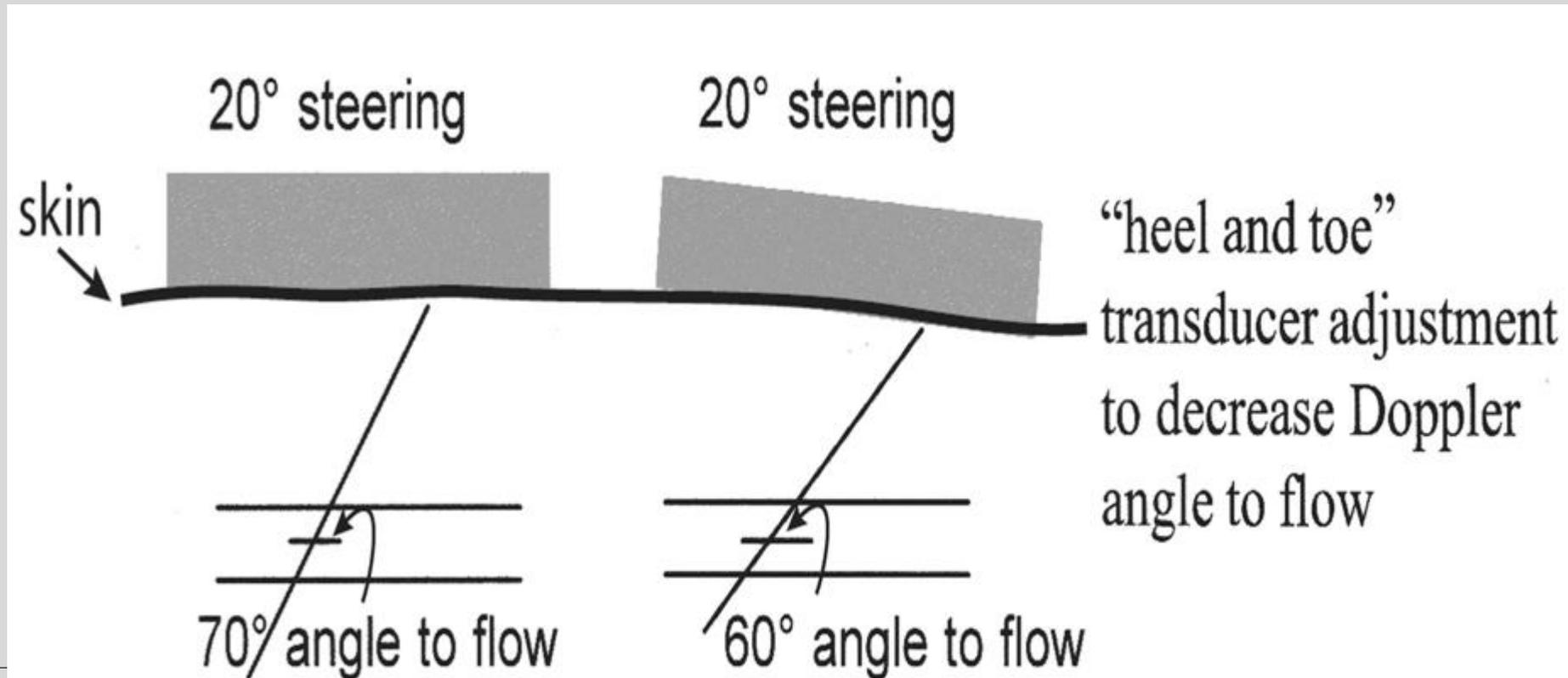
- Doppler angle cursor must be aligned to the axis of flow



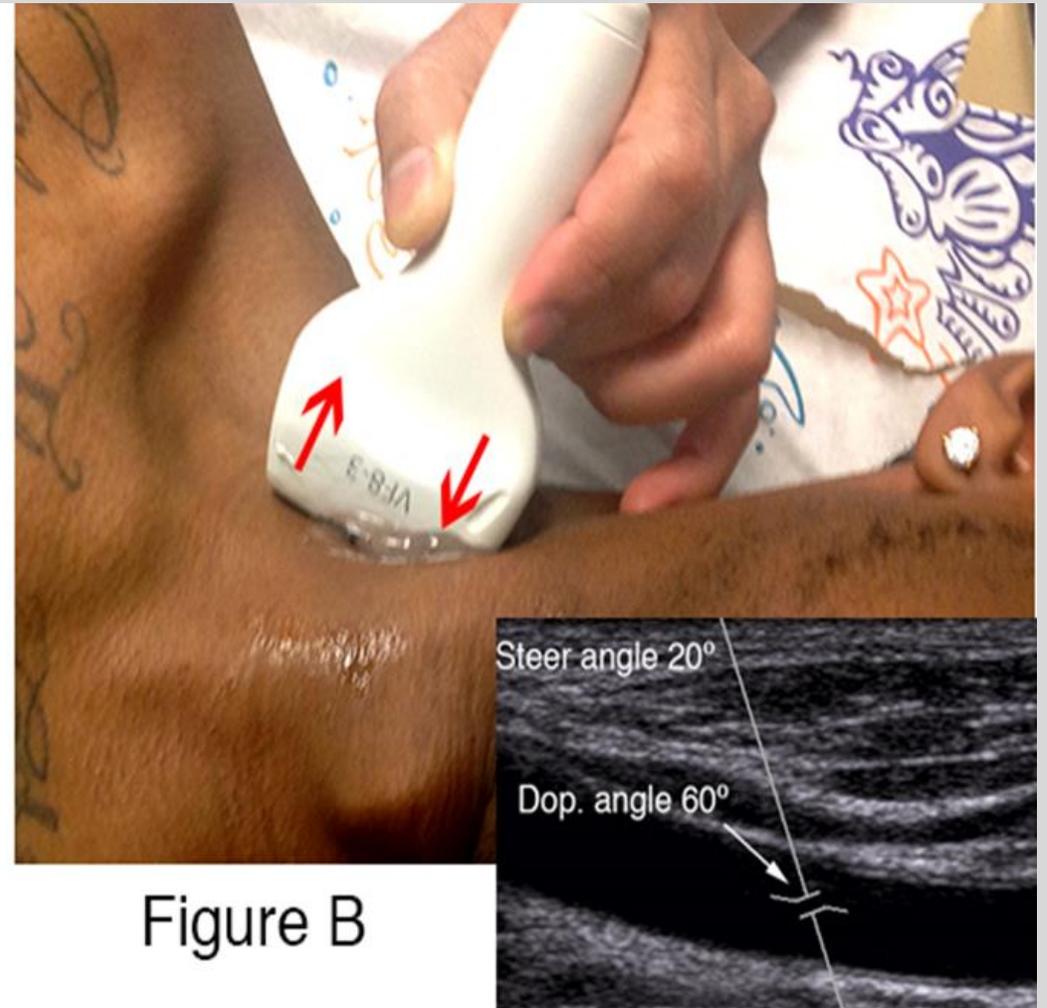
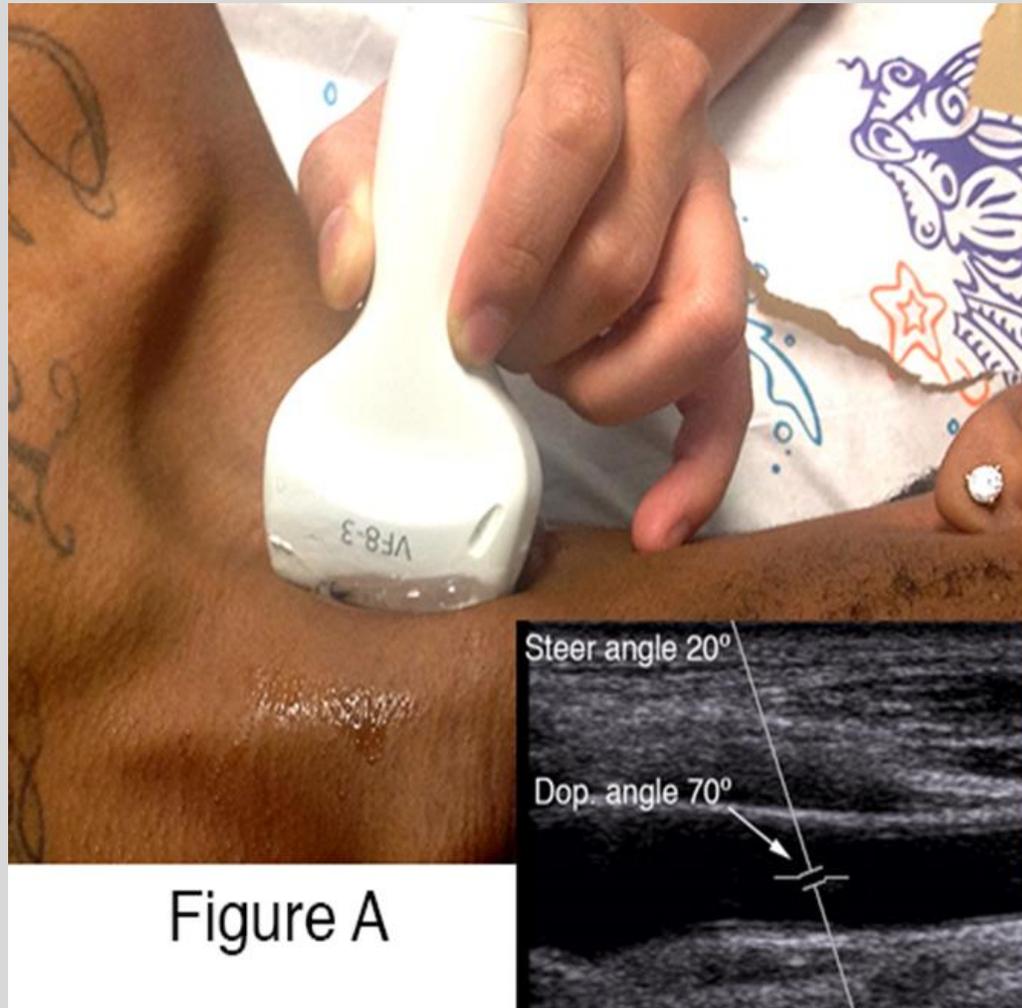
Wrong!!! The angle correction cursor is misaligned; this is **not** a 60° angle-to-flow.

“Heel & Toe”

- Manual transducer adjustment used to decrease Doppler angle flow

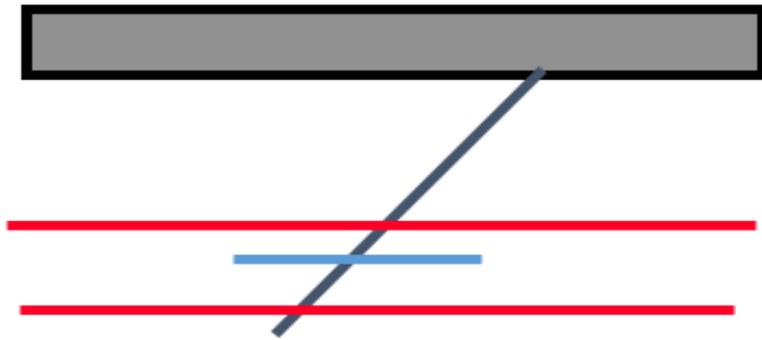


“Heel & Toe”

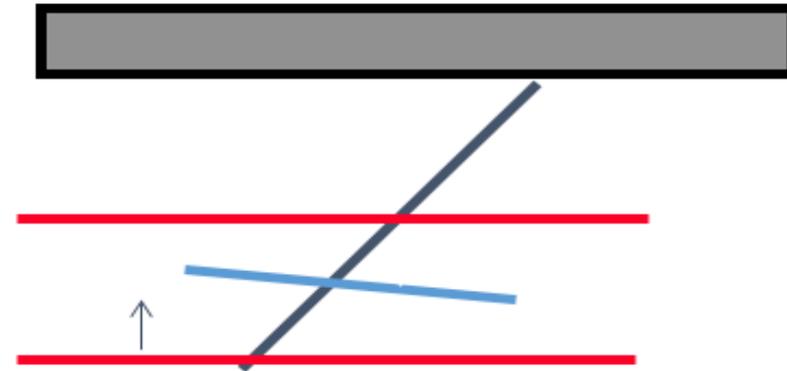


Angle Cursor Misalignment

Actual Velocity = 100 cm/s



Perfect alignment,
Velocity = 100 cm/s



5 degree inadvertent misalignment

5° off at 40° = vel. calc = 108 cm/s

5° off at 60° = vel. calc = 118 cm/s

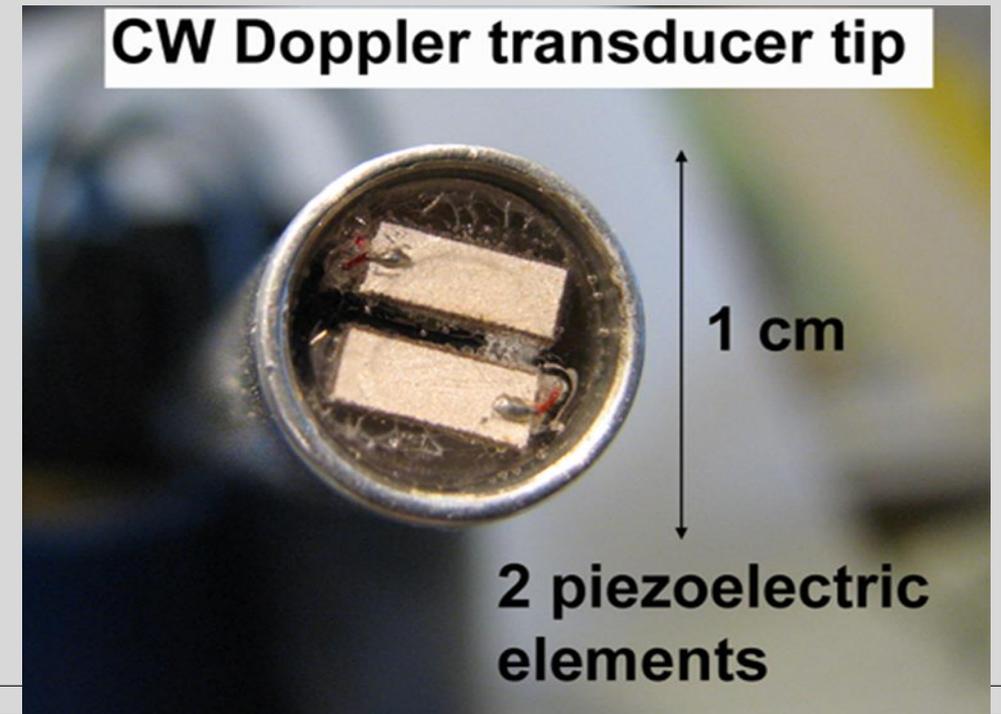
5° off at 80° = vel. calc = **195 cm/s !!**

Flow Velocity Estimation Purpose

- Helps to quantify arterial stenosis
- Defines pathologic conditions
- Typical measurements include peak systolic velocity (PSV) and end diastolic velocity (EDV)
- Frequency shift and Doppler angle to flow are essential ingredients

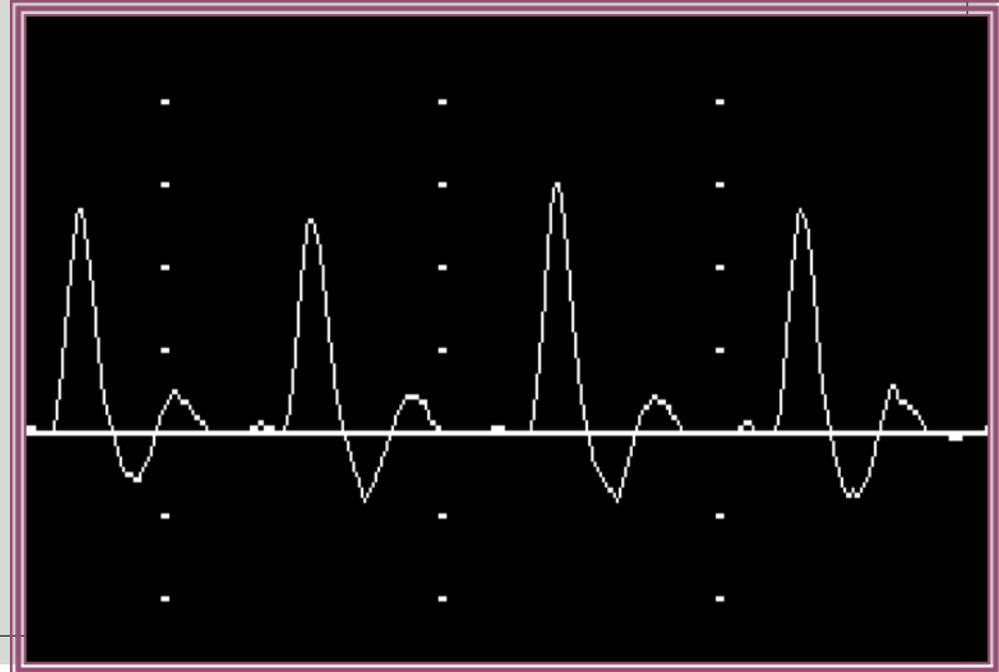
Doppler Devices

- Continuous-wave (CW) Doppler:
 - 2 piezoelectric crystals: one transmitting, one receiving
 - No aliasing artifact
 - Not specific for depth



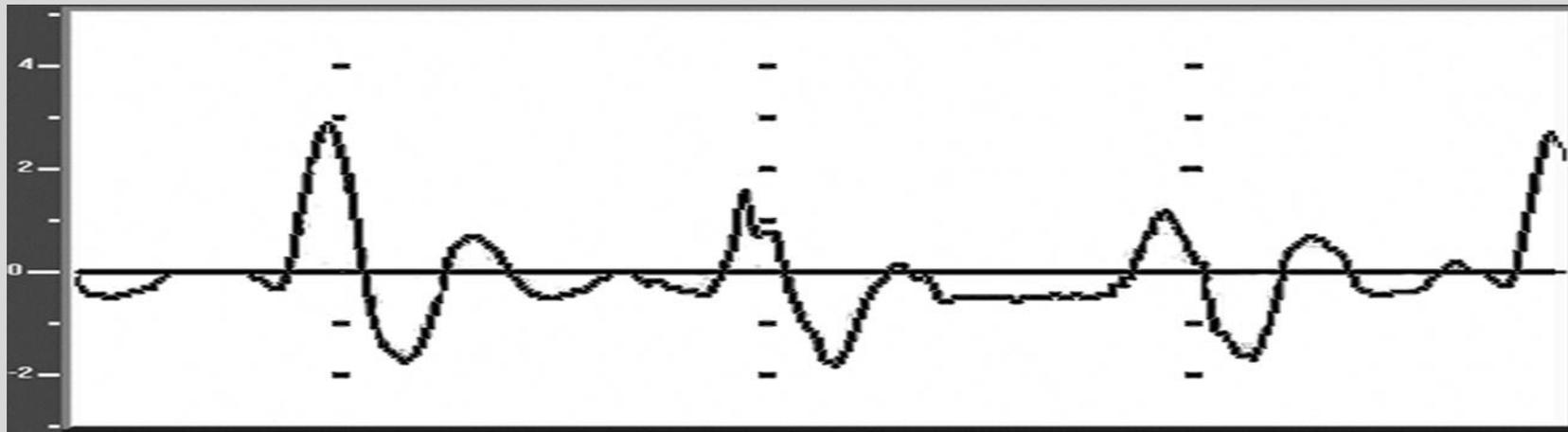
Analog Doppler

- Common form of CW Doppler
- Zero-crossing detection method
- Displays average frequency shift
- Not depth specific
- No sample volume



Analog Doppler

- If venous and arterial signals are present in the beam path, they're averaged together, and distortion of the waveform occurs

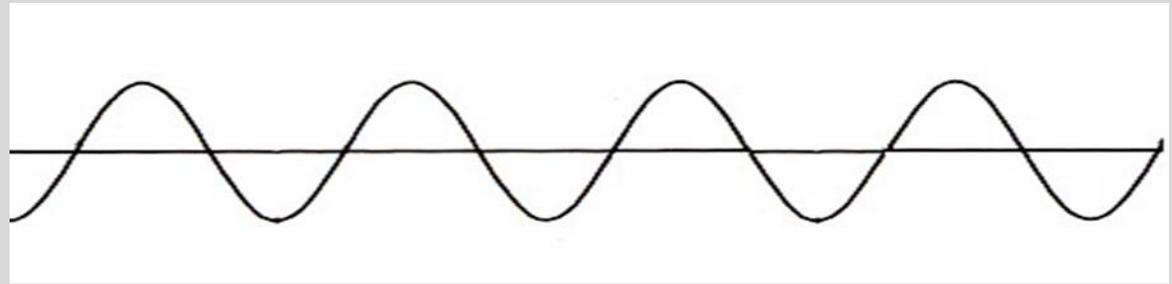
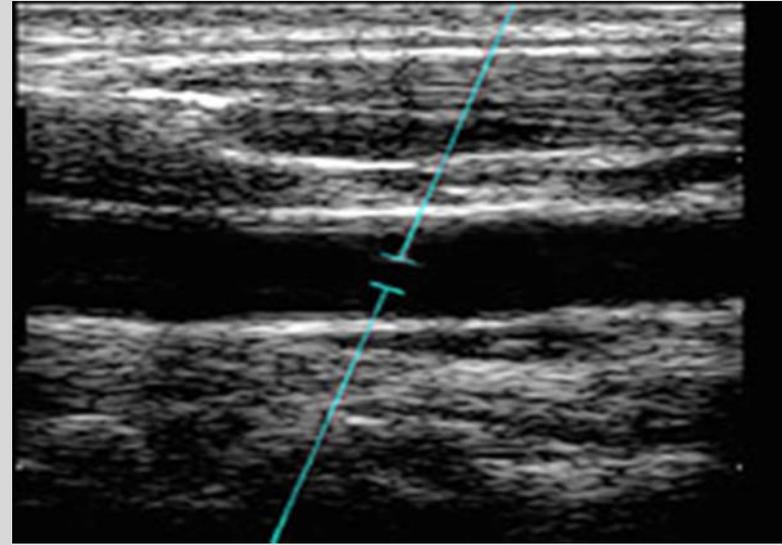


Pulsed Wave Doppler

- Alternates pulse transmission and reception
- Transducer design can be variable
- Sample volume is integral to pulse Doppler systems
 - Aka “range gate” or “sample gate”

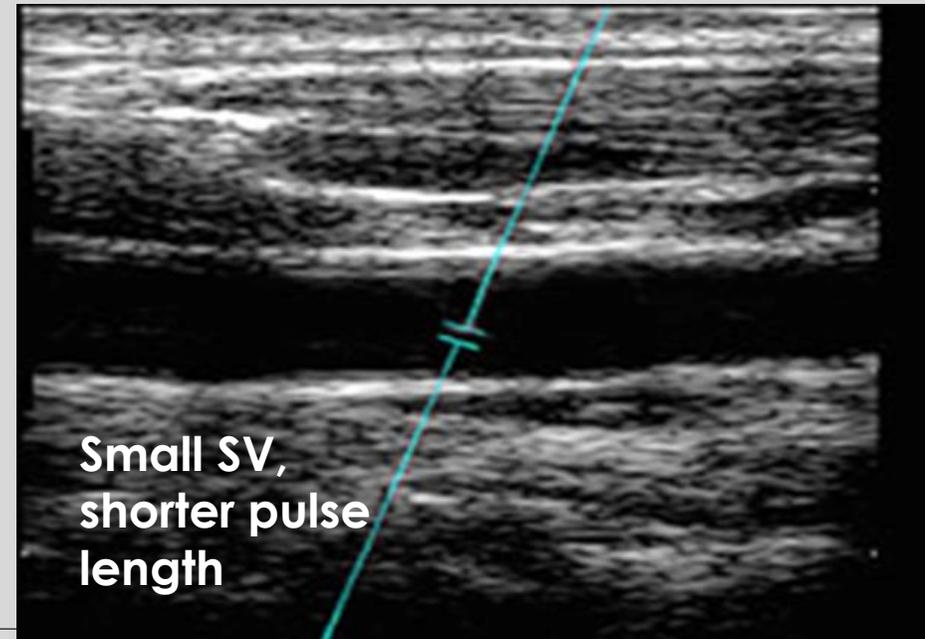
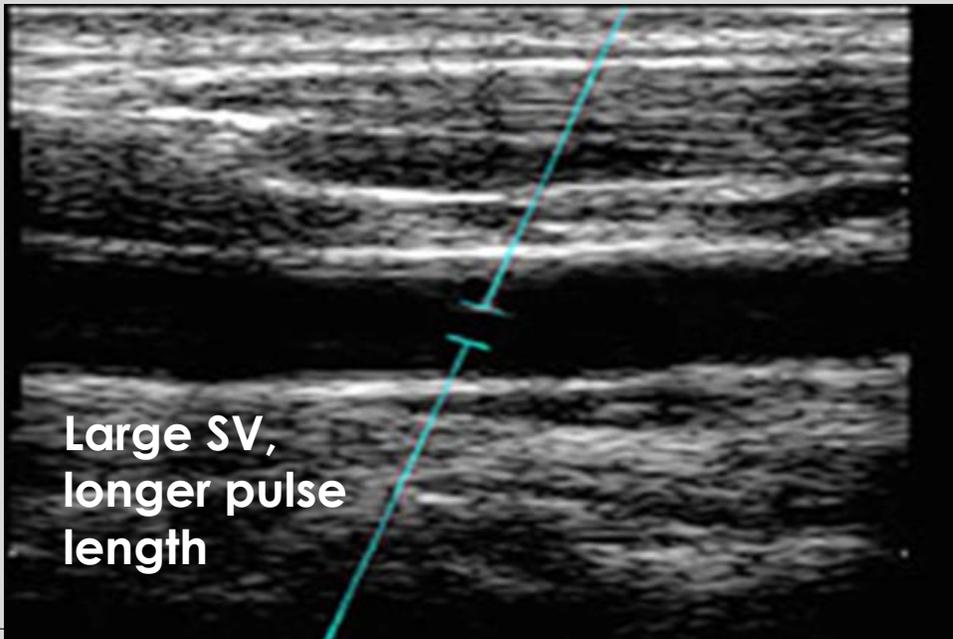
Sample Volume

- Sample volume height determines the transmit pulse
- Evaluates the “ring time” or duration of transmission



Sample Volume

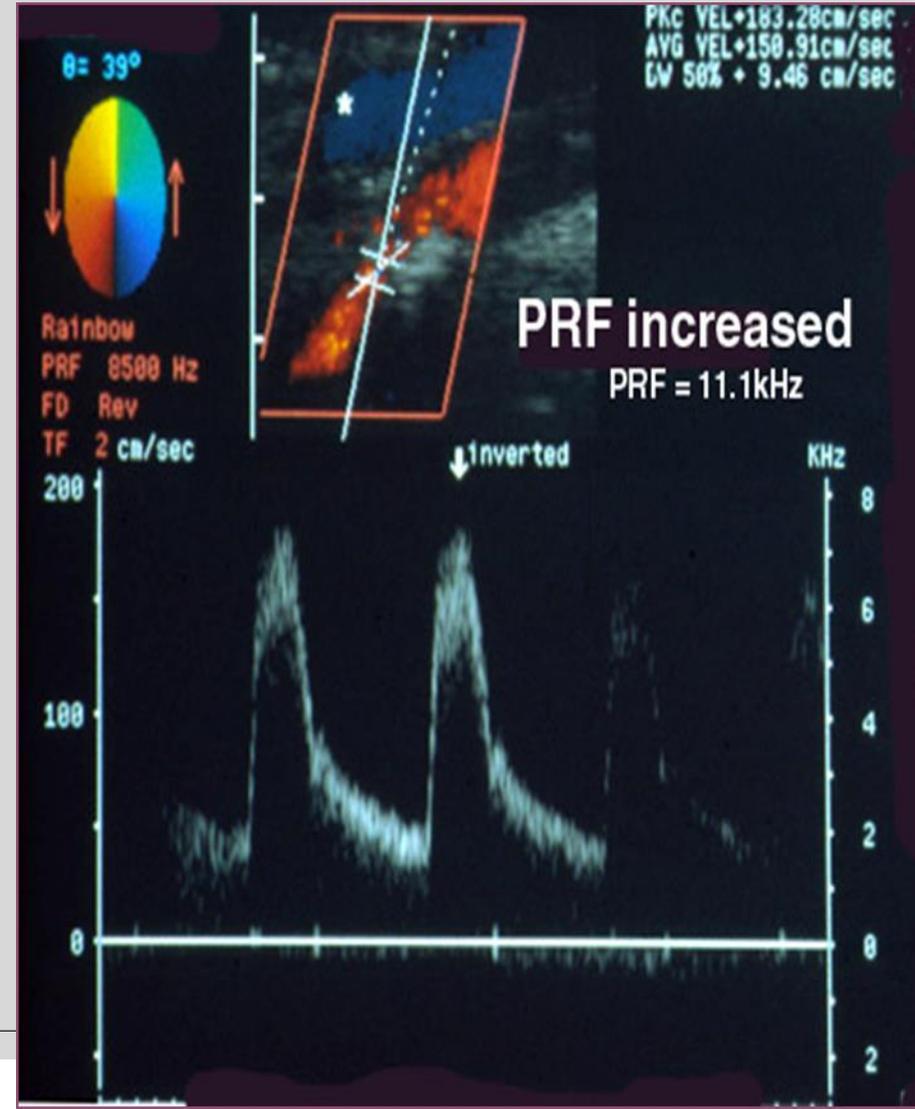
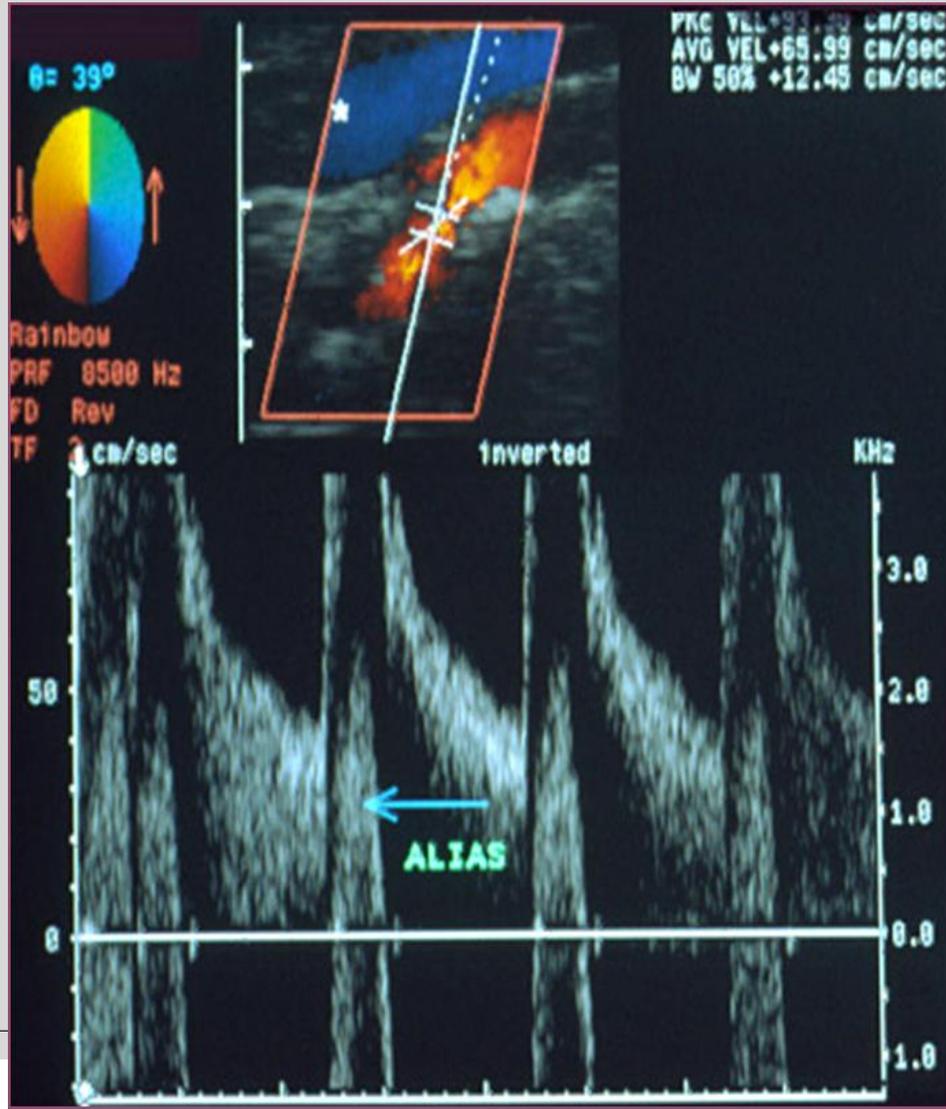
- Transmitted Doppler pulse contains numerous cycles
- The number of cycles in a pulse multiplied by the wavelength = spatial pulse length



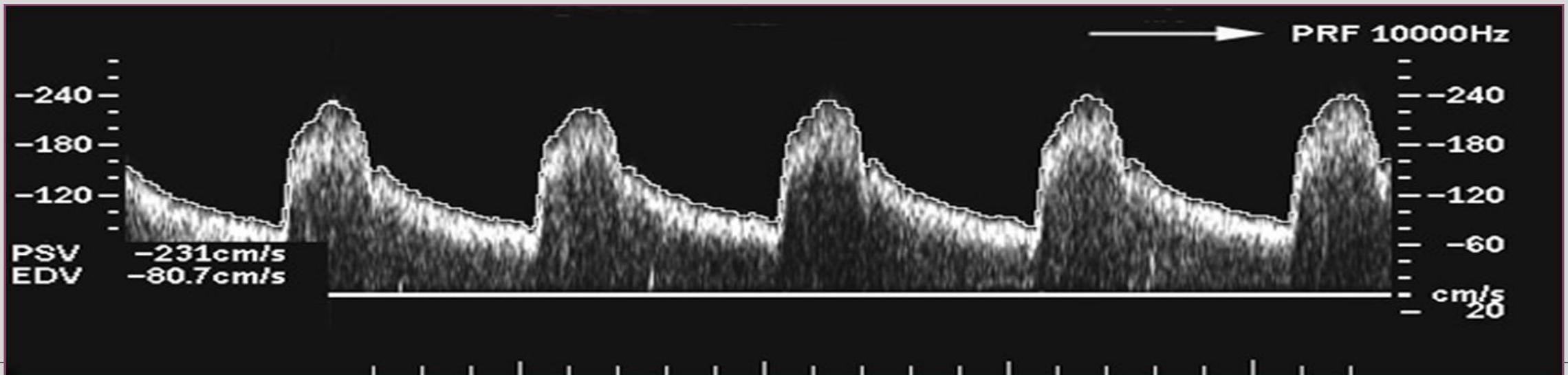
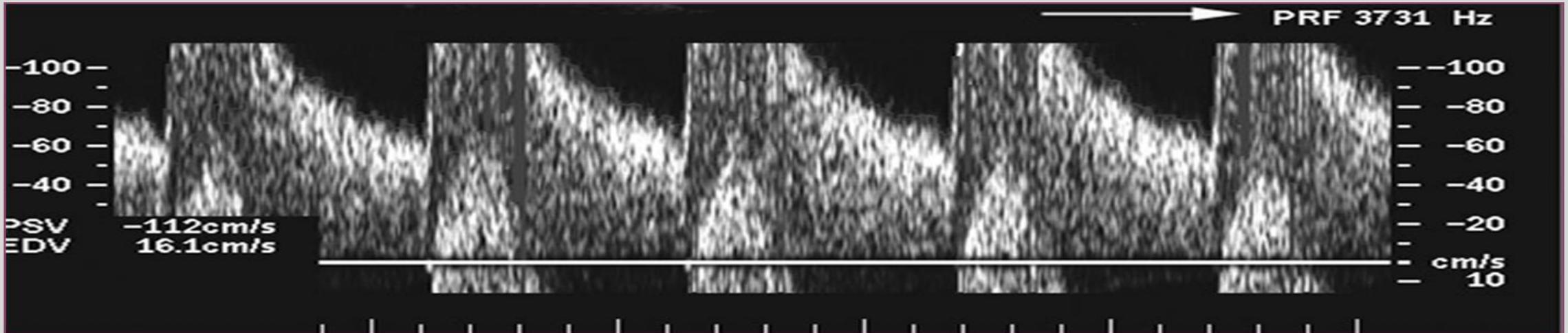
Pulse Repetition Frequency

- Number of pulse-echo cycles per second
- Units: Hz
- Aliasing occurs when Doppler shift frequencies exceed $\frac{1}{2}$ the PRF
- PRF is adjusted with “scale” control

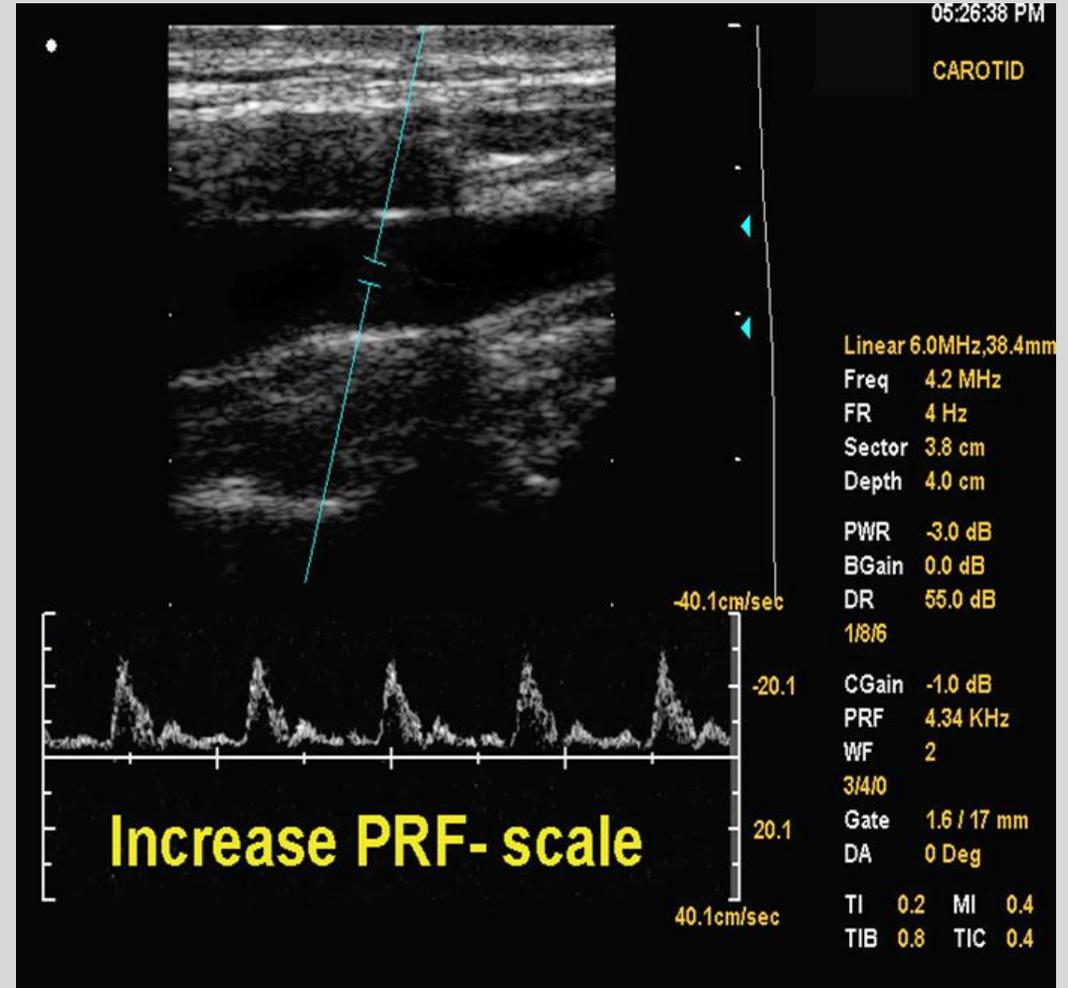
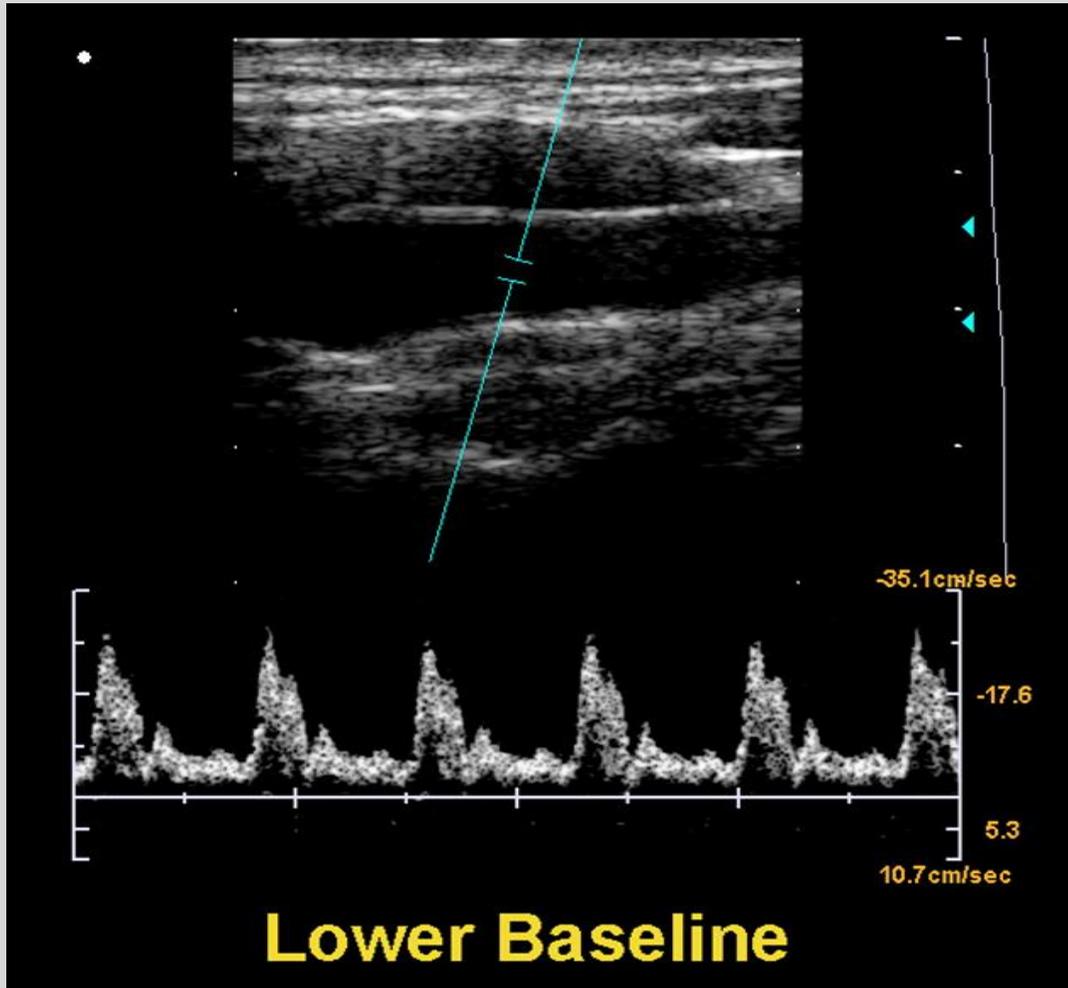
Spectral Aliasing



Aliasing



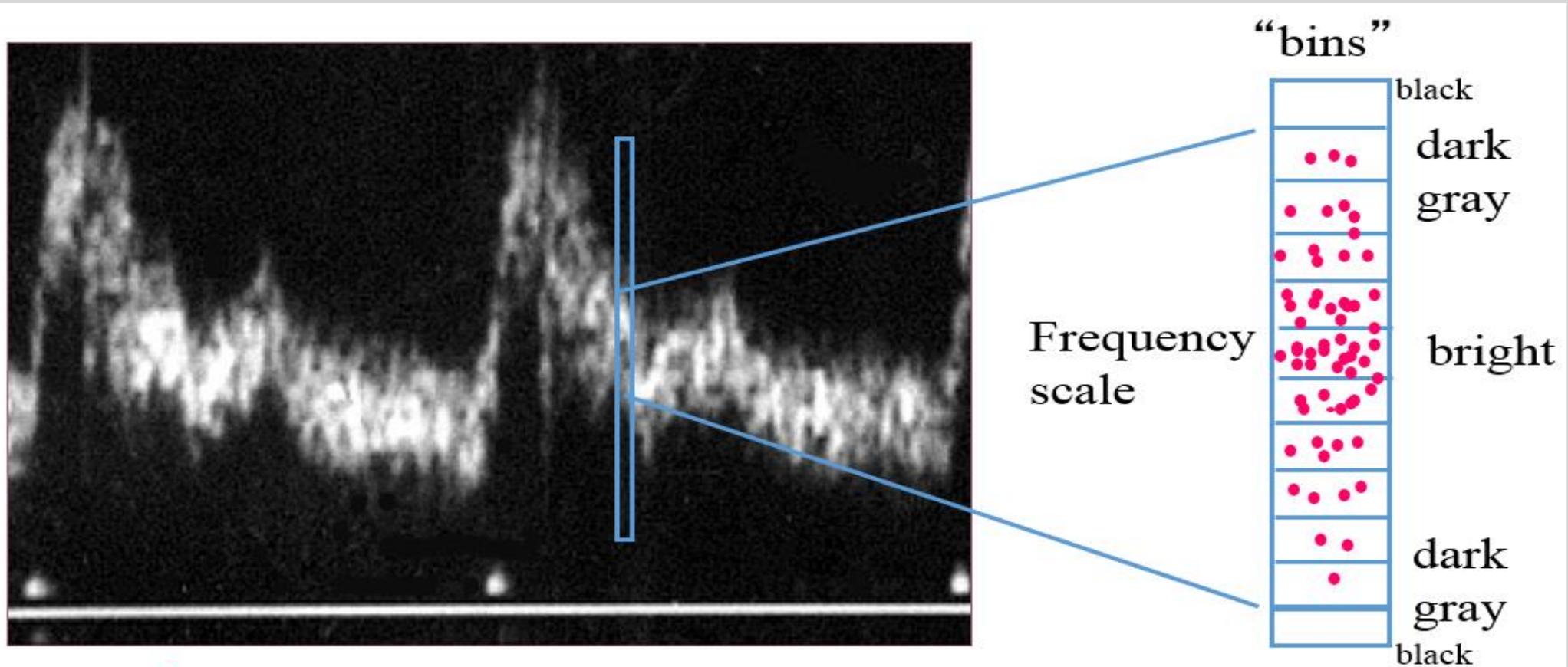
Aliasing Remedies



Fast-Fourier Transform (FFT)

- Digital technology that automatically analyzes and displays Spectral Doppler
 - Measures peak velocities
 - Distinguishes laminar from turbulent flow
- Creates a velocity profile that consists of:
 - Time on the horizontal axis
 - Frequency shifts on the vertical axis
 - Amplitude as brightness

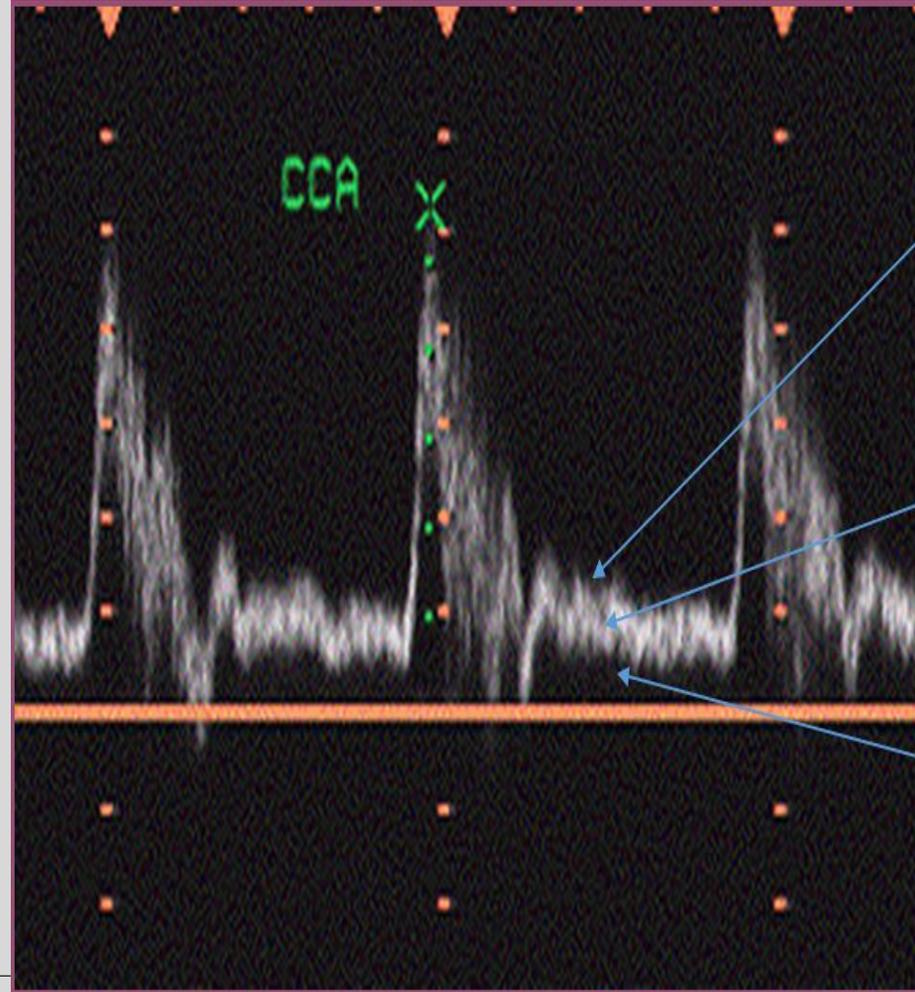
Fast-Fourier Transform (FFT)



- Frequency shifts grouped into bins

Spectral Spread

- In any one moment of “Doppler” time a multitude of RBC’s pass through the SV
- There is a range of RBC velocities – they don’t all move at the same speed!



Peak frequencies

Mean frequencies

Lowest frequencies

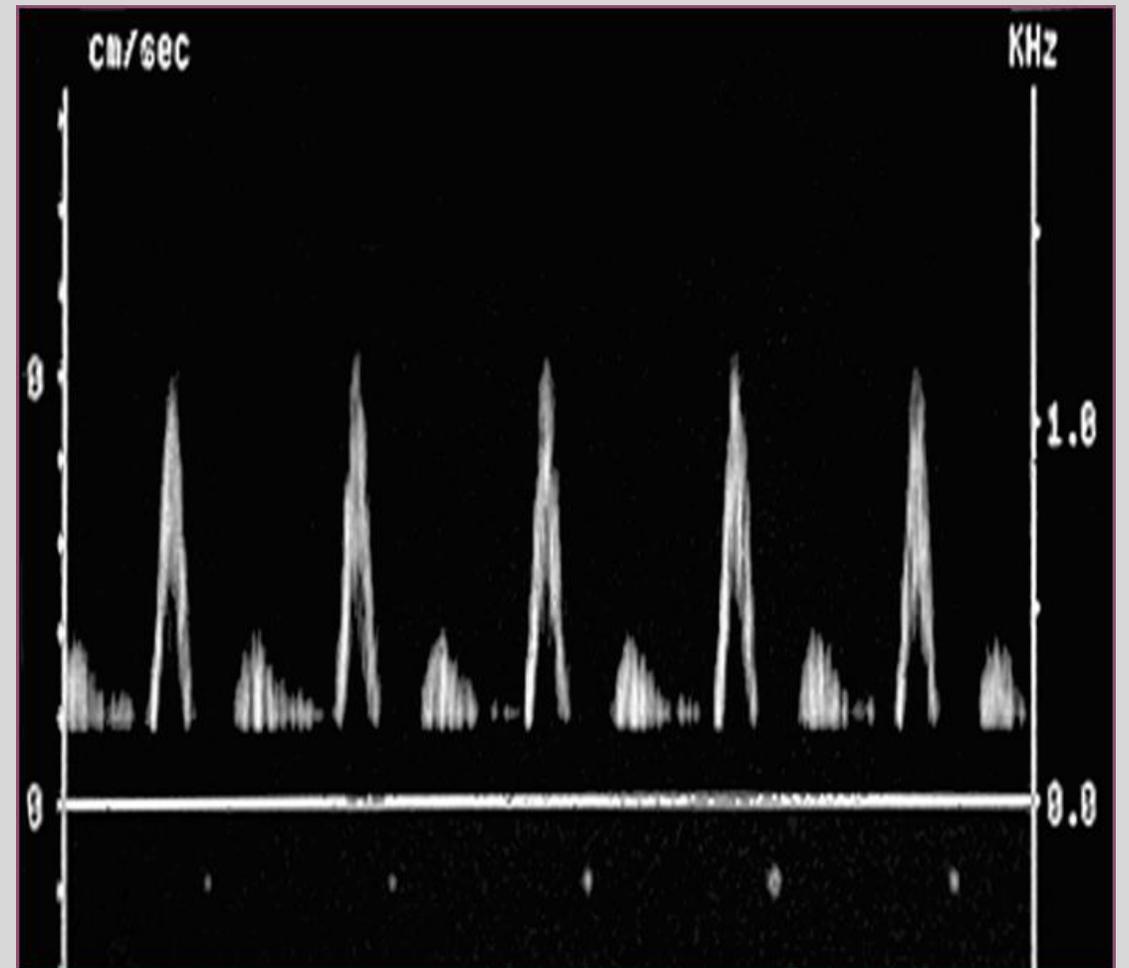
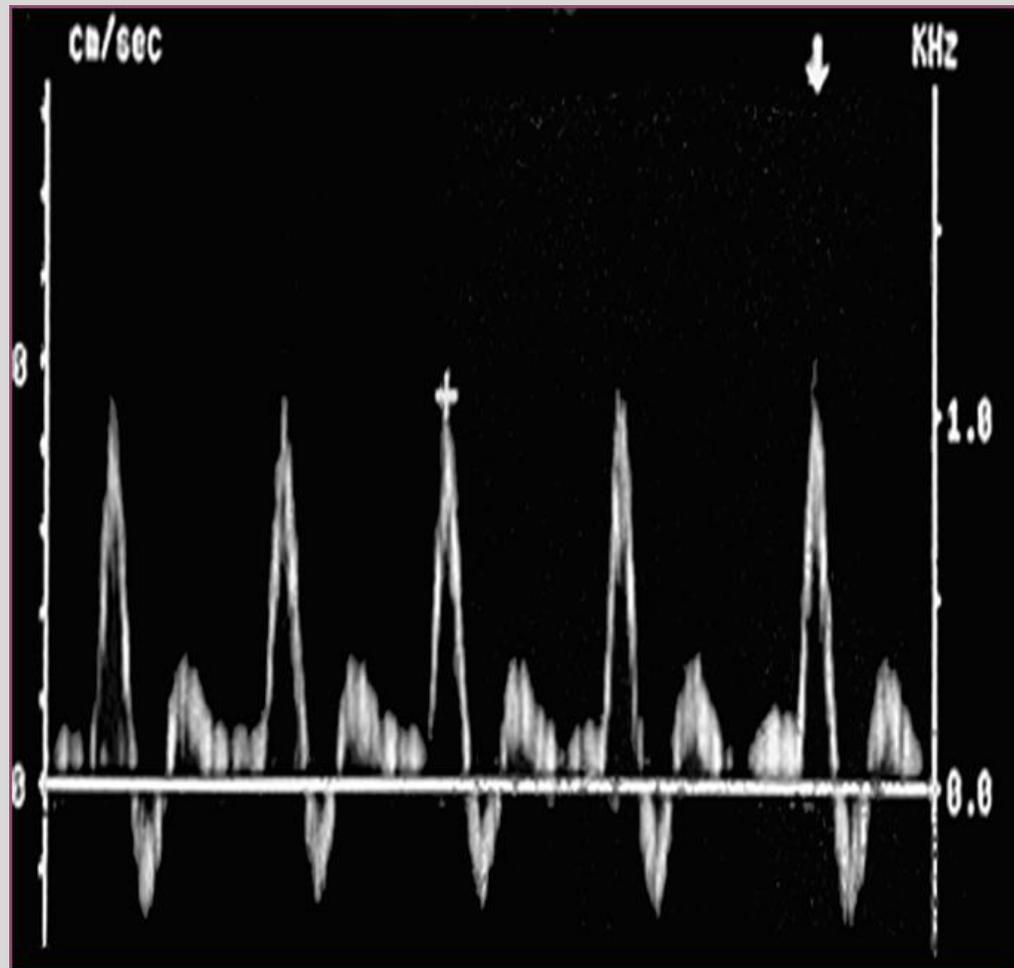
Doppler Guidelines

- For accurate velocity measurements use angles of 45-60 degrees
 - 60° is preferable
- Obtain multiple samples from stenosis
- For carotid follow-up exams
 - Use same Doppler angle in stenosis
 - Use same Doppler steering angle

Wall Filters

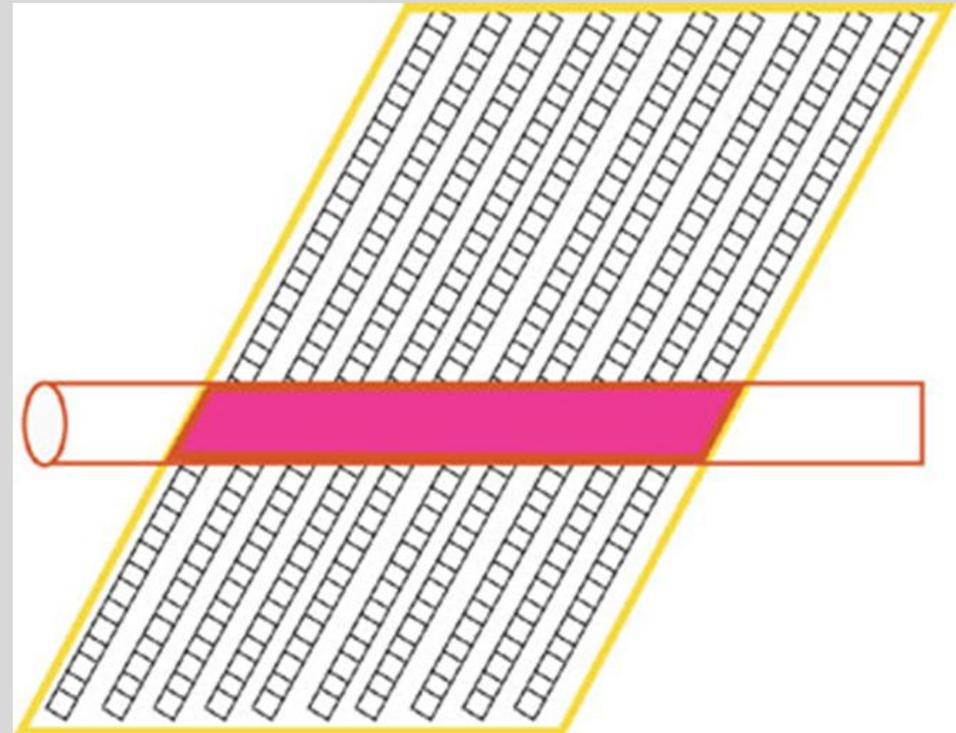
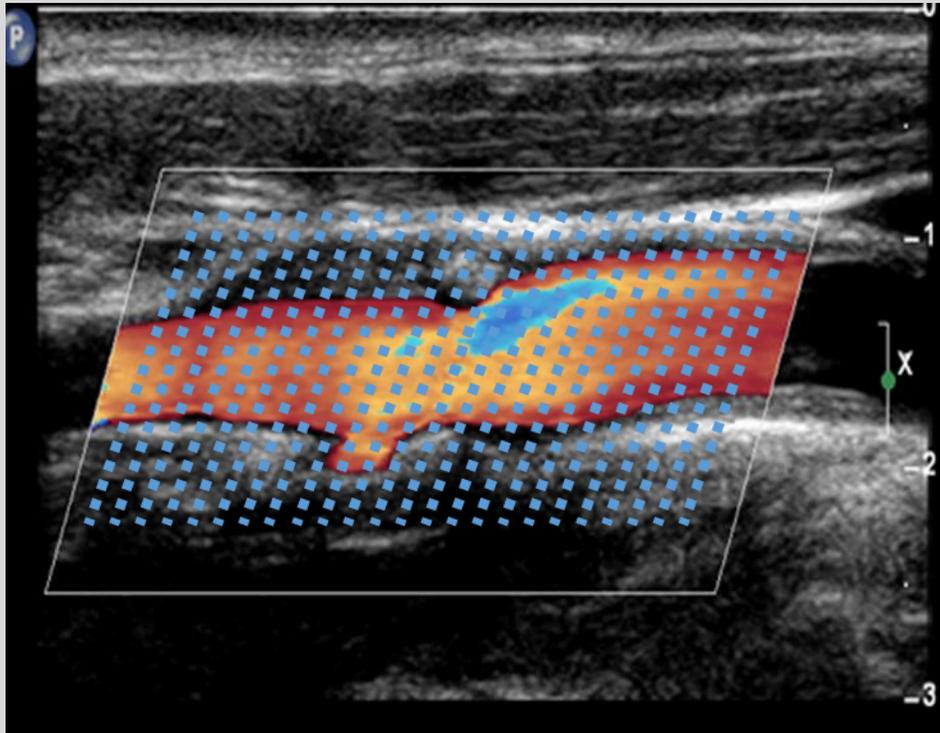
- Also called:
 - High pass filters
 - Thump filters
- Essential in eliminating low frequency noise, but if set improperly, can adversely affect waveform morphology

Wall Filters



Color Doppler

- A color image frame is obtained by using multiple color scan lines



Autocorrelation

- Digital technology that is used to analyze color flow Doppler
- Can process an enormous amount of data quickly
- Displays:
 - Mean velocity measurements of moving RBC's
 - Flow direction
 - Variance
 - Power

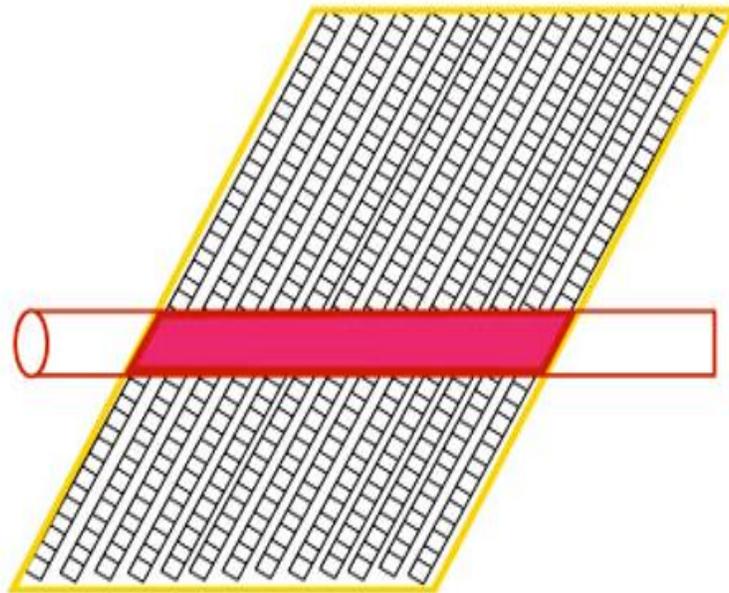
Pulses per Scanline

- B-Mode = 1 pulse used for each scanline
- Color = 3-20 (commonly 8-10) pulse/scanline
- High number produces an image of robust, full color with a low frame rate
- Low number produces an image of weak, spotty color, but a much faster frame rate

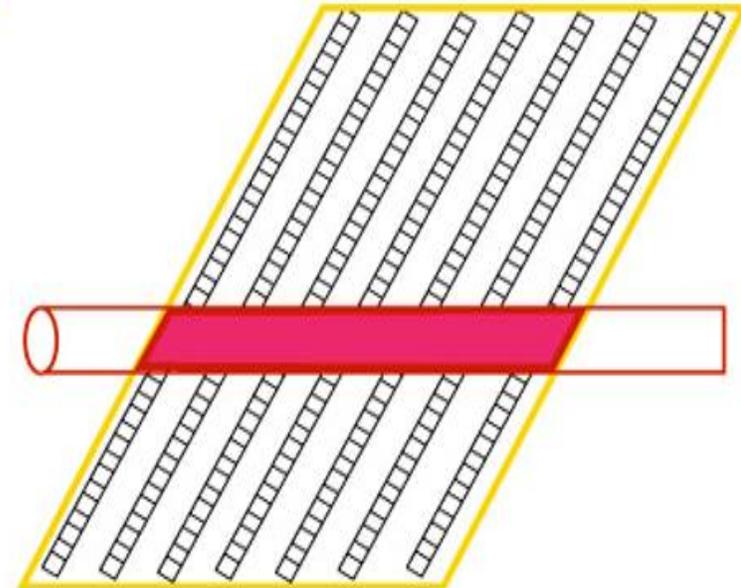
Pulses per Scanline

- Also known as:
 - Packet size
 - Ensemble length
 - Color sensitivity
 - Color quality

High scanline density



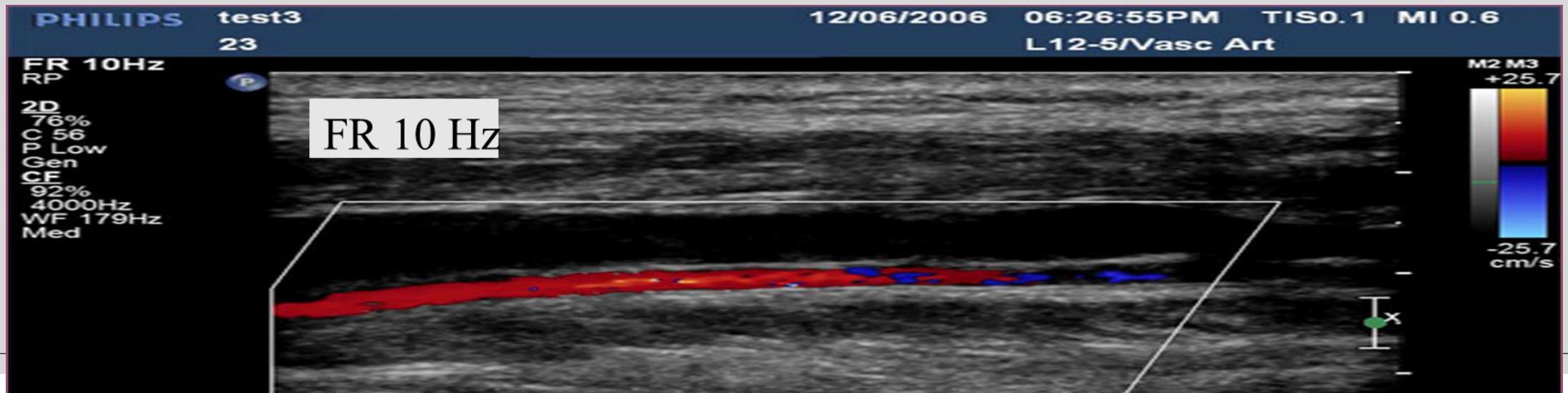
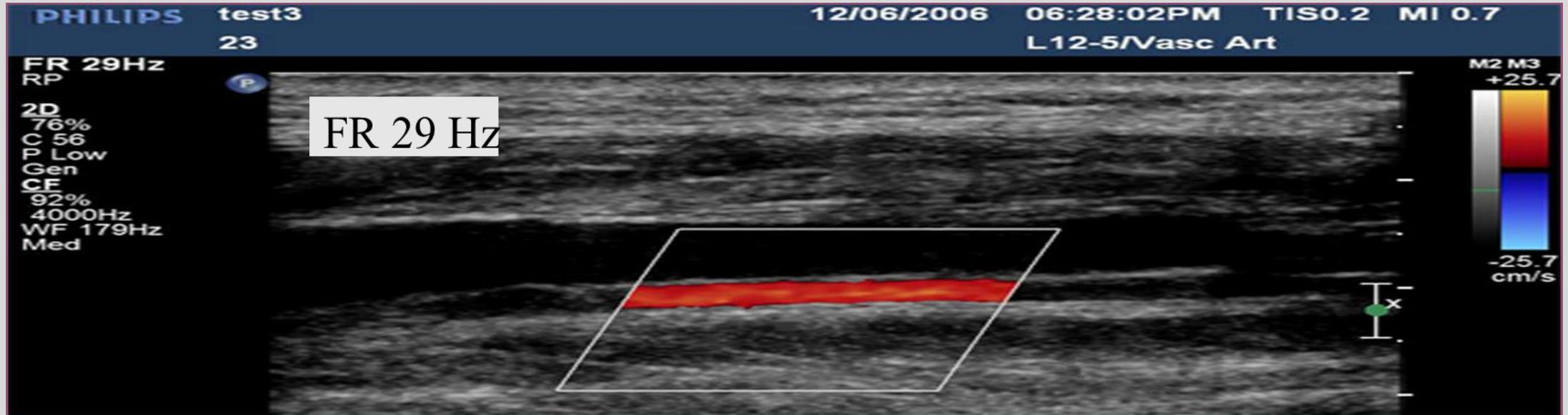
Low scanline density



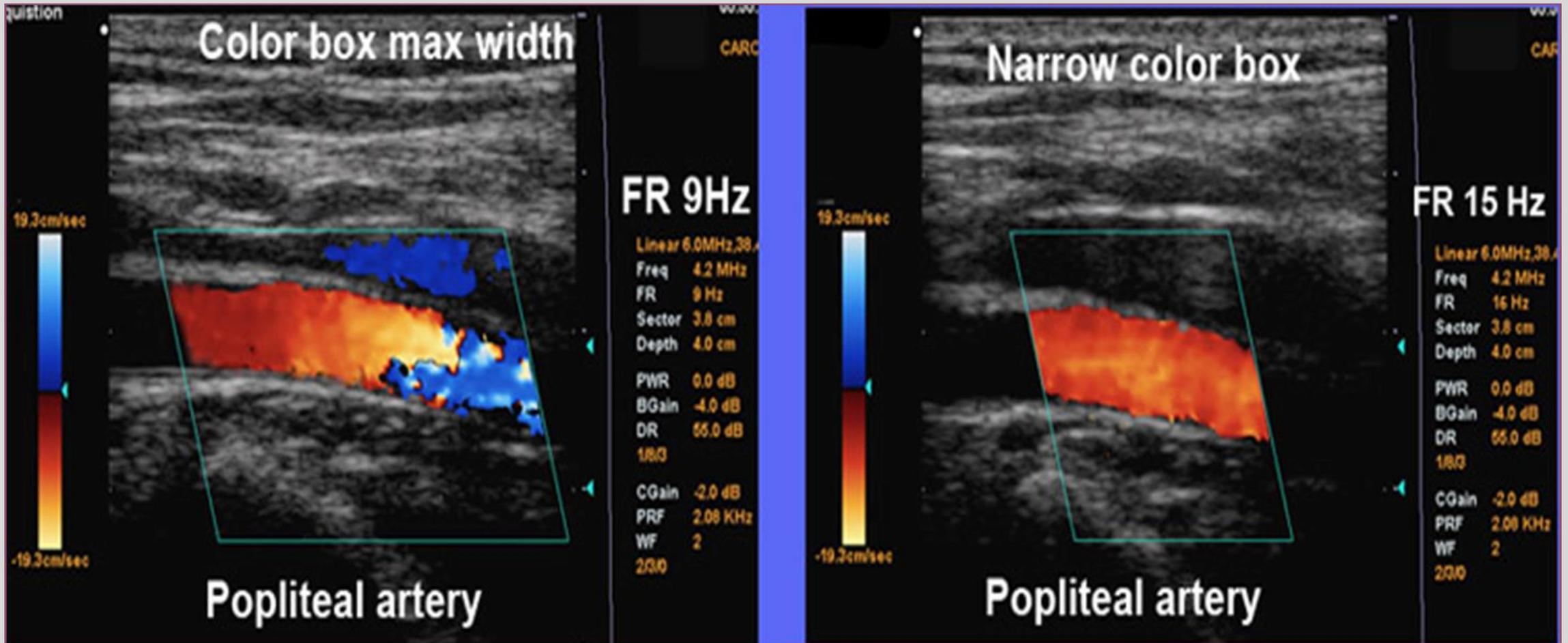
Color Frame Rate

- Dependent upon several factors:
 - Pulses per scanline (packet size)
 - Density of scan lines
 - Color box width
 - PRF

Frame Rate vs Color Box Size

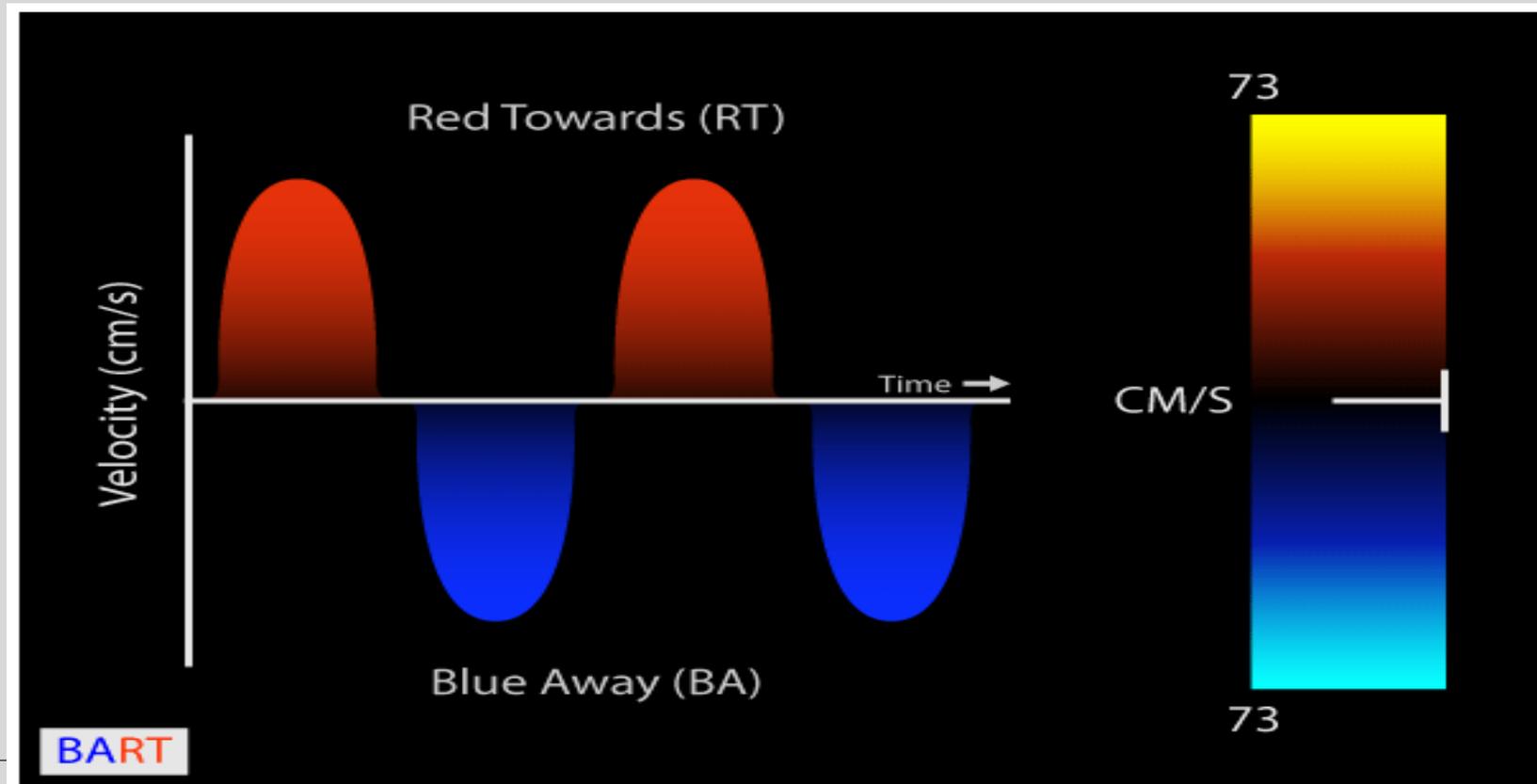


Color Box Size

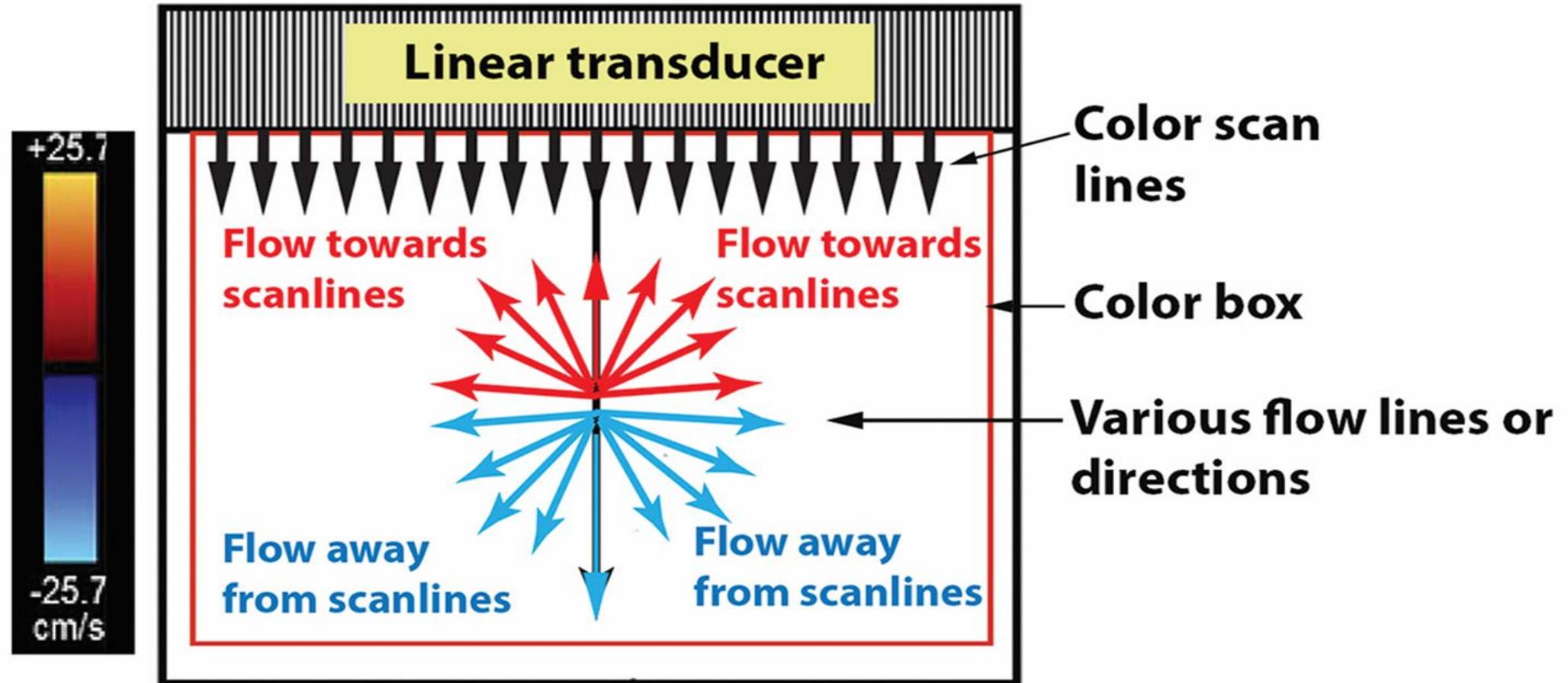


Flow Direction

- Flow relative to Doppler beam is either Towards, Away, or Perpendicular

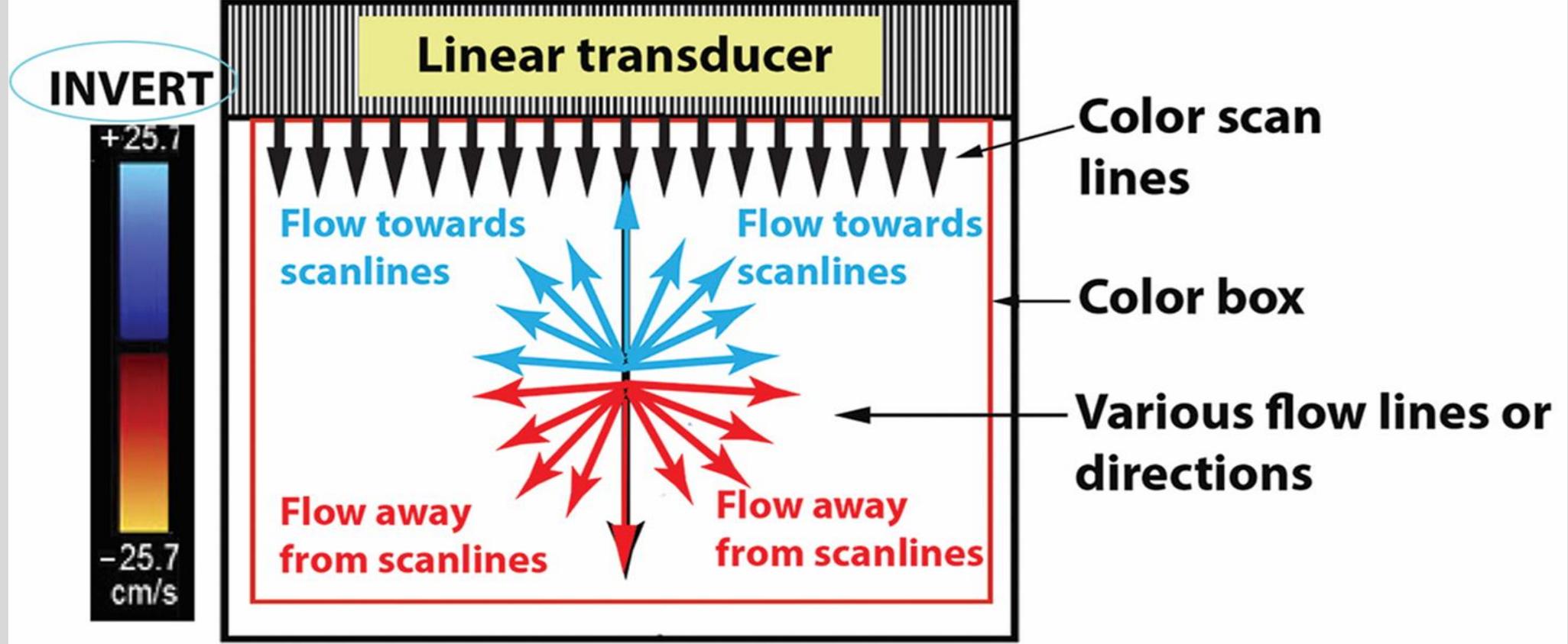


Color Doppler unsteered



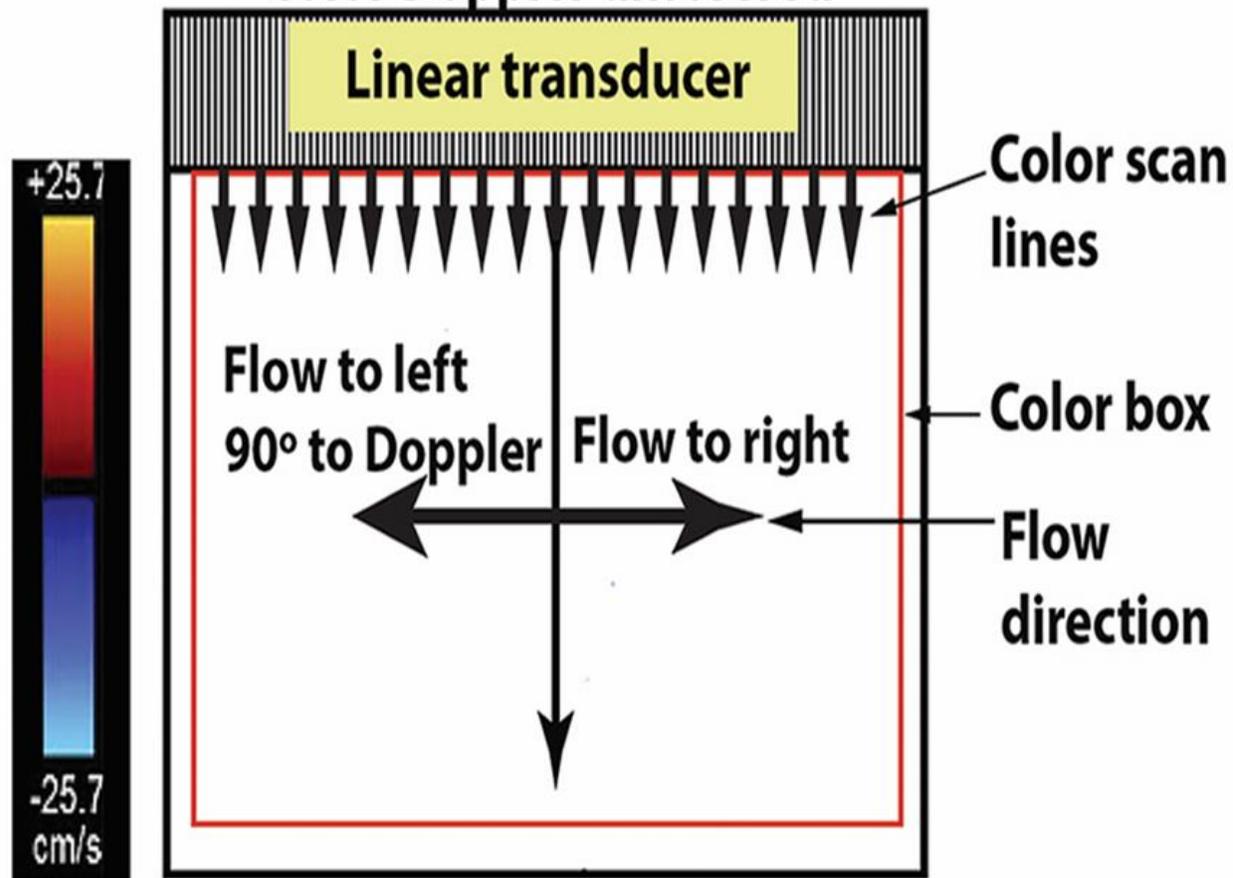
All flow "away" from the Doppler beams is color-coded blue, flow "towards" is colored red.

Color Doppler unsteered

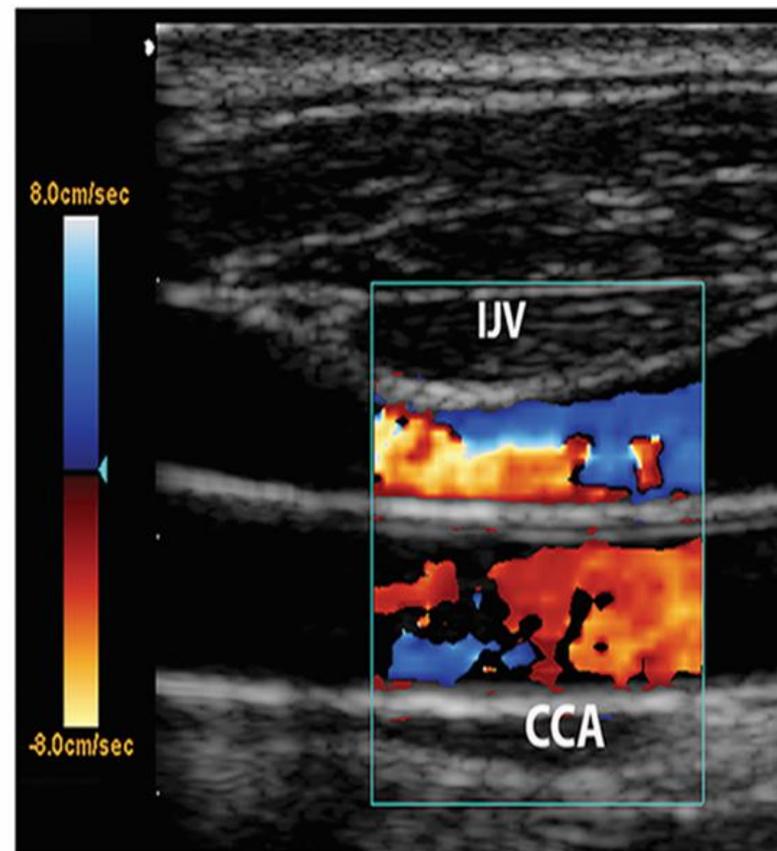


Color is Inverted: All flow "away" from the Doppler beams is color-coded RED, flow "towards" is colored BLUE .

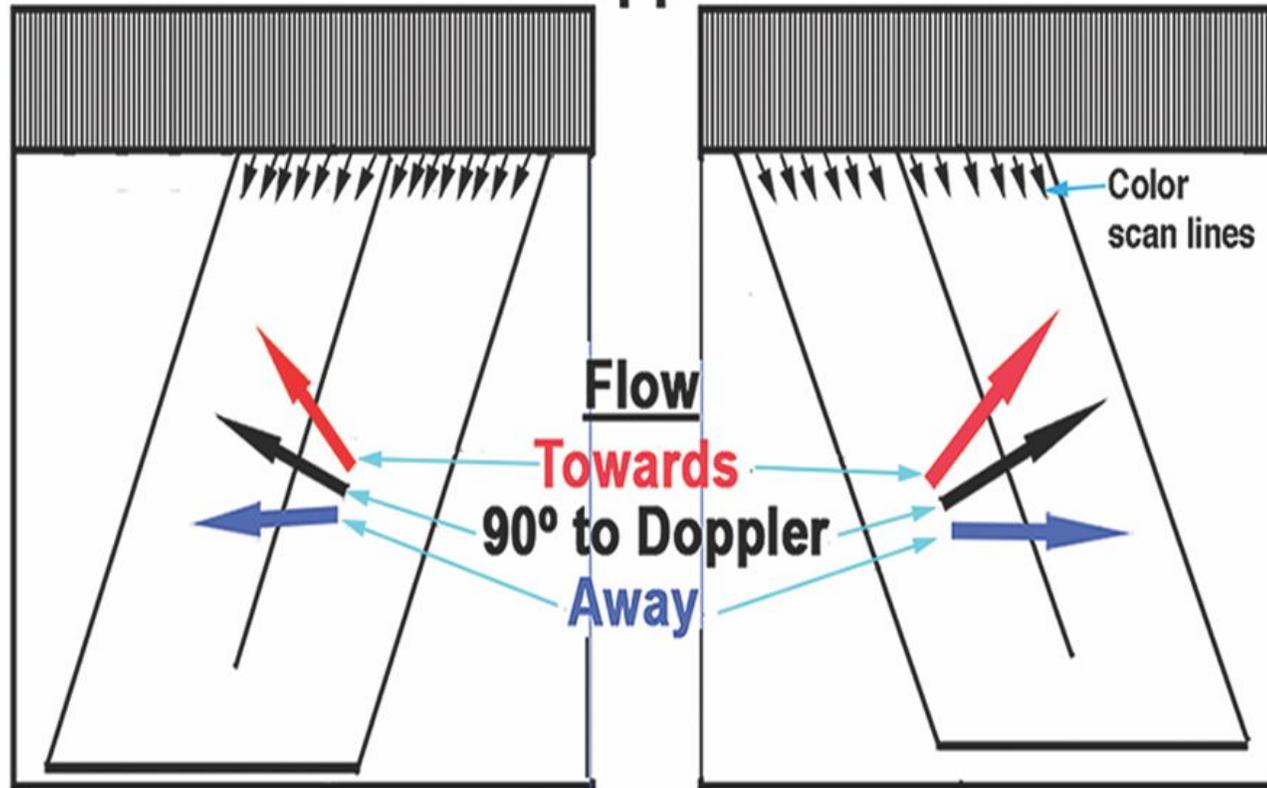
Color Doppler unsteered



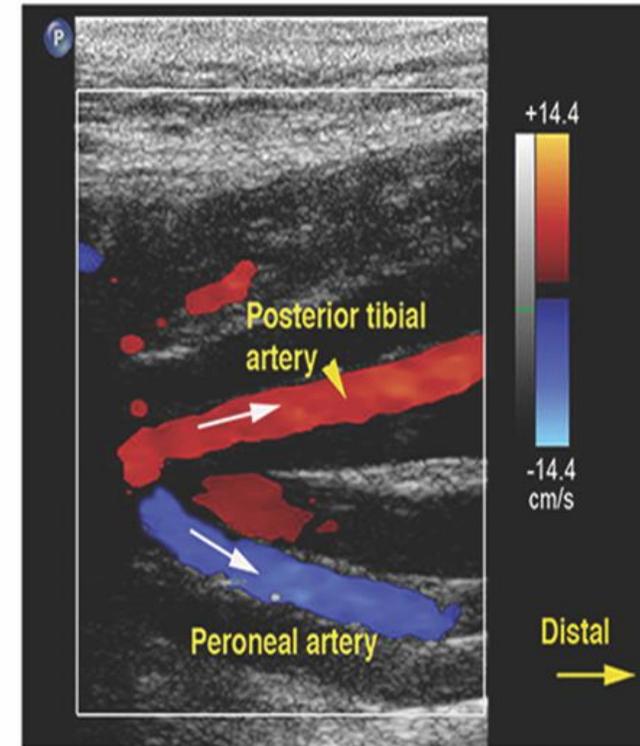
Flow perpendicular to Doppler beams is poorly color-coded, or color is absent



Color Doppler steered



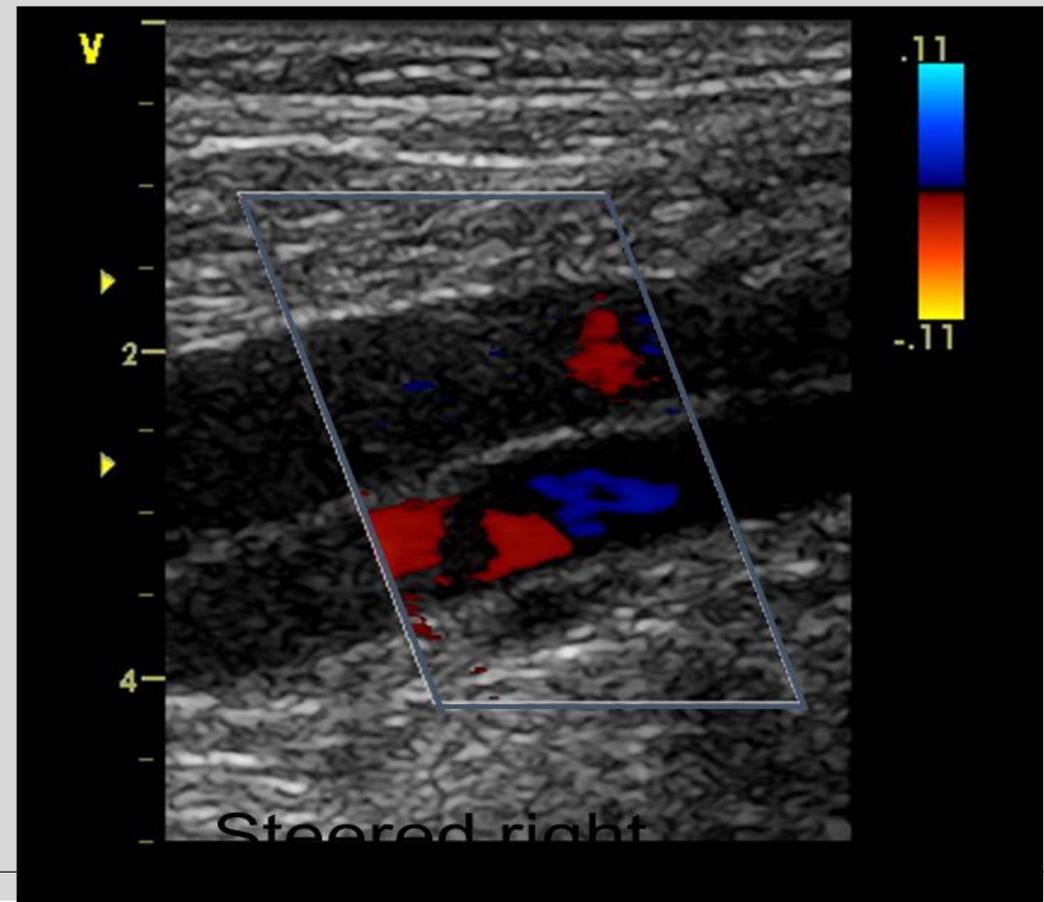
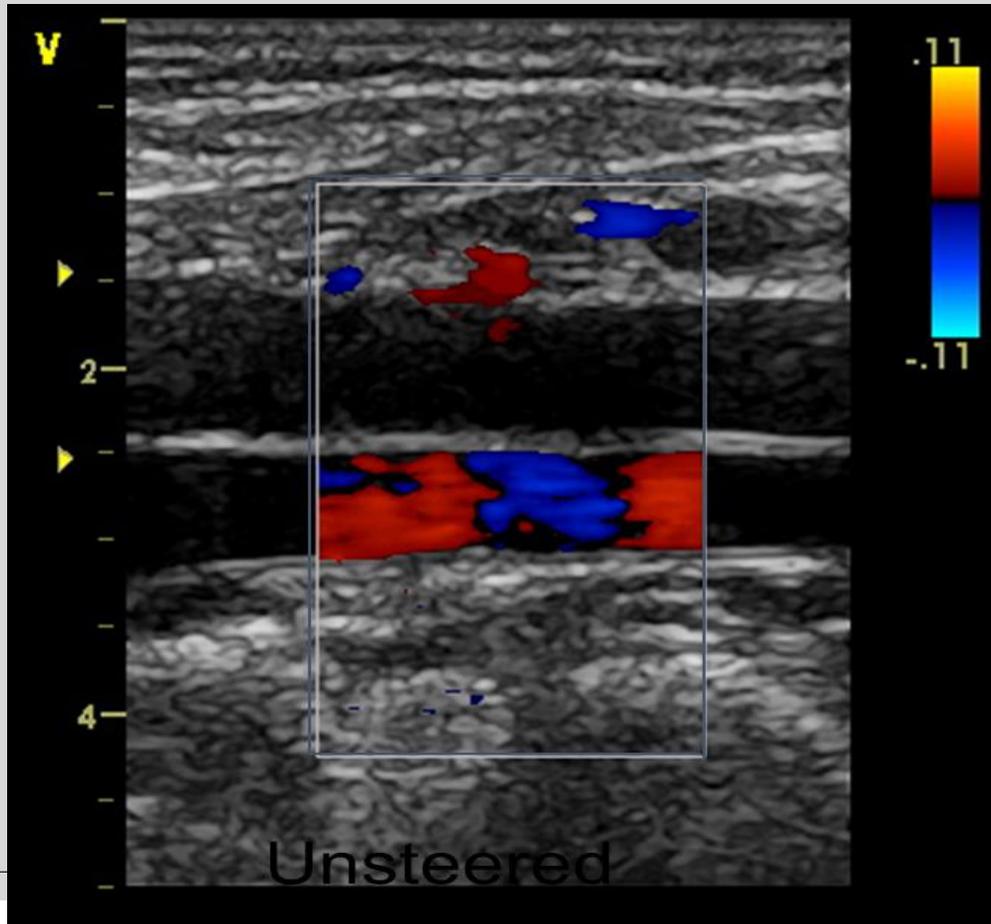
Color coding depends on whether flow is towards or away from the Doppler beam, and not necessarily whether it's flowing left or right on the screen



Flow direction demonstration

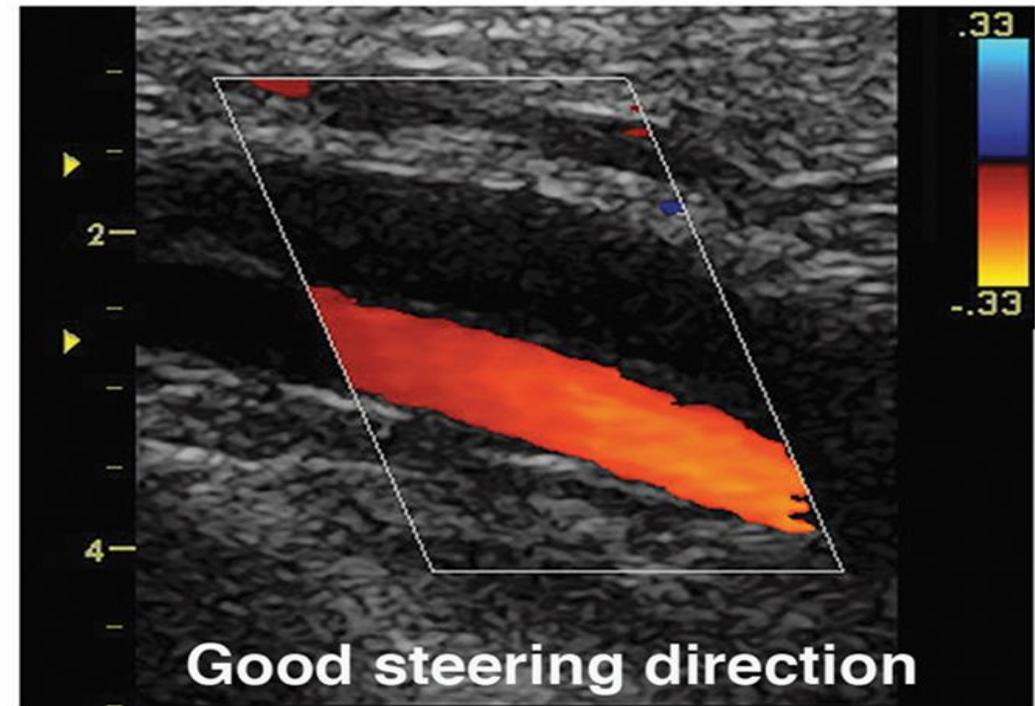
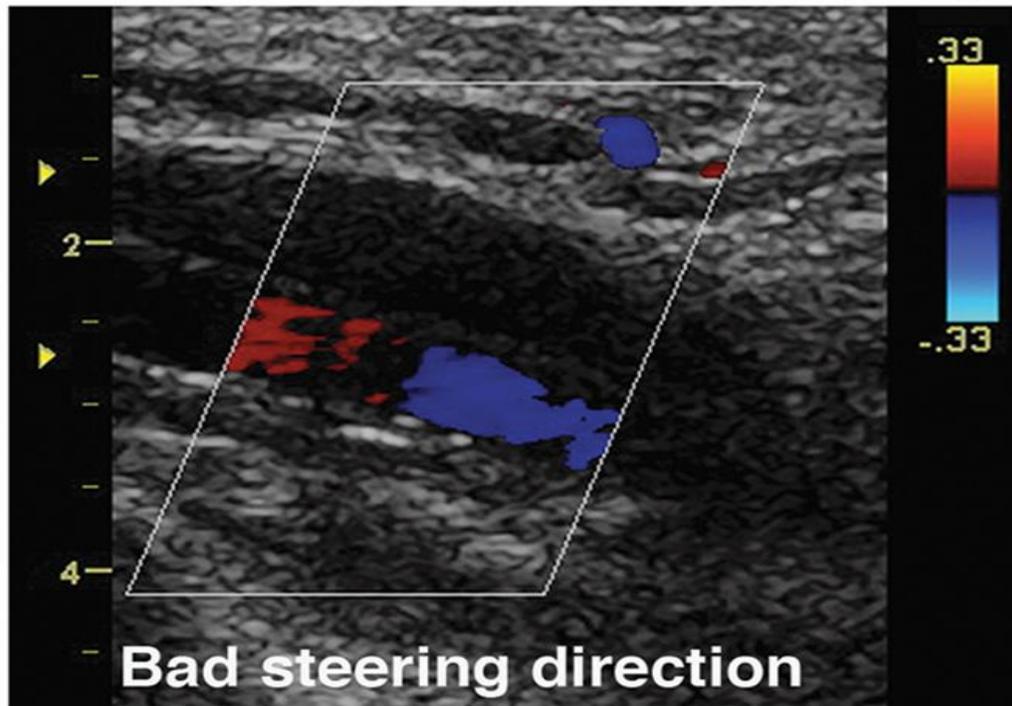
Color Steering

- Why is the color so lousy?



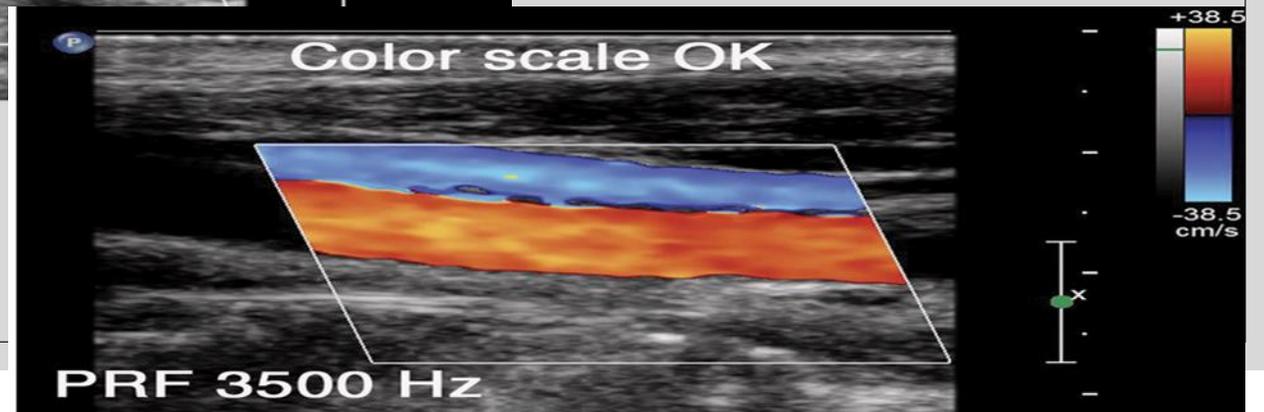
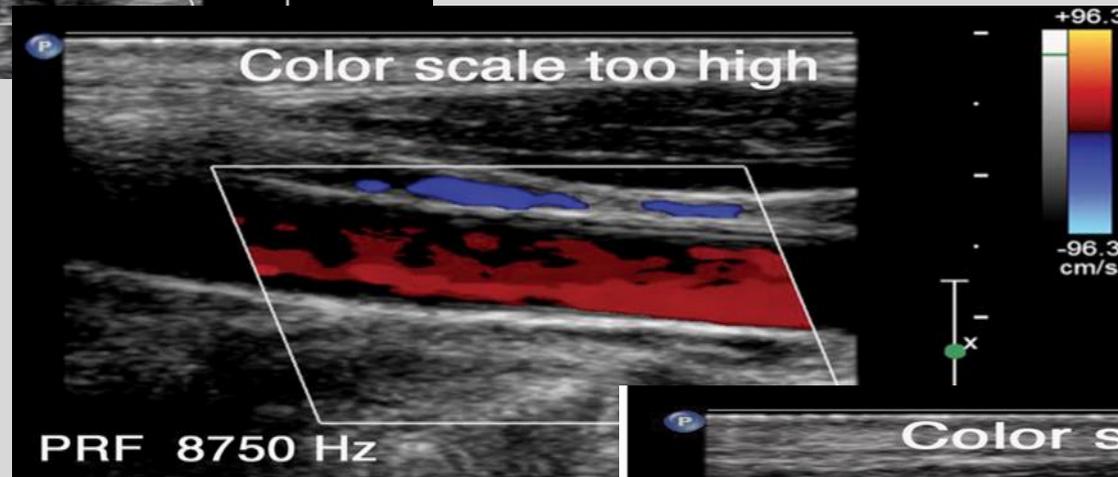
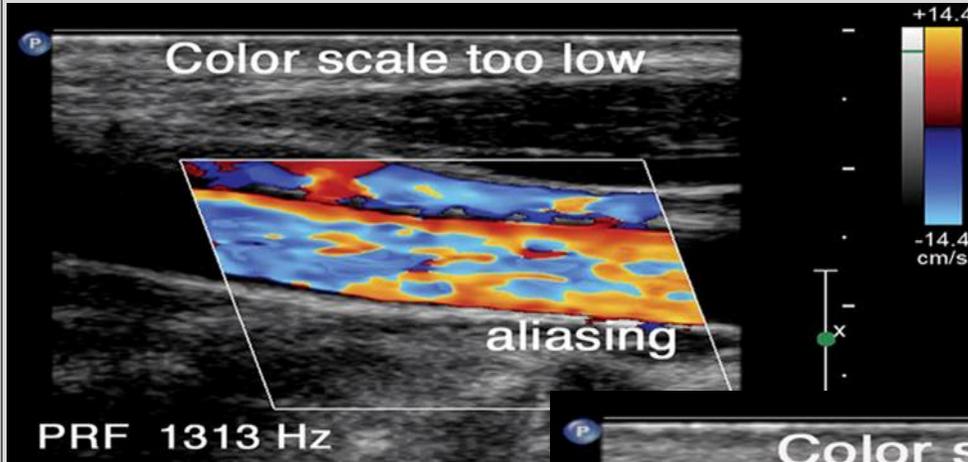
Color Steering

Distal Popliteal Artery

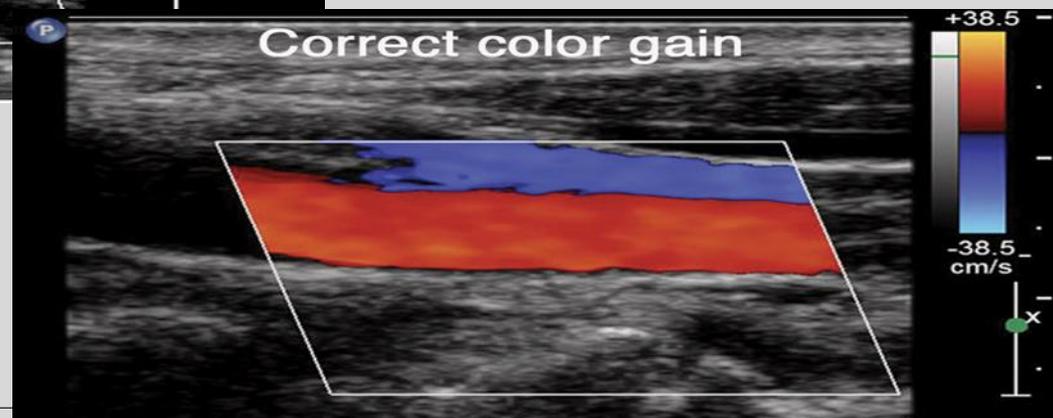
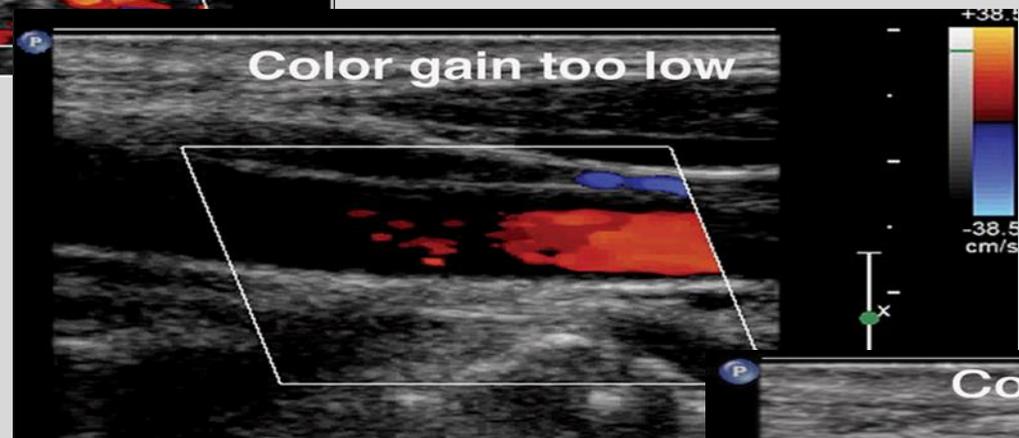
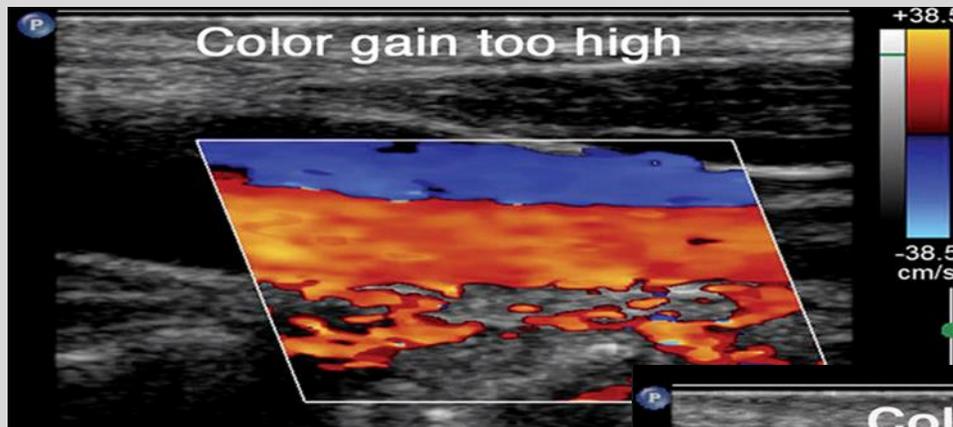


**Color Doppler must be steered to optimize angle to flow.
As with spectral Doppler, steer to the side where the vessel dives,
as in the right image above.**

Color Scale

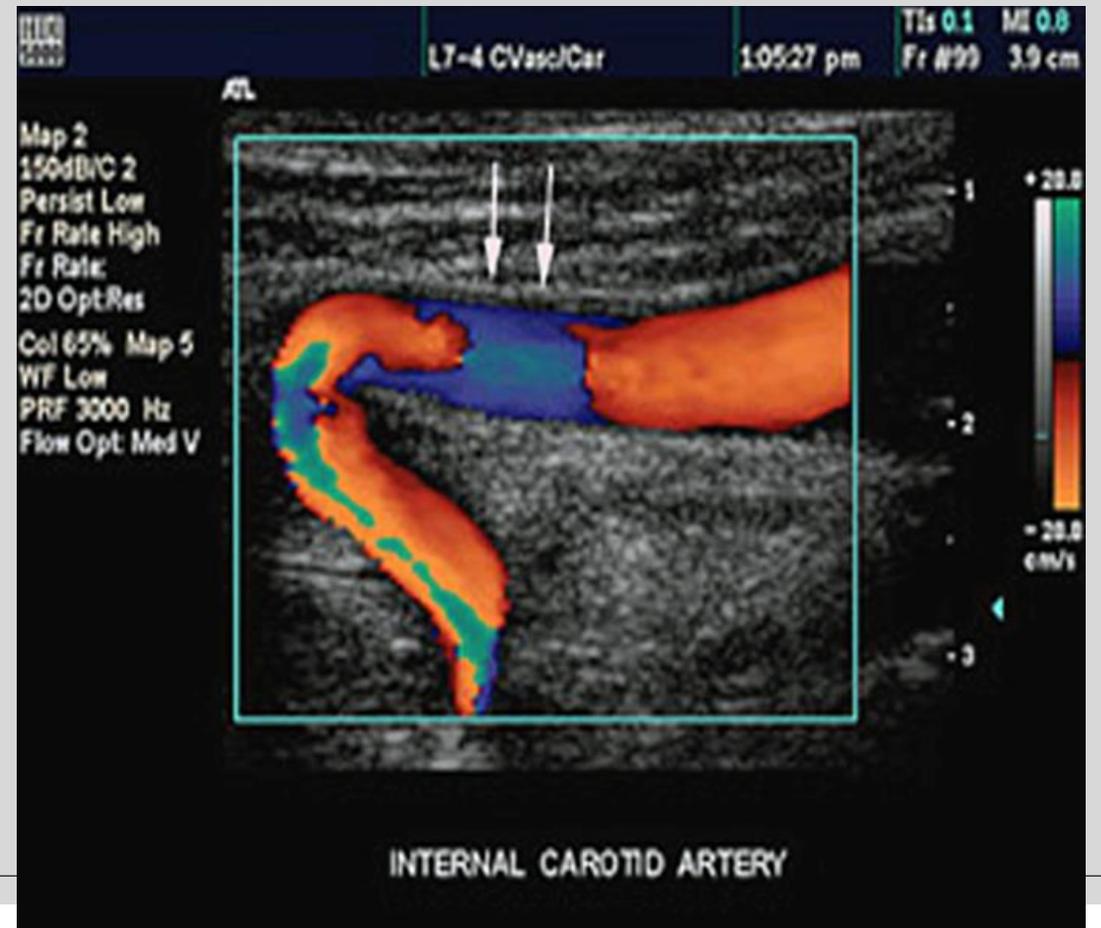
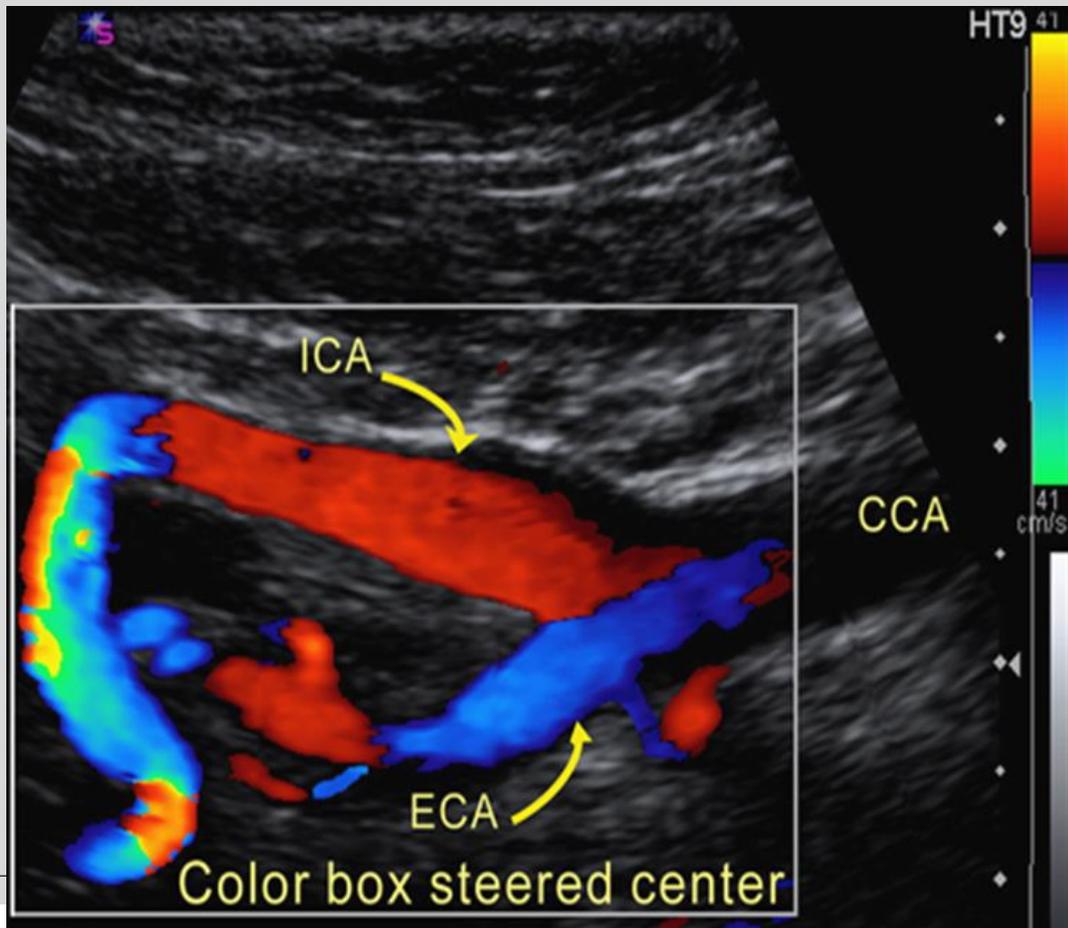


Color Gain

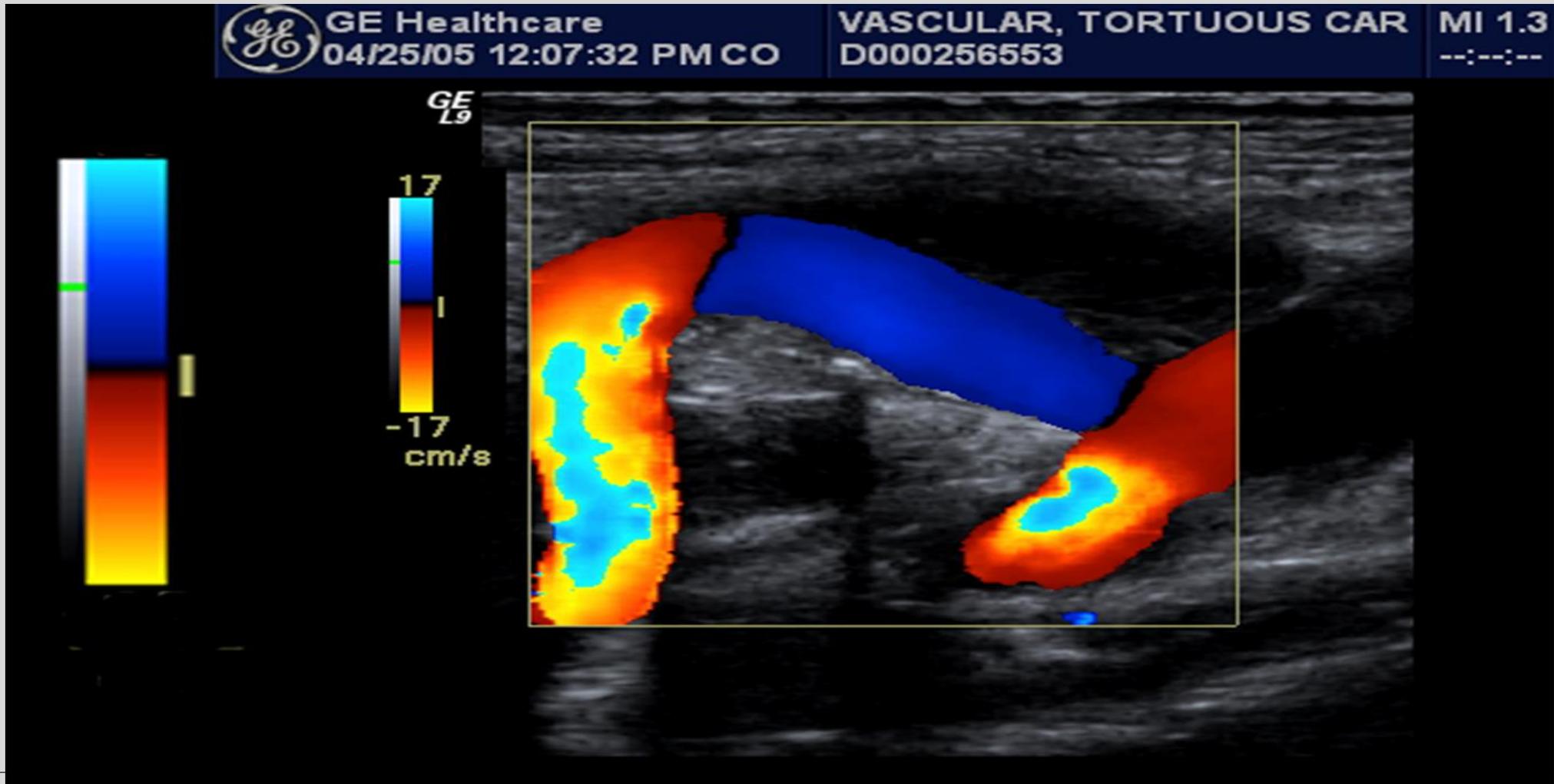


Color Angles

Explain the blue colors in the images below.



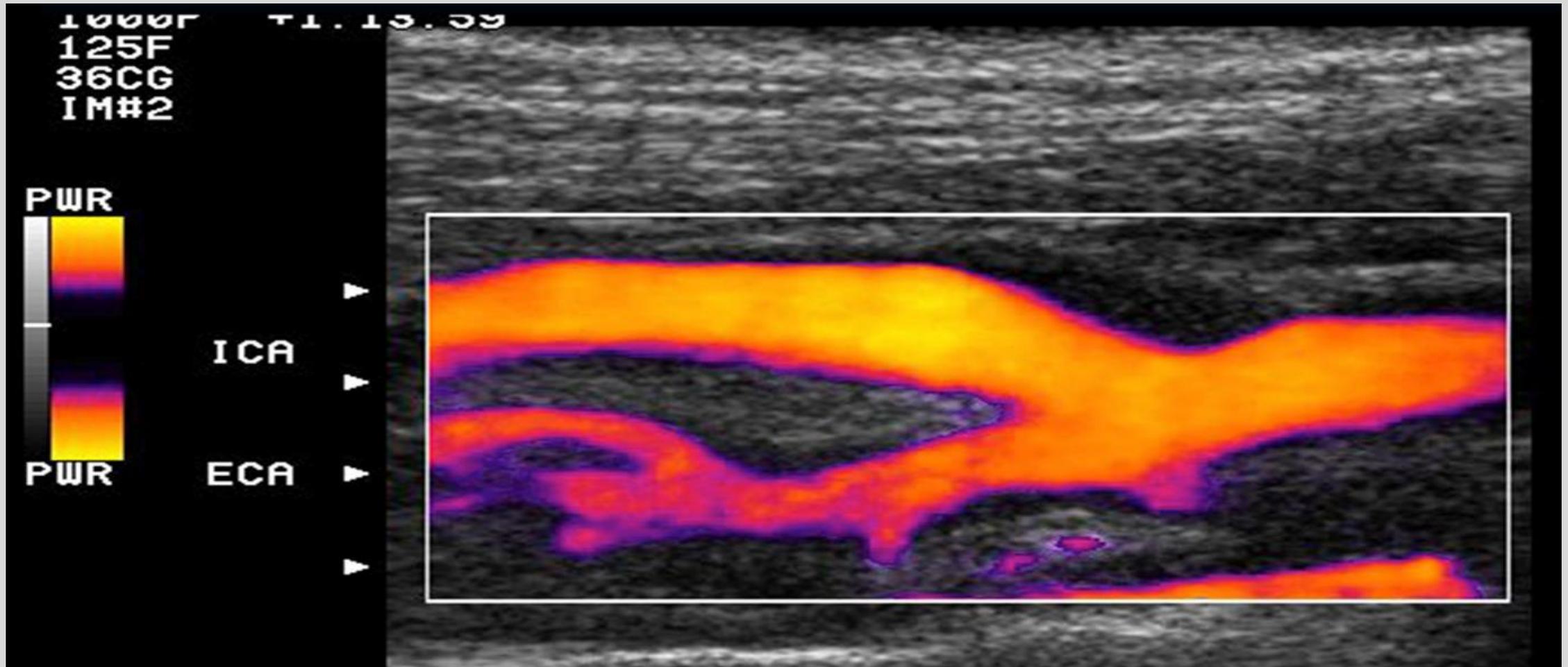
Aliasing vs. Flow Reversal



Power Doppler

- Also known as:
 - Angio
 - Color Doppler Energy
 - Color Power Angio
 - Power Doppler Imaging
 - Convergence Power Doppler

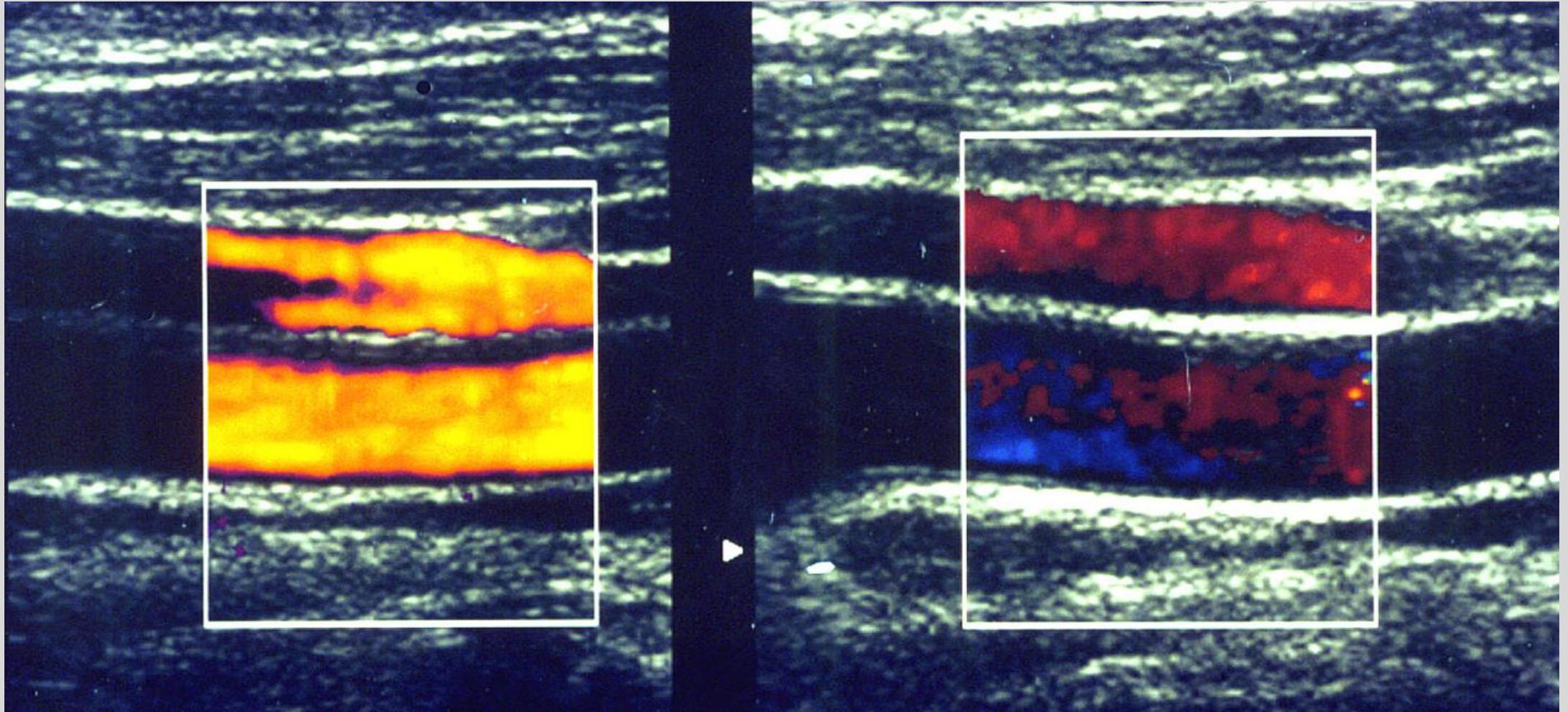
Power Doppler



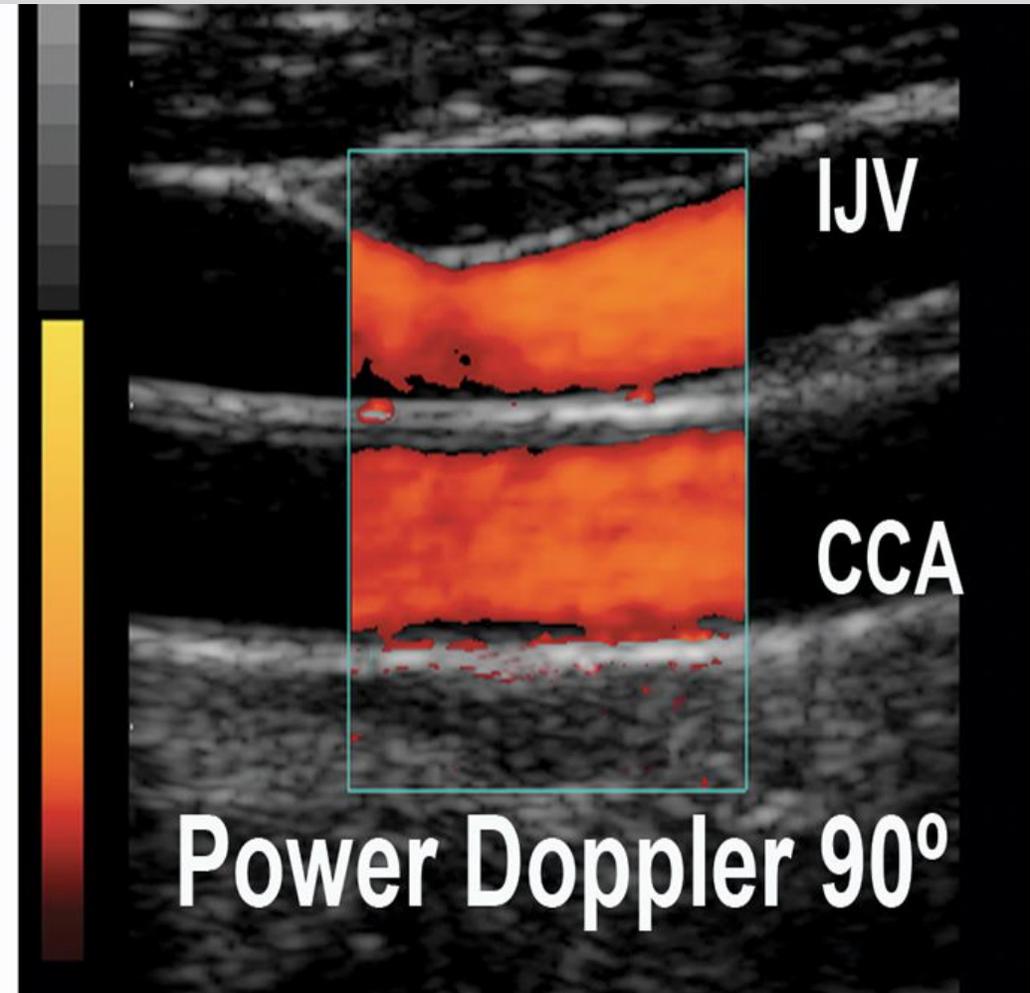
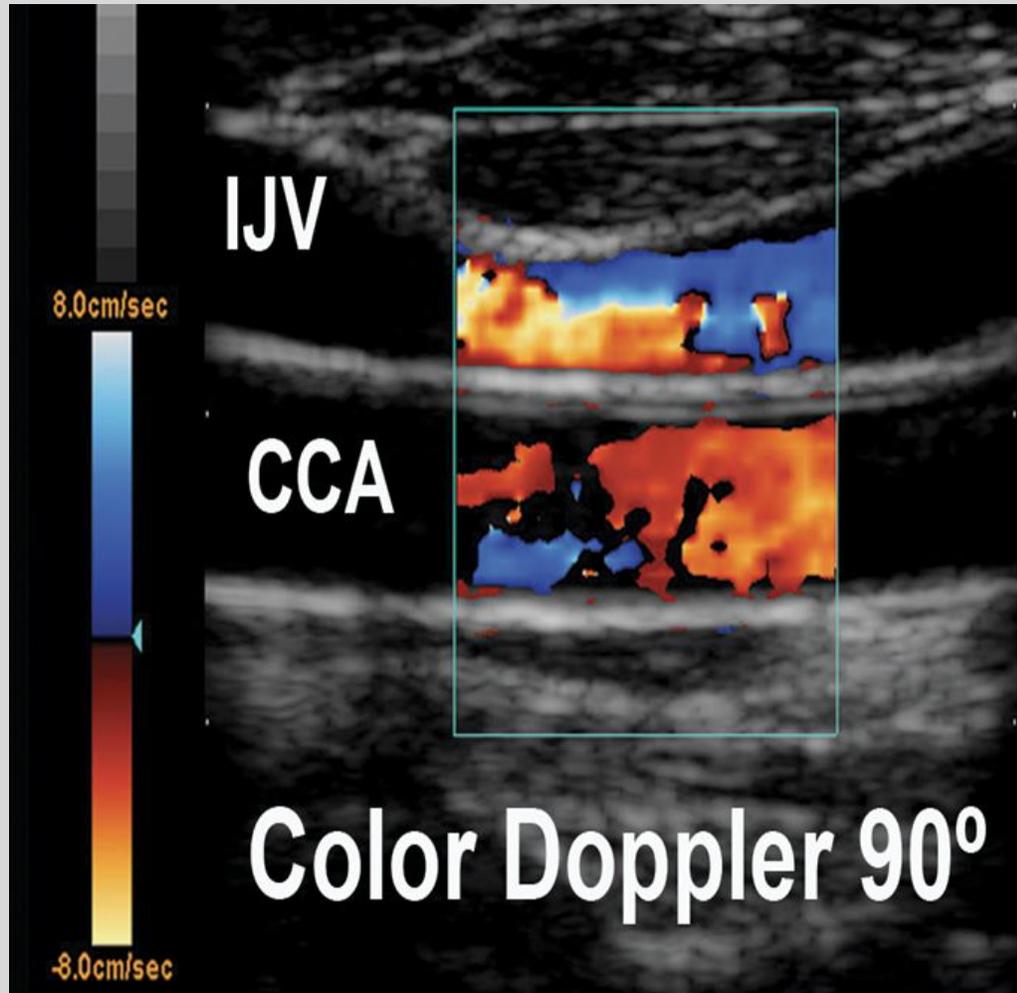
Power Doppler

- Advantages:
 - Color encoding at 90°
 - More sensitive than color Doppler
 - Good wall definition
 - No aliasing

Power Doppler



Power Doppler

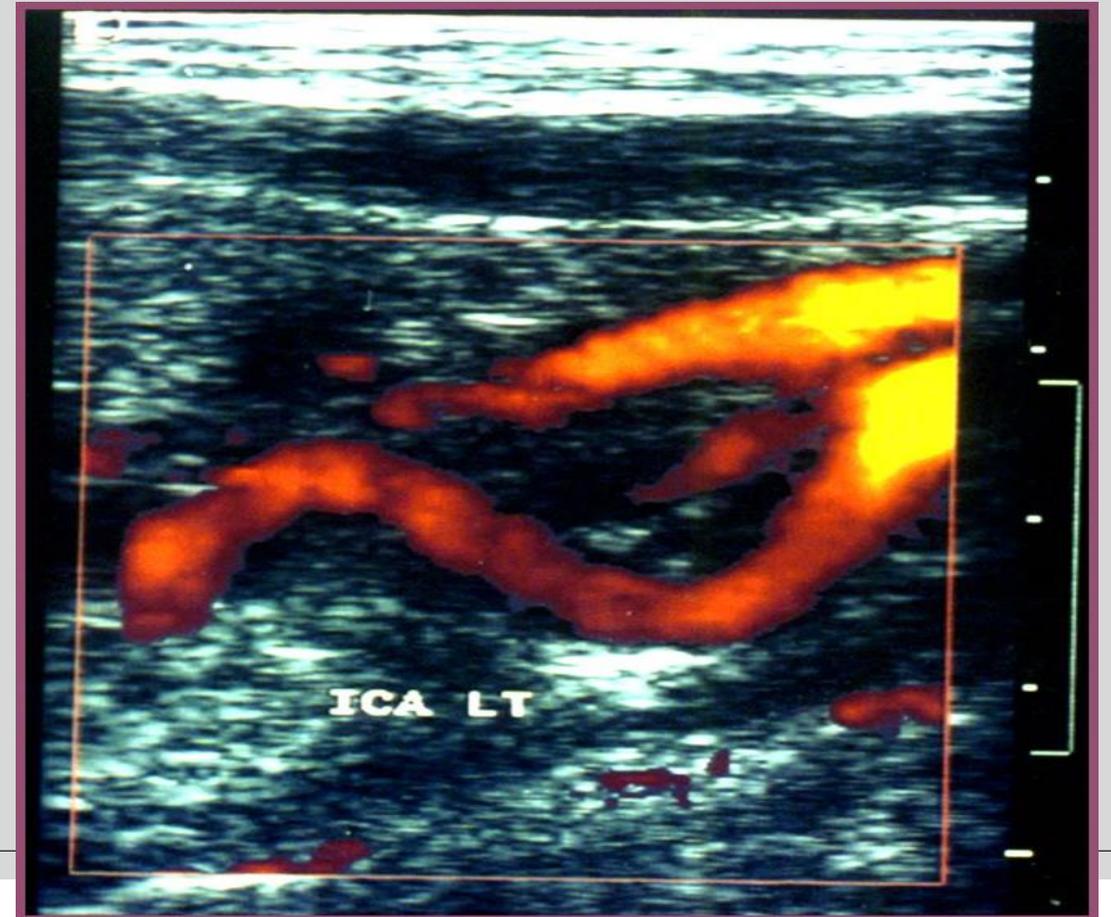


Power Doppler

Near total occlusion



Tortuous vessels – distal ICA



Power Doppler

- Limitations:
 - Wall definition – “bleeding”
 - High persistence – slow frame rate
 - Cannot detect increased velocity
 - Differentiation of arterial venous flow
 - Flow direction

Power Doppler

- Disadvantage: Unable to see turbulence

