Doppler Waveform Analysis

Michigan Sonographers Society
5th Annual Fall Symposium

Patricia A. Poe, BA RVT FSVU
Vascular Laboratory Educator and Consultant
Philadelphia, PA

Disclosures:

No relevant financial relationships with commercial interests

Arterial waveform principles

It’s not only about the velocities…..

Analysis of waveform morphology is crucial to improve diagnostic accuracy

- Acceleration / upstroke
- Systolic peak
- Deceleration / downstroke
- Diastolic components

•Identification of flow direction

New SVM / SVU consensus document 2020

Interpretation of Peripheral Arterial and Venous Doppler Waveforms: A Consensus Statement From the Society for Vascular Medicine and Society for Vascular Ultrasound

Journal for Vascular Ultrasound 1–26 © 2020, Society for Vascular Ultrasound

Society for Vascular Medicine

SVM members:

- Esther SH Kim (Chair)
- Aditya Sharma (Co-Chair)
- Gene Zierler
- Guillame Mahe
- Paul Wennberg
- Marie Gerhard-Herman
- Robert Eberhardt
- Rita Shugart

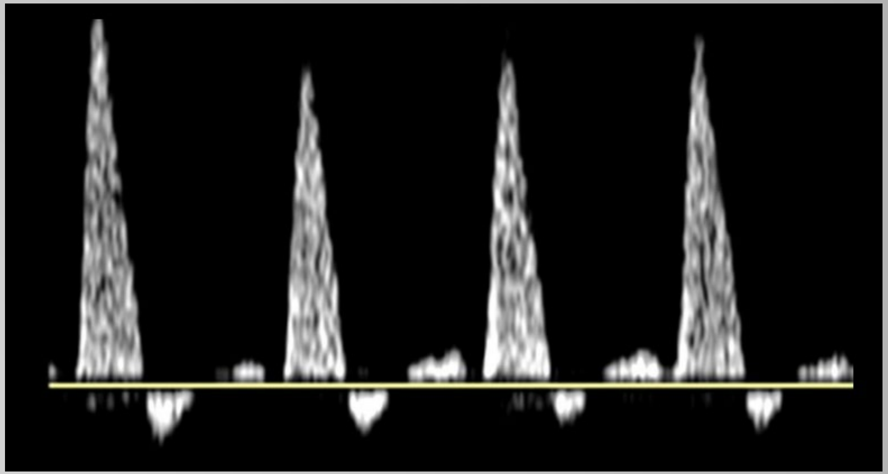
SVU Society for Vascular Ultrasound

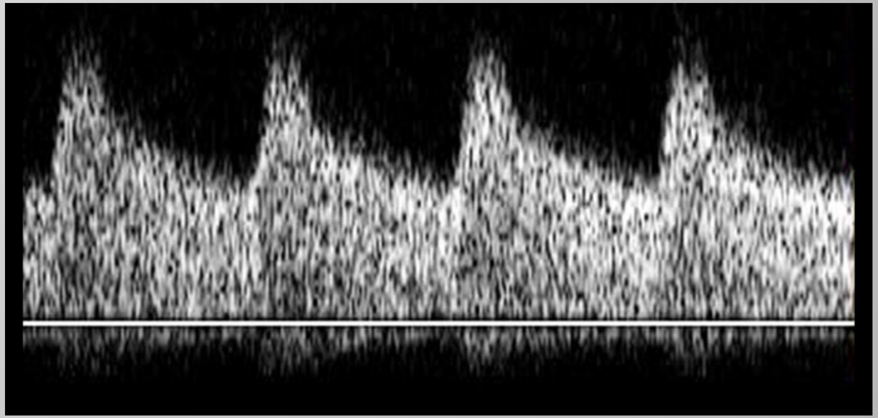
SVU members:

- Robert Scissons (Co-Chair)
- Marsha Neumyer
- Steve Knight
- Ann Marie Kupinski
- David Williams
- JP Hughes
- Tish Poe
- David Dawson

Normal Peripheral Arterial Doppler Waveform

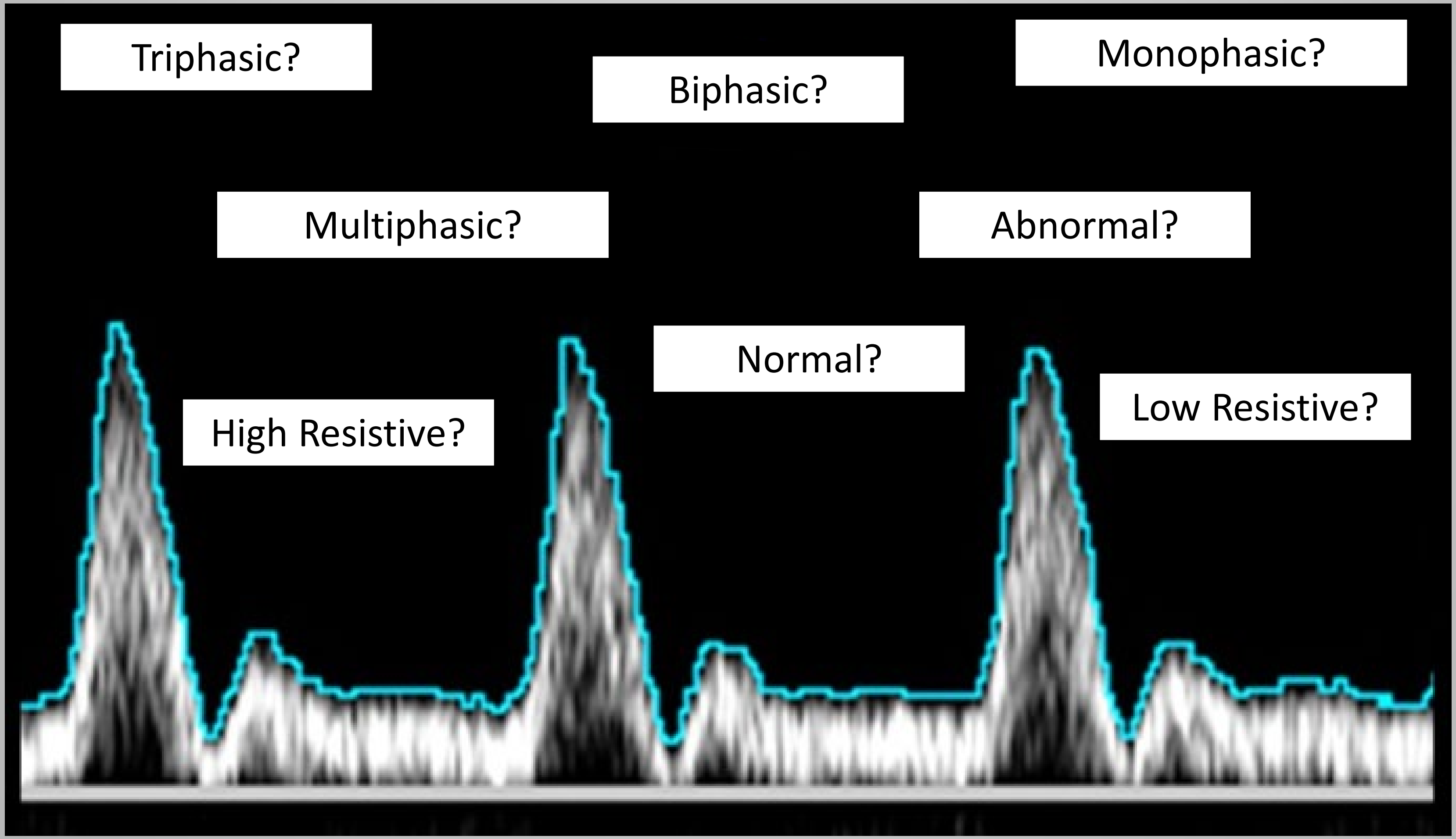
- “Triphasic”
  1. High forward flow during systole
  2. Transient period of flow reversal
  3. Forward flow component
- Physiologic conditions and disease states that alter this pattern are numerous
  - Reactive hyperemia
  - Exercise
  - Arterial Stiffening
  - Proximal high-grade stenosis
- Most can identify the “normal” and “abnormal” as “triphasic” and “monophasic”





Scissons R. JDMS 2008;24:269-276

How would you describe this waveform?



JDMS 24:269–276 September/October 2008 269

ARTICLES

Characterizing Triphasic, Biphasic, and Monophasic Doppler Waveforms

Should a Simple Task Be So Difficult?

ROBERT SCISSONS, RVT

Doppler waveform analysis is a fundamental part of evaluating peripheral arterial disease. Waveform characteristics are traditionally defined as multiphasic (triphasic, biphasic) and monophasic. The purpose of this investigation is to evaluate whether sonography professionals correctly classify waveforms into these three categories. Thirty Doppler waveforms (15 continuous-wave [CW] and 15 pulsed-wave [PW] Doppler) were obtained from patients with previous noninvasive peripheral arterial evaluations. Participating readers were asked to interpret waveforms as triphasic, biphasic, or monophasic using standard definitions. "Other" was used to classify waveforms whose morphology could not be determined or accurately classified as triphasic, biphasic, or monophasic. Because multiphasic waveforms with pandiastolic flow have been associated with biphasic and monophasic waveform terminology, answer key responses were based on waveform descriptors used by interpreters of the originating noninvasive evaluation. There were a total of 97 participants, and of all Doppler waveforms, 73% were correctly identified (75% CW and 71% PW). Participants training or specializing in medical sonography misidentified an average of 27% triphasic, biphasic, or monophasic CW and PW Doppler waveforms and correctly interpreted more CW than PW waveforms. Because there is considerable variability among sonography professionals and educators in defining and classifying peripheral arterial waveforms, this issue deserves higher priority.

Key words: waveform, characterization, analysis

From Jobst Vascular Center Laboratory, Toledo, Ohio.

Correspondence: Robert Scissons, RVT, Jobst Vascular Center Laboratory, 2109 Hughes Drive, Conrad Jobst Tower, Suite 400, Toledo, OH 43606. E-mail: bob.scissons@promedica.org.

DOI: 10.1177/8756479308323128

Doppler waveform analysis is fundamental to the evaluation and correct interpretation of peripheral arterial disease. Many factors, however,

Details of the 97 individuals participating in the study are as follows:

- 22 sonography students
- 8 American Registry for Diagnostic Sonography (ARDMS®), Registered Vascular Technologists® (RVT)
- 18 ARDMS® Registered Diagnostic Medical Sonographers® (RDMS)
- 24 multispecialty ARDMS® RVT, RDMS, or Registered Diagnostic Cardiac Sonographers (RDCS®): 6 RVTs with RDCS and 18 RVTs with RDMS
- 25 physicians: doctor of medicine or doctor of osteopathic medicine (11 with RVT).

Triphasic: three phases—forward flow, flow reversal, and a second forward component

Biphasic: two phases—one forward flow and one reverse component

Monophasic: single phase—forward flow with no reverse flow component

Other: waveform considered neither triphasic, biphasic, nor monophasic or a waveform that could not be categorized.

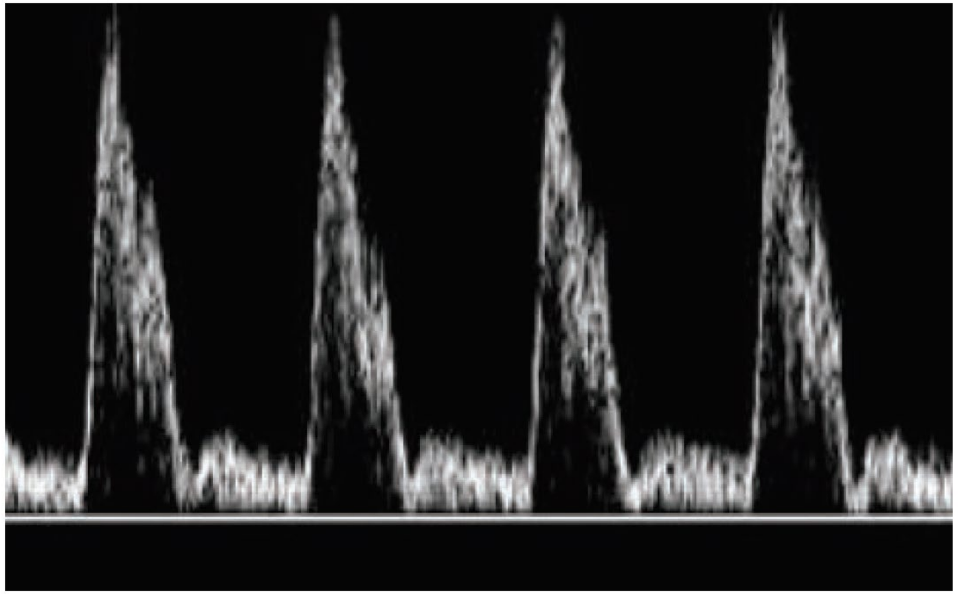


FIGURE 17. Multiphasic, common femoral artery pulsed-wave (PW) waveform with no significant inflow disease. Responses: triphasic, 24%; biphasic, 38%; monophasic, 33%; other, 5%.

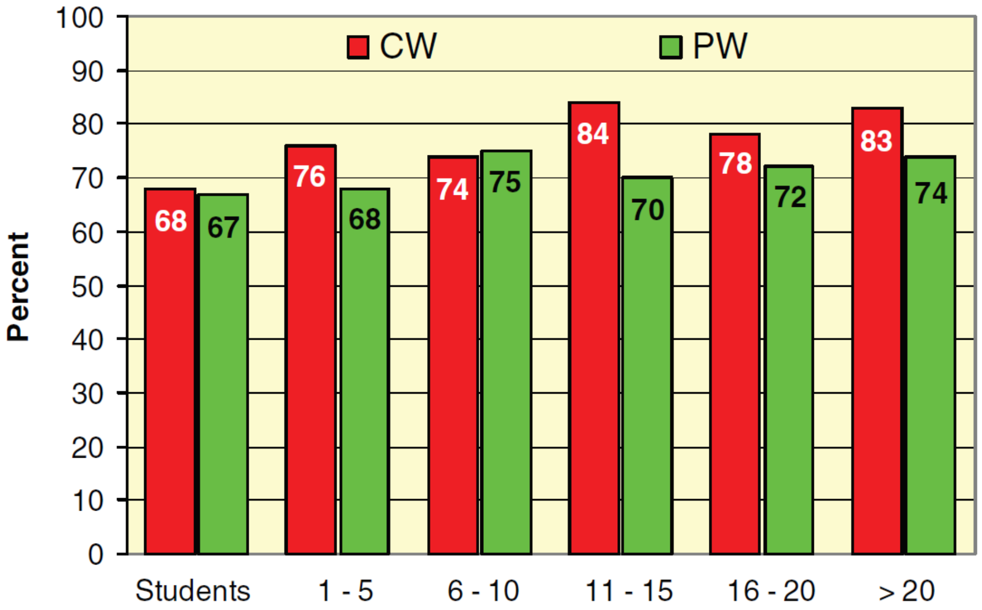


FIGURE 3. Correct continuous-wave (CW) and pulsed-wave (PW) interpretations: years of sonography experience.

First Point of Consensus - KISS

- **Key words**: simplify, nomenclature, applicability to end user (ordering MD), teachability, applicable across acquisition modalities, adaptable to current practice, connect to clinical context
- Describe normal in each vascular bed, then describe abnormal
- Describe versus interpret

Basic Consensus Points

- ***Consensus:*** A nomenclature system utilizing descriptor and modifier categories will be adopted
- **Consensus**: for arterial beds “multiphasic” will replace “triphasic” and “biphasic”
- ***Consensus:*** phasicity will be defined in relation to crossing the zero flow baseline
- ***Consensus:*** aim is to develop “descriptors” of findings, not “interpret” the waveforms.

- It is the responsibility of the interpreter to determine which descriptors are “normal” for a particular vascular bed
- *Examples of interpretation, not findings:* normal/abnormal, post-stenotic

Consensus paper: Doppler waveform nomenclature

Interpretation of Peripheral Arterial and Venous Doppler Waveforms: A Consensus Statement From the Society for Vascular Medicine and Society for Vascular Ultrasound

Journal for Vascular Ultrasound 1–26 © 2020, Society for Vascular Ultrasound

Arterial Key major descriptors

- Flow direction (antegrade, retrograde, bidirectional, absent)
- Phasicity (multiphasic, monophasic)
- Resistance (high, intermediate, low)

Additional modifier terms may also be used

- Upstroke (rapid, prolonged)
- Sharp peak
- Spectral broadening
- Staccato
- Dampened
- Flow reversal

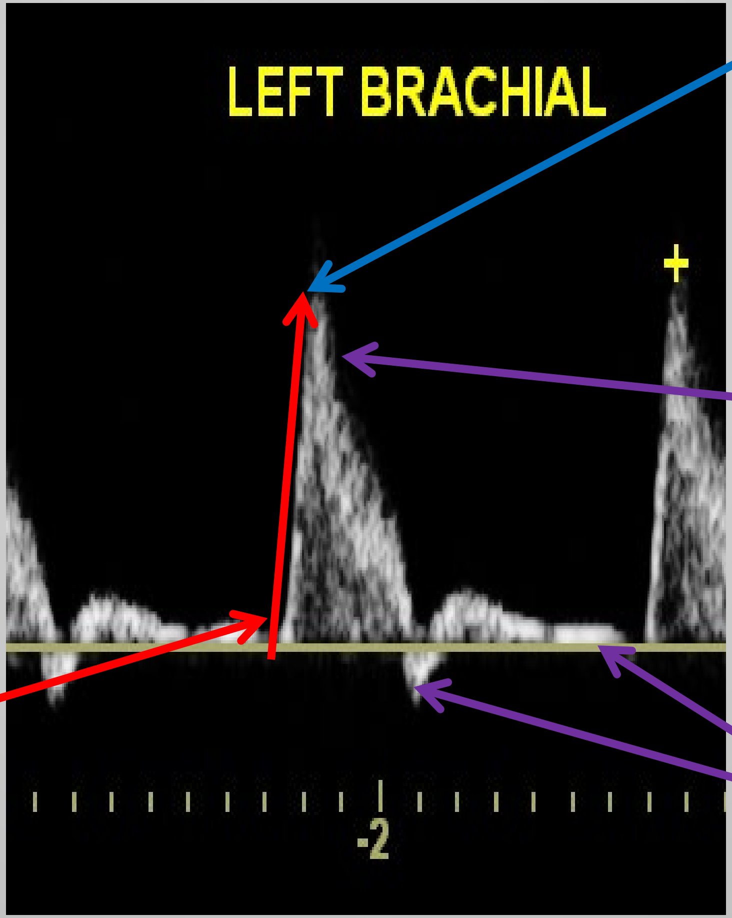
Arterial waveform morphology depends on:

- Cardiac function
- Lumen size at the sample site and sample volume size
- Pressure reducing lesions /obstructions proximal to the sample site
- Distal vasomotor tone at the level of the arterioles in the muscular beds
- Distal obstructions

Arterial waveform principles: Past, Present, Future

Systolic peak:

the **present**, or fastest flow before deceleration

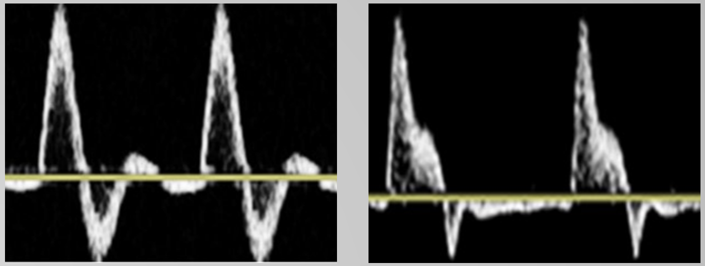


Upstroke, acceleration: reflects the **past**, or how the flow arrived (fast or slow)

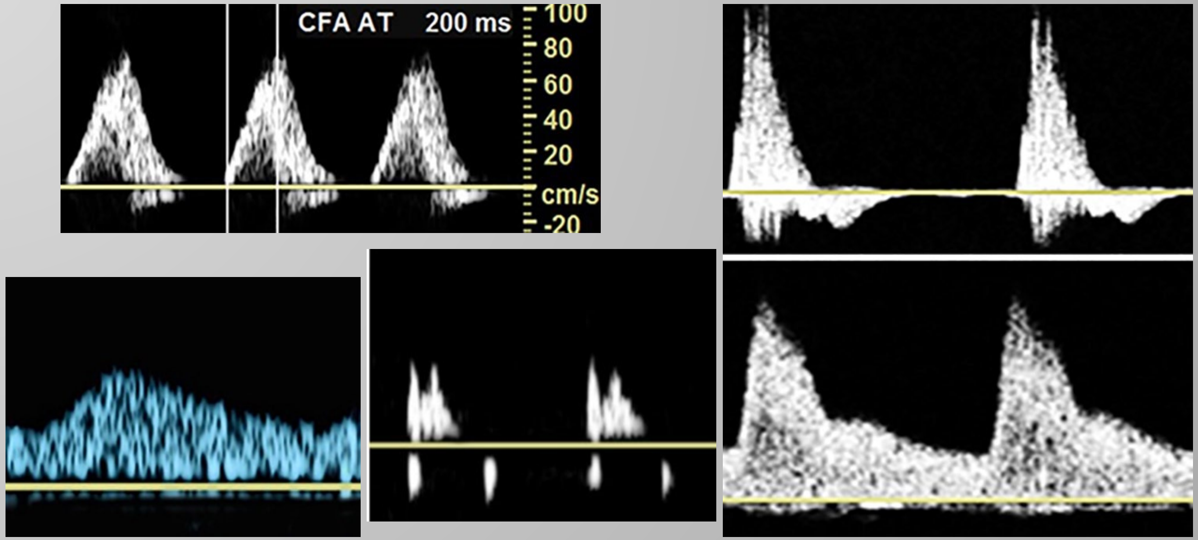
Downslope, deceleration and diastolic components: the **future**, or what type of vascular beds are being fed

Arterial waveform diagnostic elements

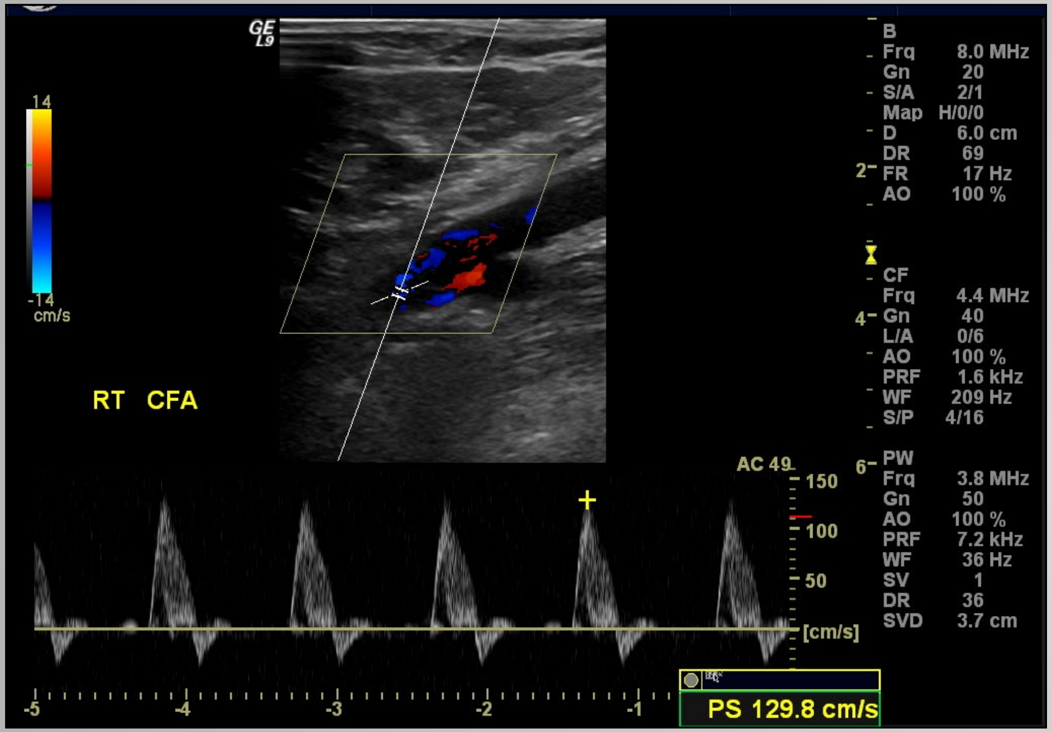
- Normal resting arterial waveforms: rapid upstroke, sharp peak, narrow spectral bandwidth, multiphasic, normal velocity and velocity ratio <2 along consecutive segments

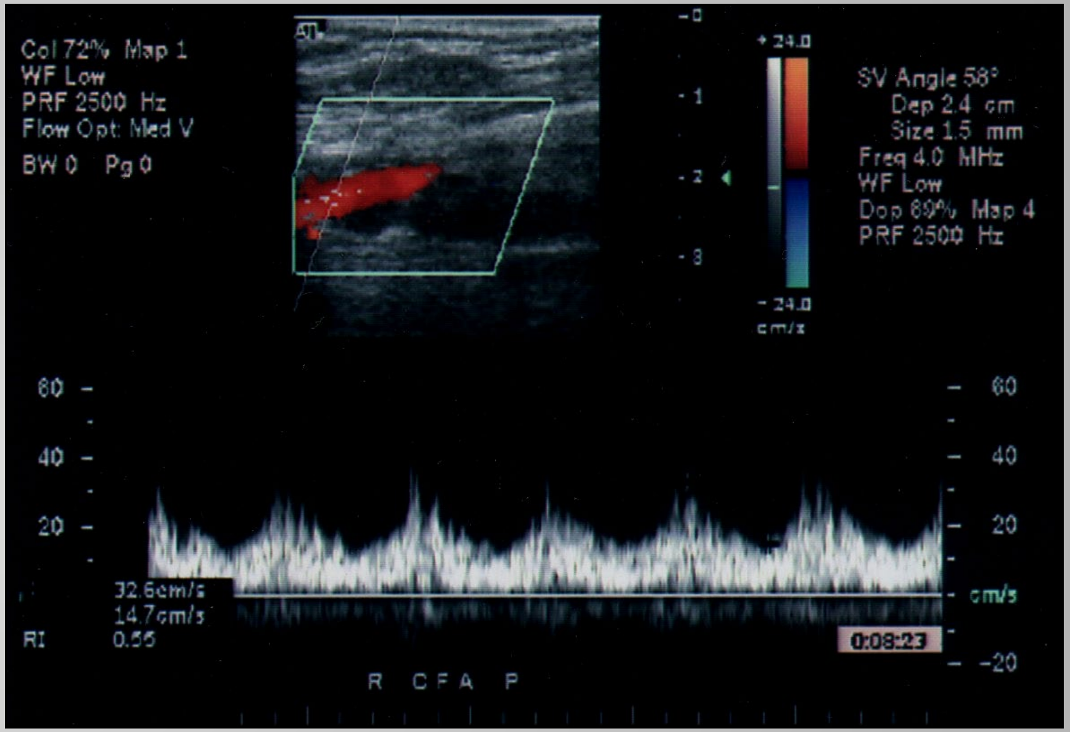


- Abnormal resting arterial waveforms: delayed upstroke, rounded systolic peak, prolonged downstroke, loss of early diastolic flow reversal, spectral broadening, dampened, staccato, elevated velocity with ratio >2 across contiguous segments,



Evaluating extremity waveform components





Multiphasic (sharp peak): Normal

Tish term: RAD

Rapid **A**cceleration to **D**eceleration

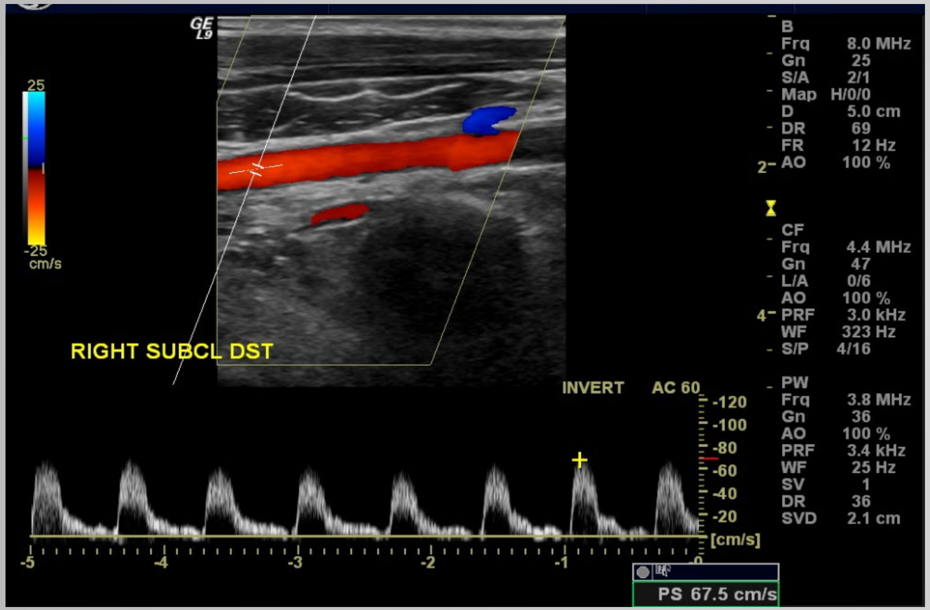
Monophasic (rounded peak): Abnormal

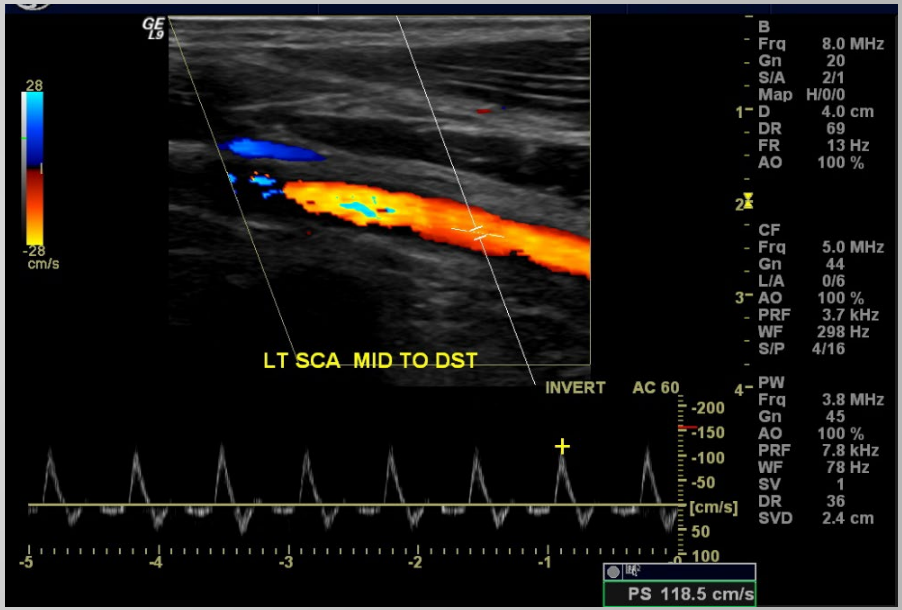
Tish term: SAD

Slow **A**cceleration to **D**eceleration

Evaluating waveform components

Always look for symmetry side-to-side

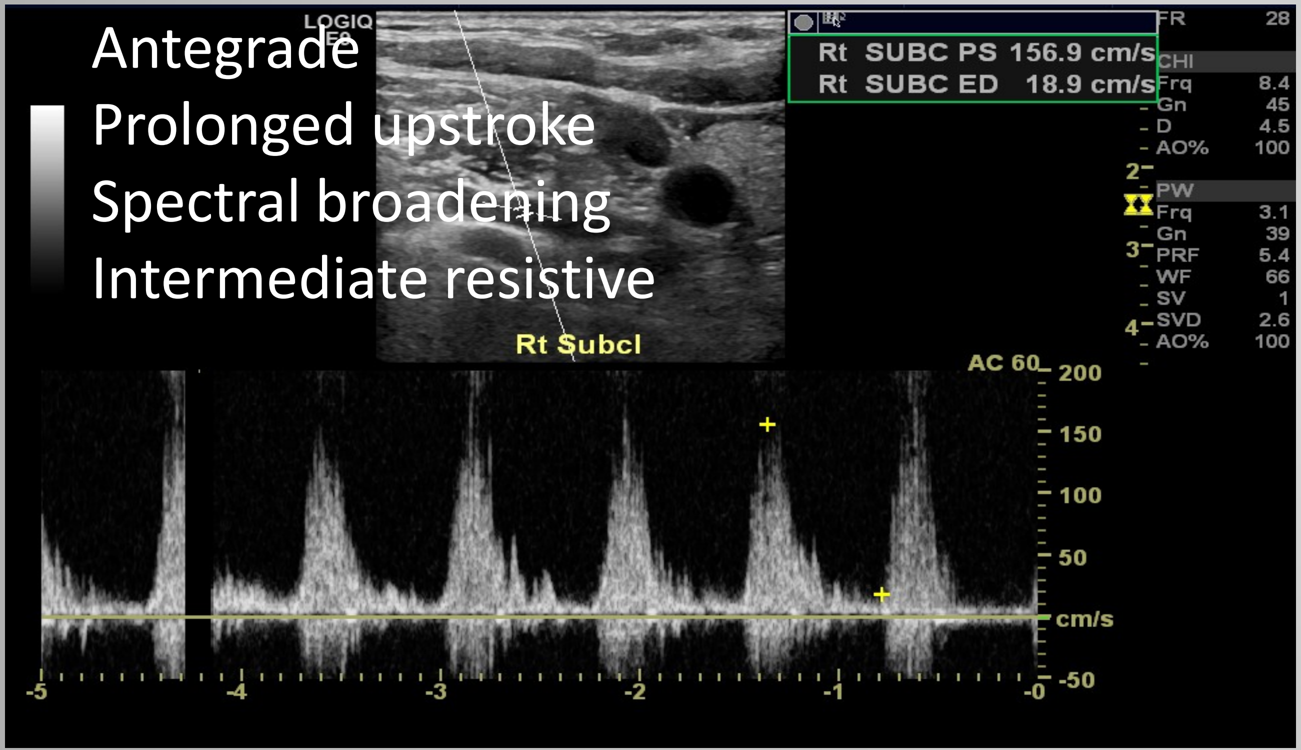




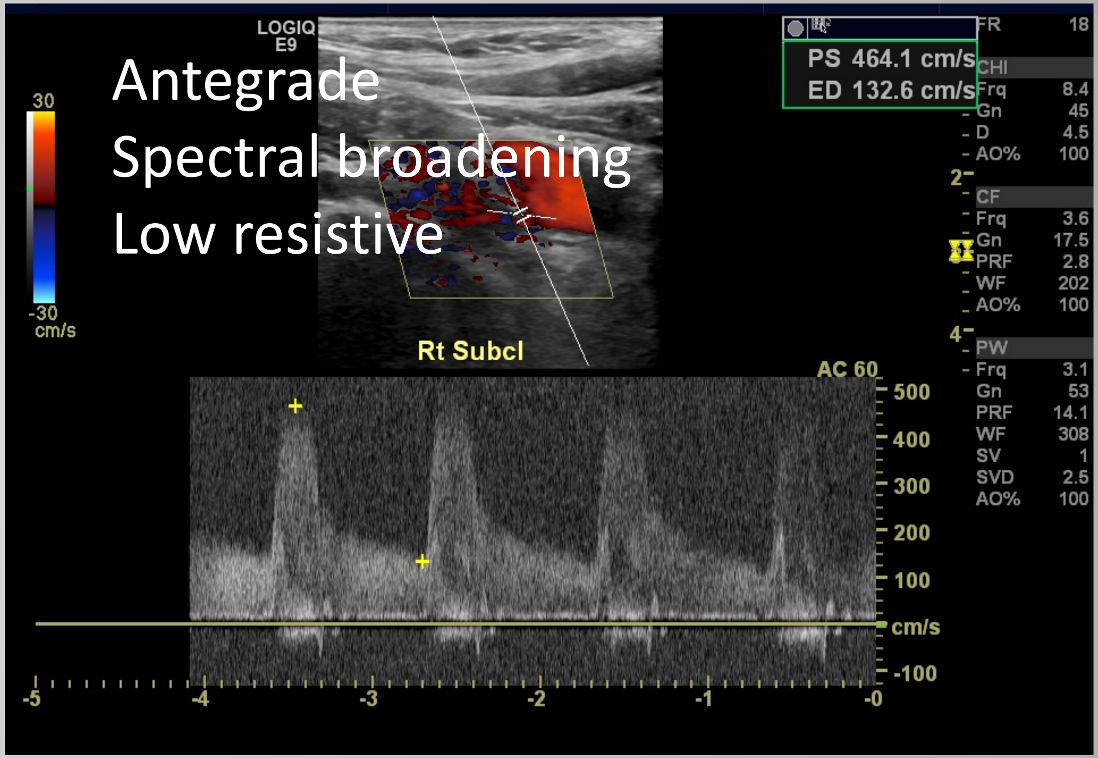
Rapid acceleration, rounding of the systolic peak, slowed deceleration with reduced distal vasomotor tone.

Rapid acceleration and deceleration, sharp peak and normal resting vasomotor tone.

Evaluation of a right subclavian artery stenosis:



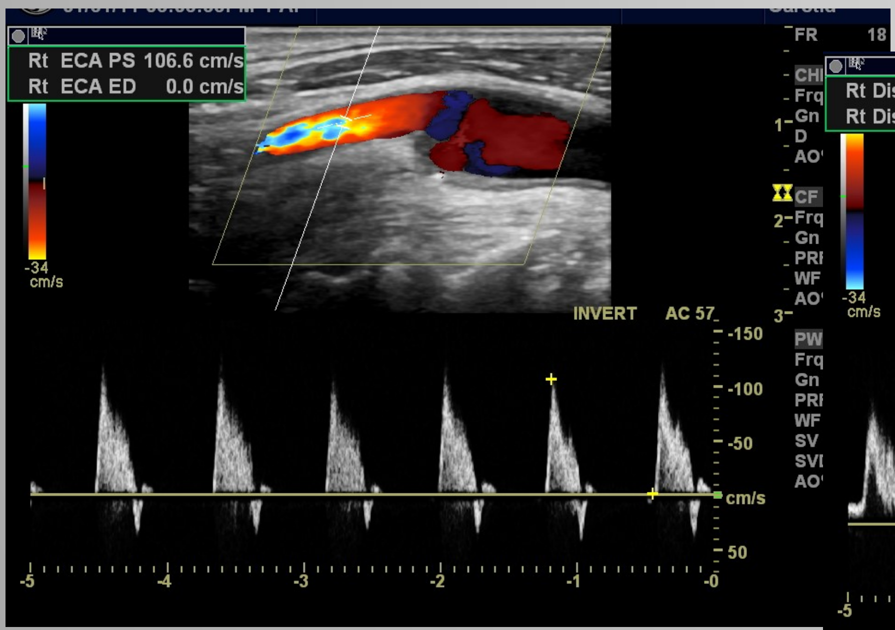
How would you interpret these right mid-subclavian artery Doppler velocity waveforms?

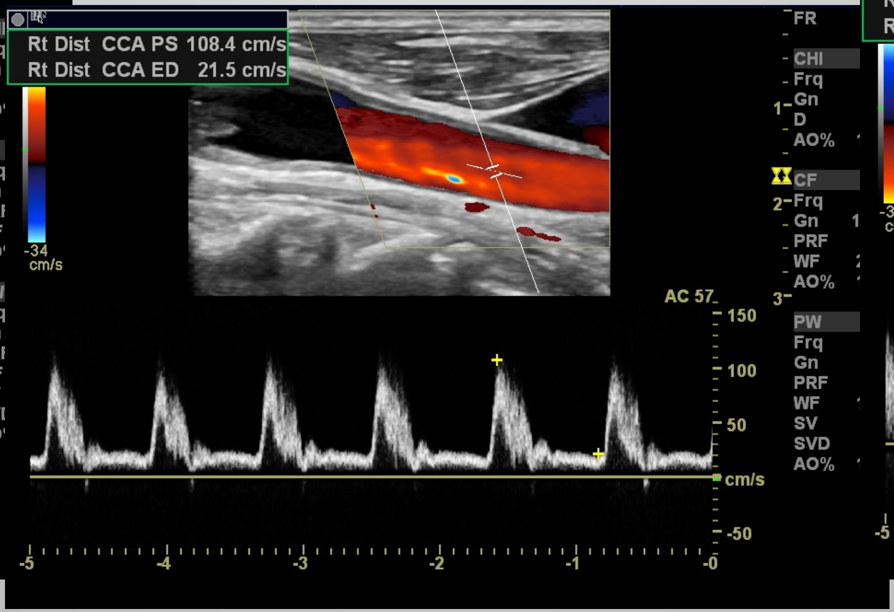


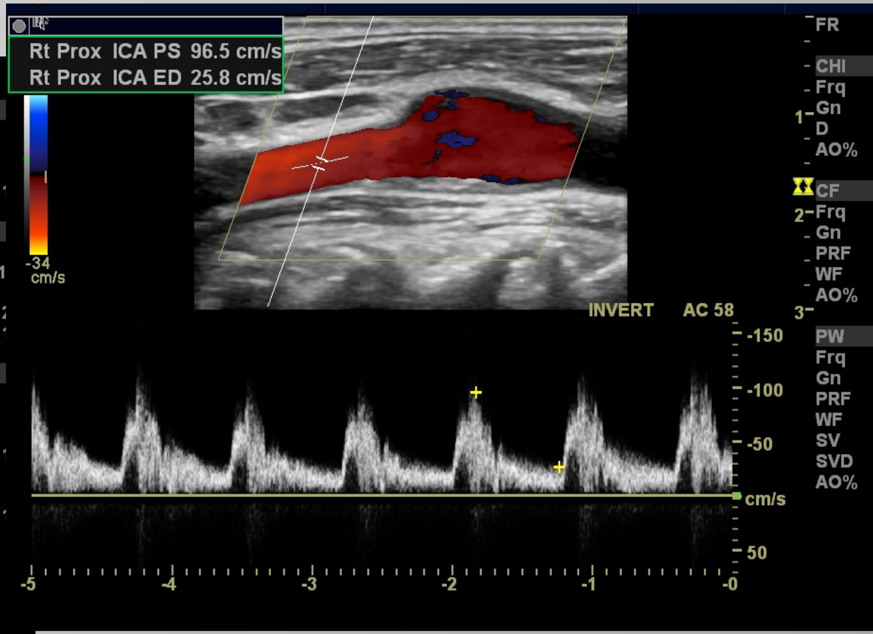
Right subclavian artery origin Doppler velocity waveforms?

Peripheral arterial waveforms

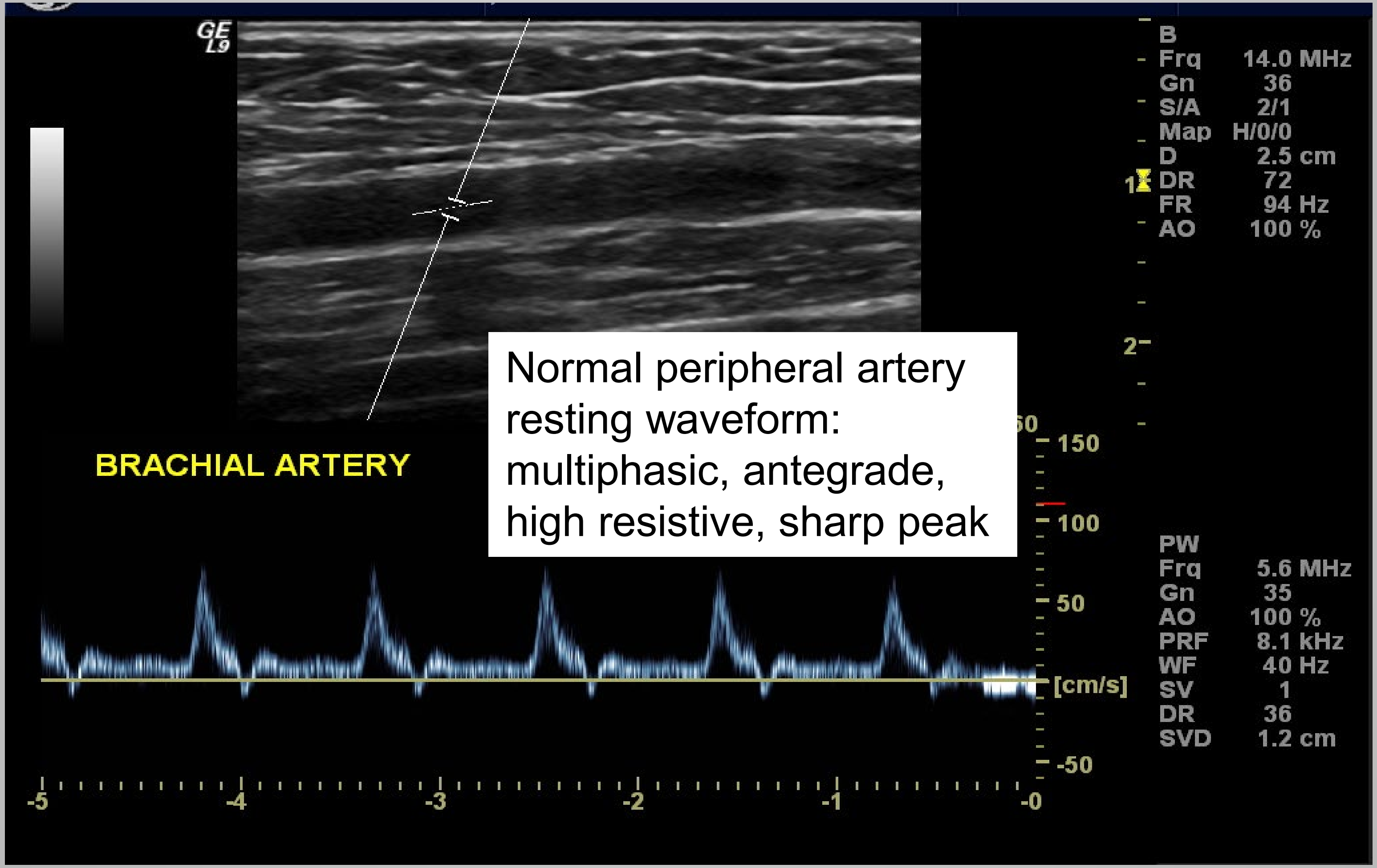
- Arteries feeding variable metabolic demand tissues (ECA), resting skeletal muscles, fasted intestine have high to intermediate resistance
- Arteries feeding high metabolic demand in the distal tissues (ICA), renal, hepatic, splenic post-prandial intestine have low resistance
- Arteries feeding into branches that supply high and low metabolic demand combine features of both (CCA), aorta



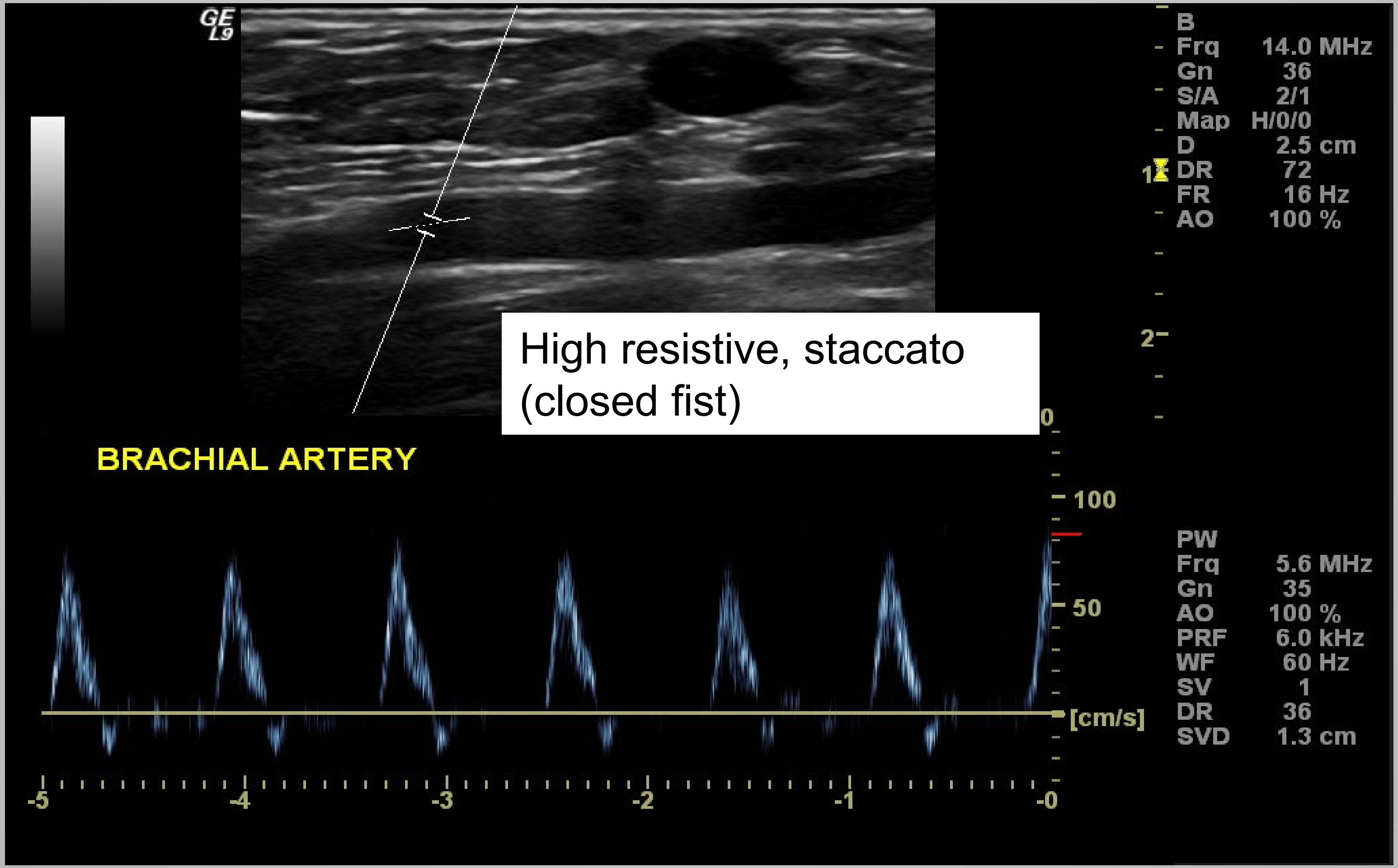




Arterial resistance patterns change based on vasomotor tone at the arteriolar level

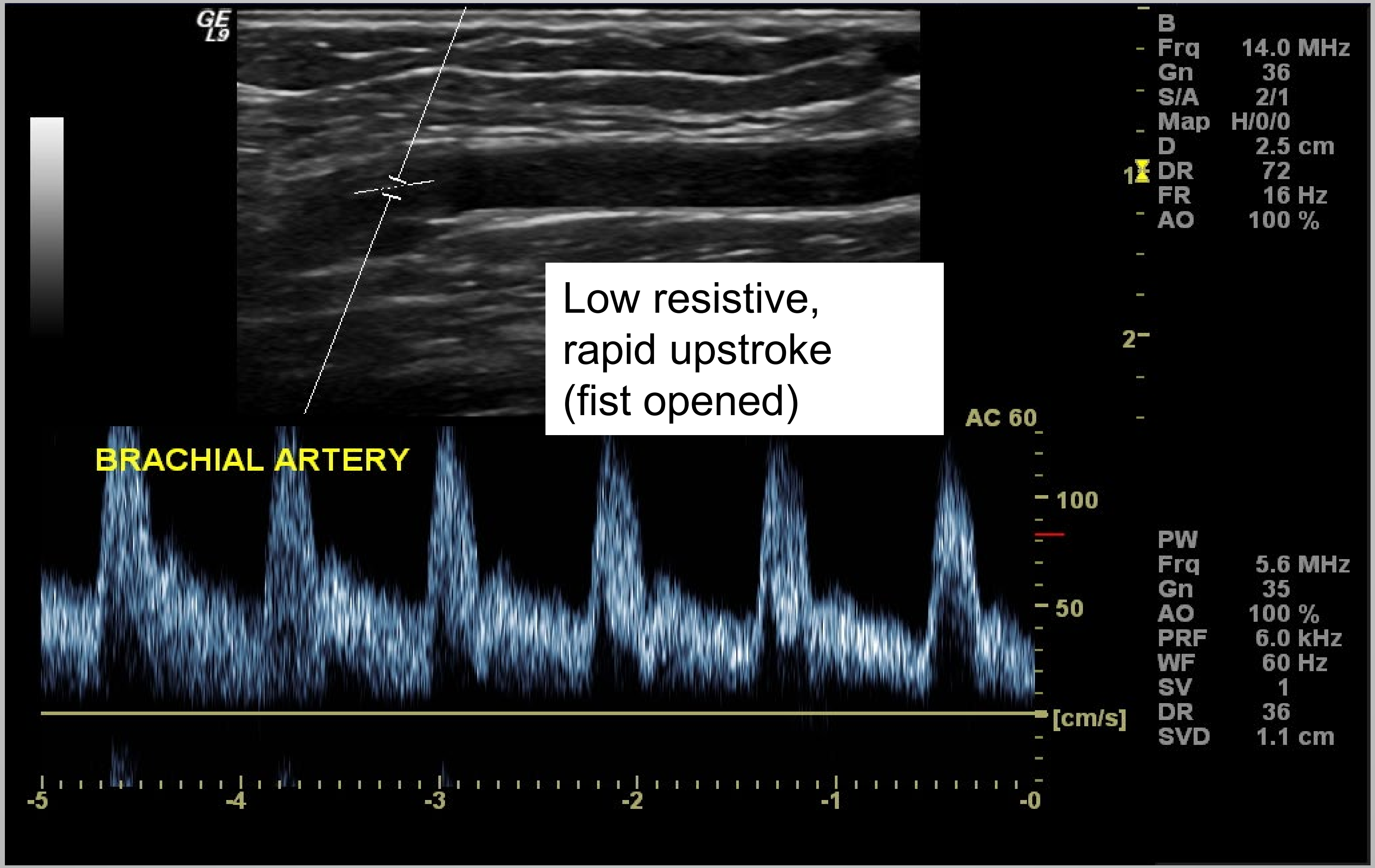


Arterial resistance patterns: same person

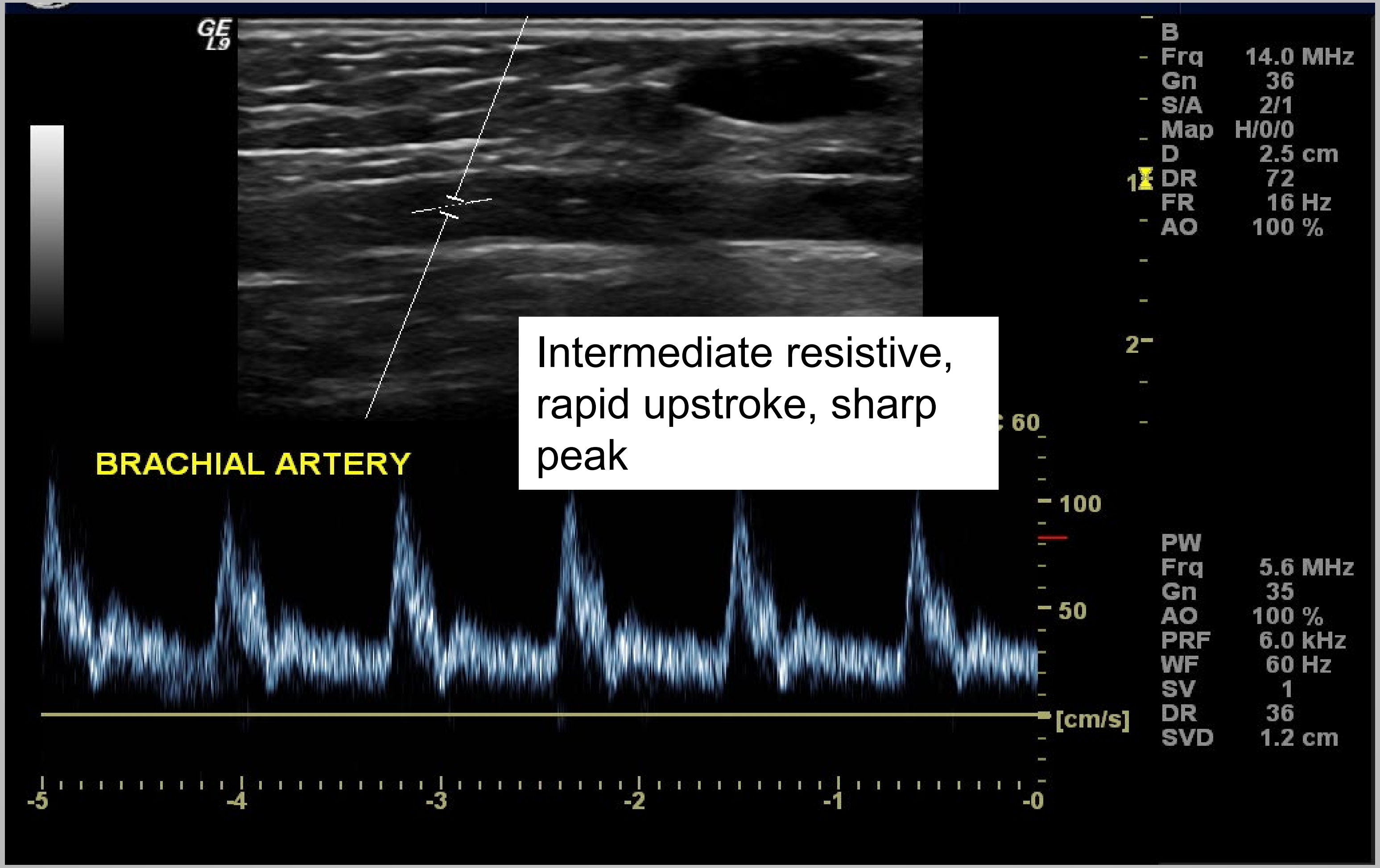


High resistive, staccato (closed fist)

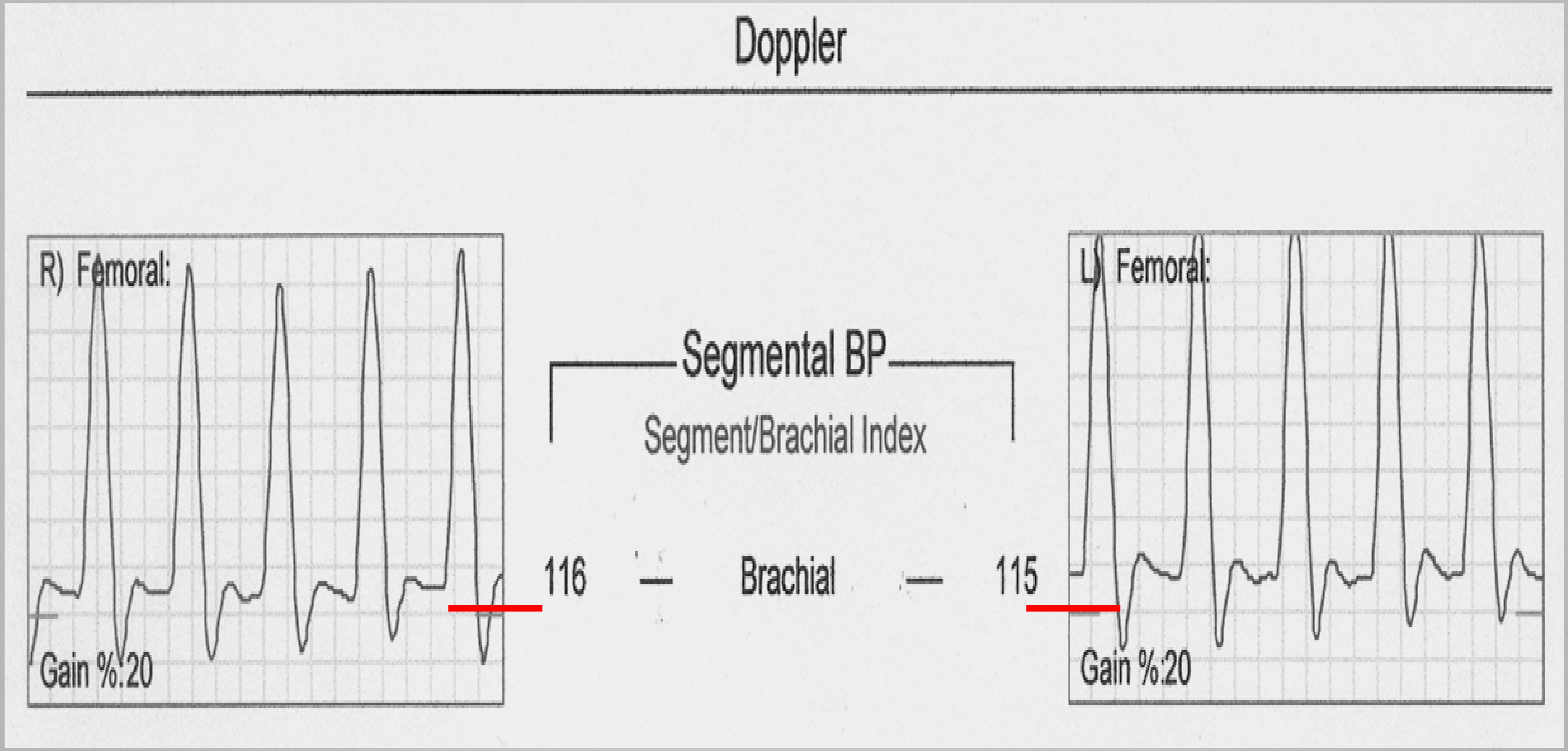
Arterial resistance patterns: same person



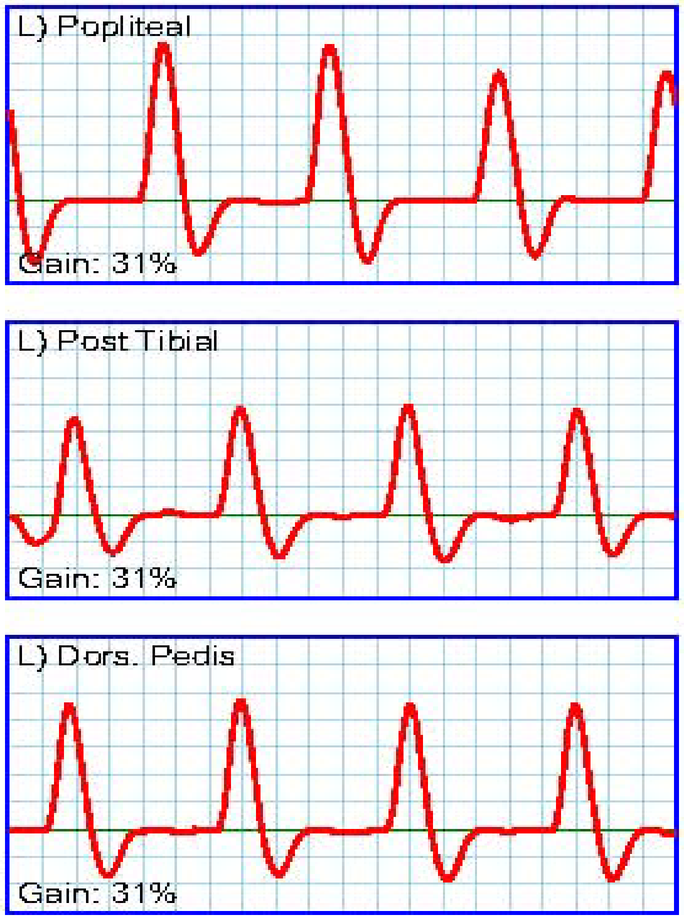
Arterial resistance patterns: same person



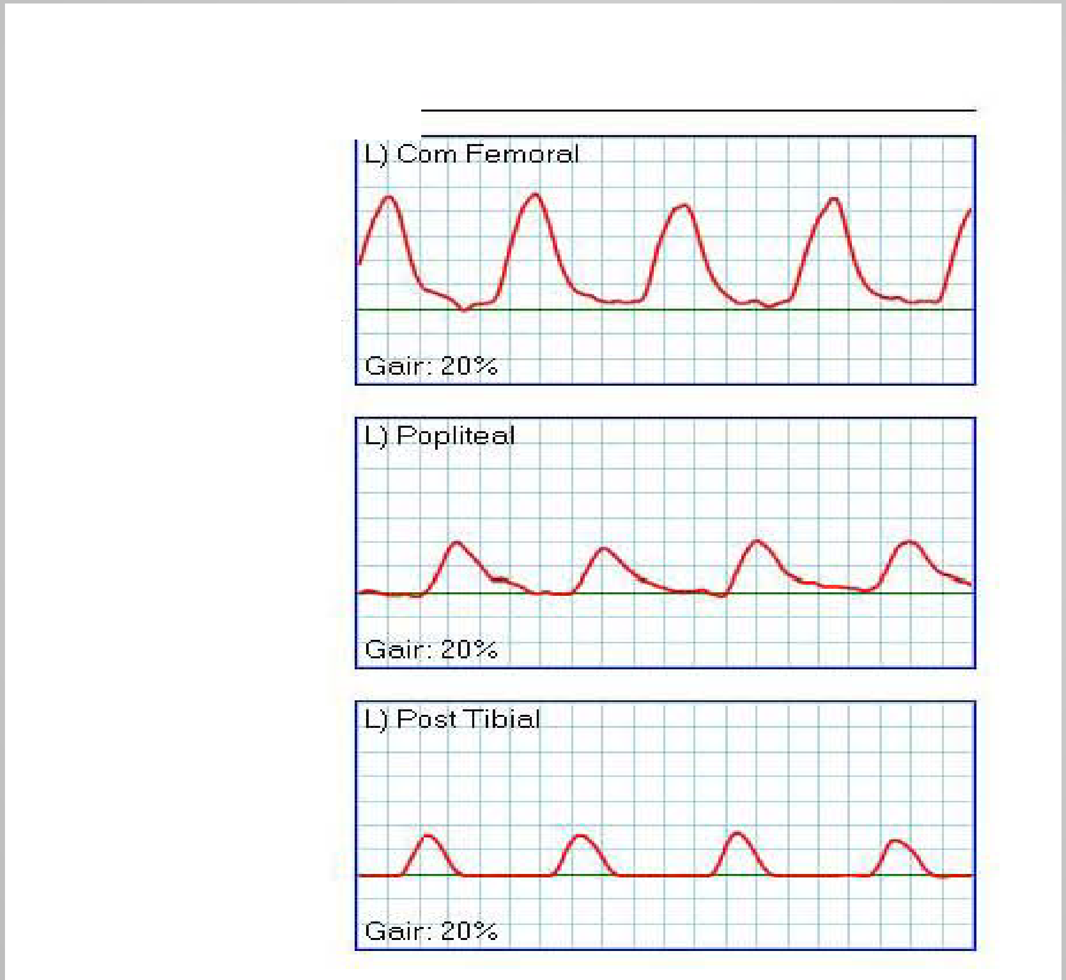
CW Doppler: Multiphasic Analog processing



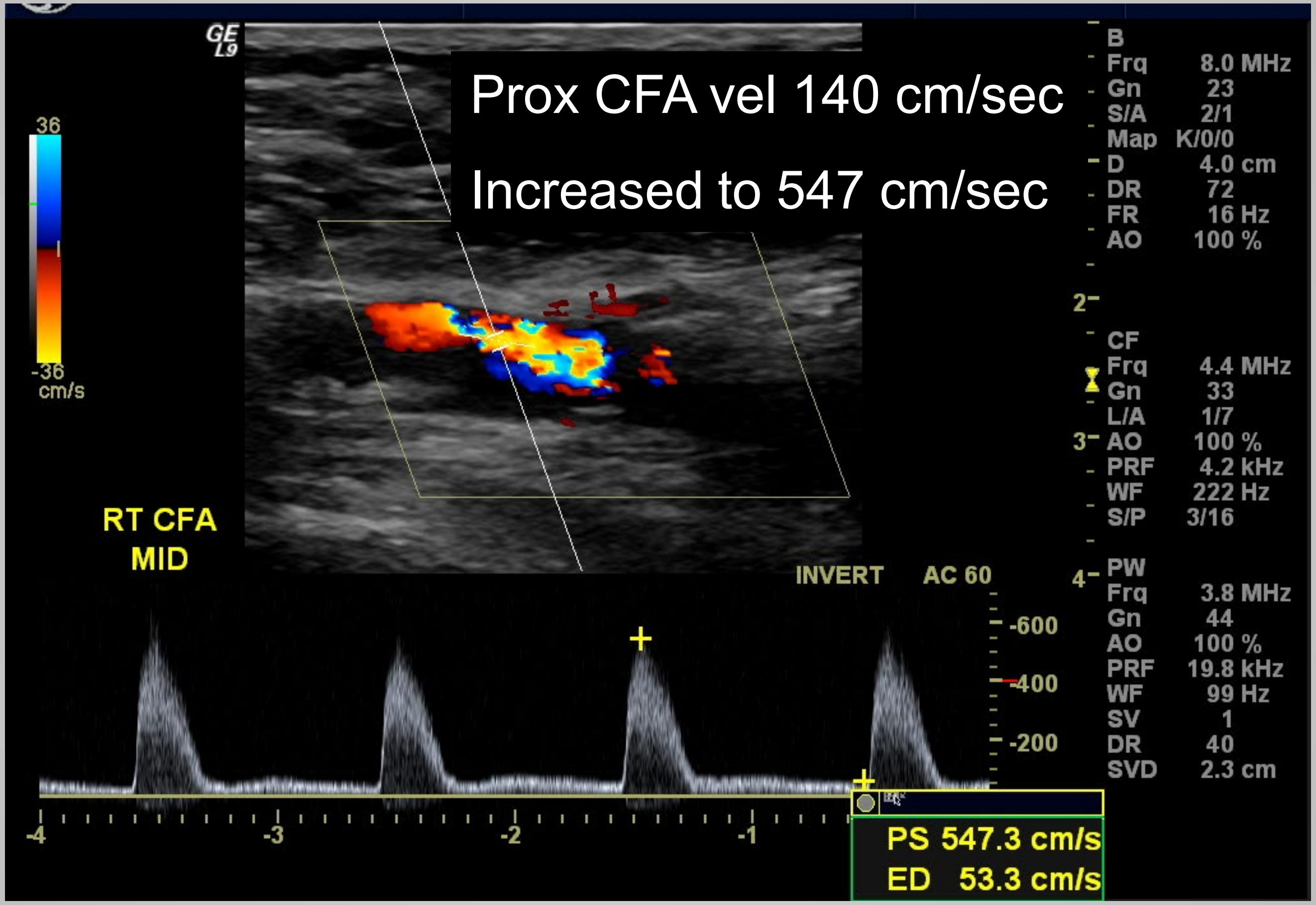
CW Doppler: Multiphasic



CW Doppler: Monophasic

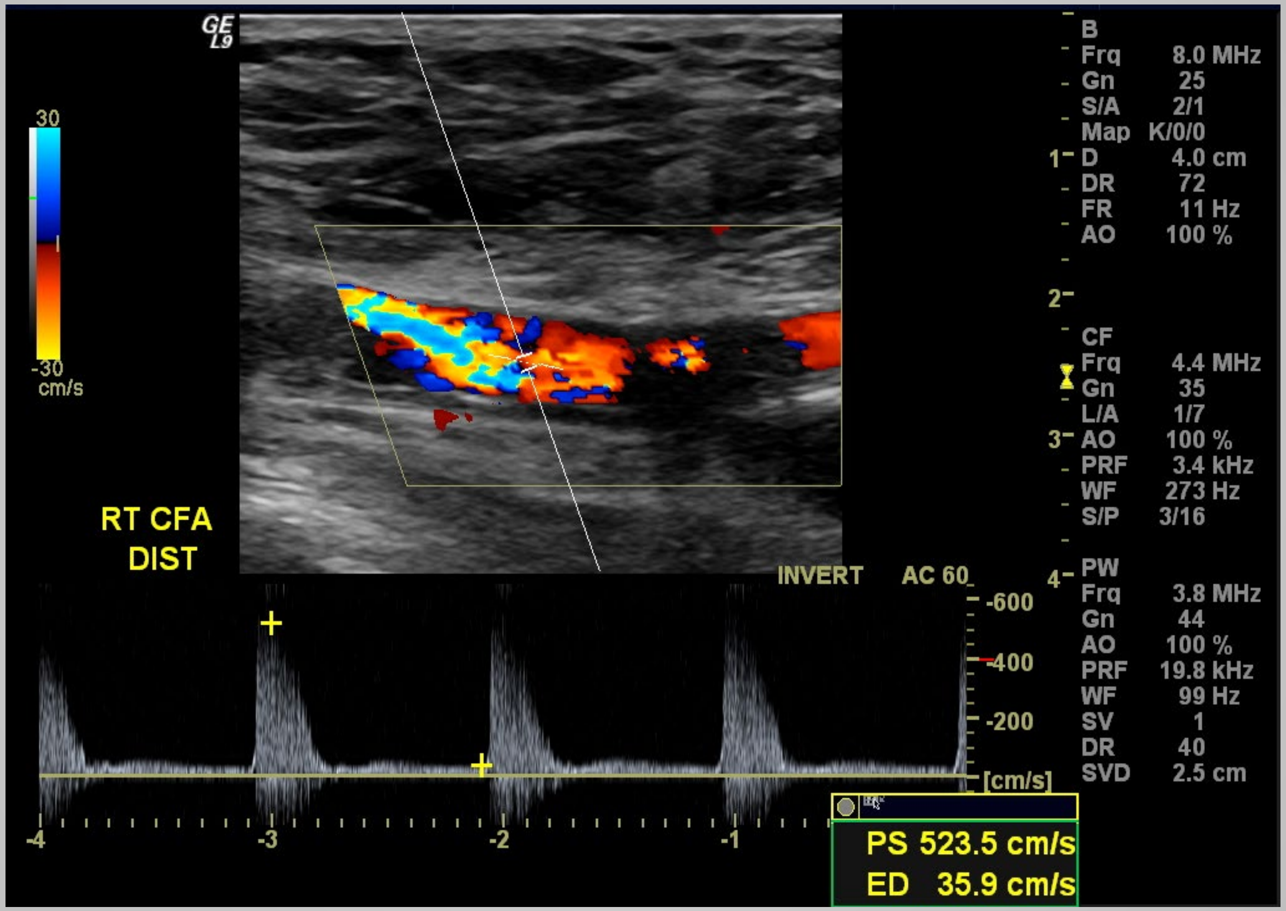


Arterial Stenosis



Velocity increases from pre to peak in areas of significant stenosis (diameter reduction)

Arterial Stenosis



Post-stenotic turbulence is present just distal to hemodynamically significant stenosis (serrated, choppy waveforms with flow reversal under the systolic peak)

PW Doppler

PW Doppler
(**P**ulsed **W**ave Doppler)

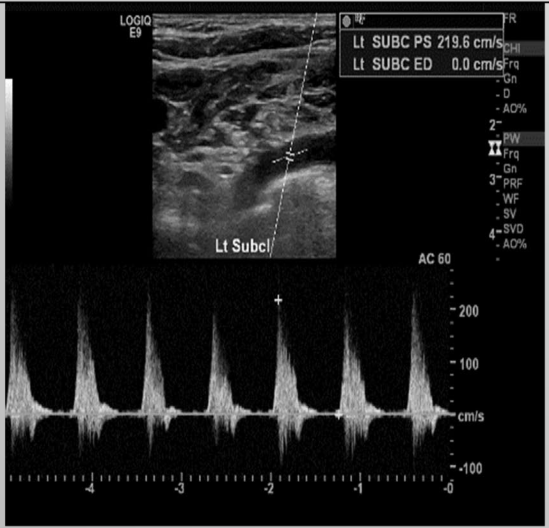
Learning goals:

- Demonstrate correct transducer position
- Identify flow direction
- Interpret waveform morphology

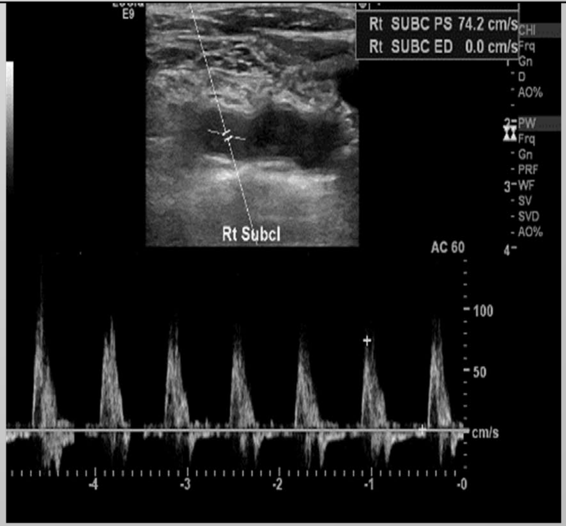
PW Doppler and angle correction

- The Doppler line of insonation must always be aligned properly to the flow vector ≤60˚
- If you are evaluating only the waveform morphology (usually veins), then the angle correction cursor does *not* need to be engaged
- If you are evaluating velocity along with waveform morphology (usually arteries), then the angle correction cursor *must* be engaged, aligned parallel to the vessel walls at angles of ≤60˚

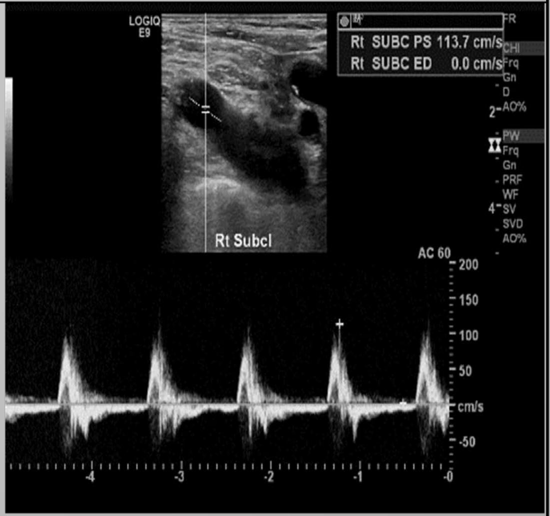
Doppler line angled to left



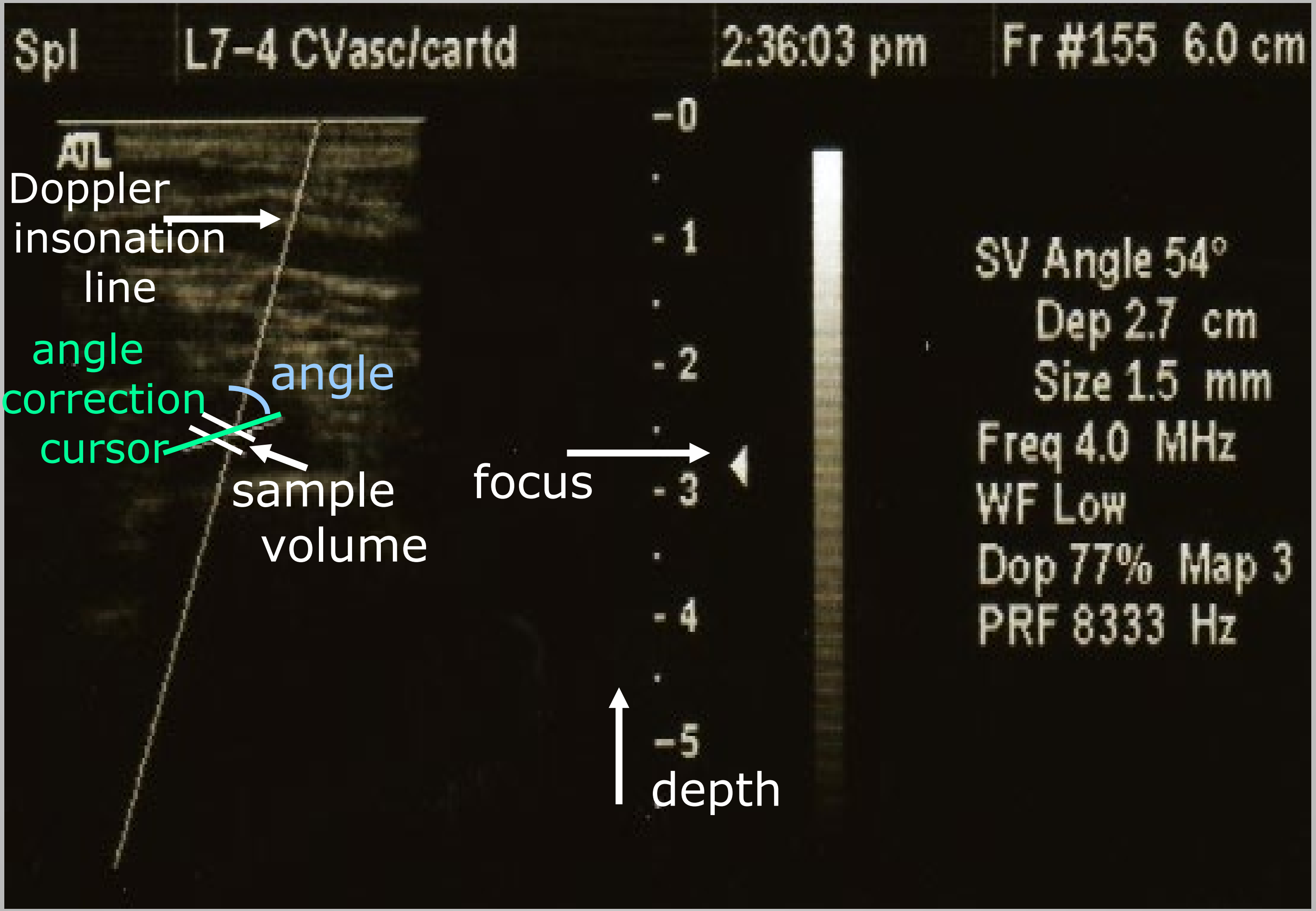
Doppler line angled to right



Doppler line angled straight down

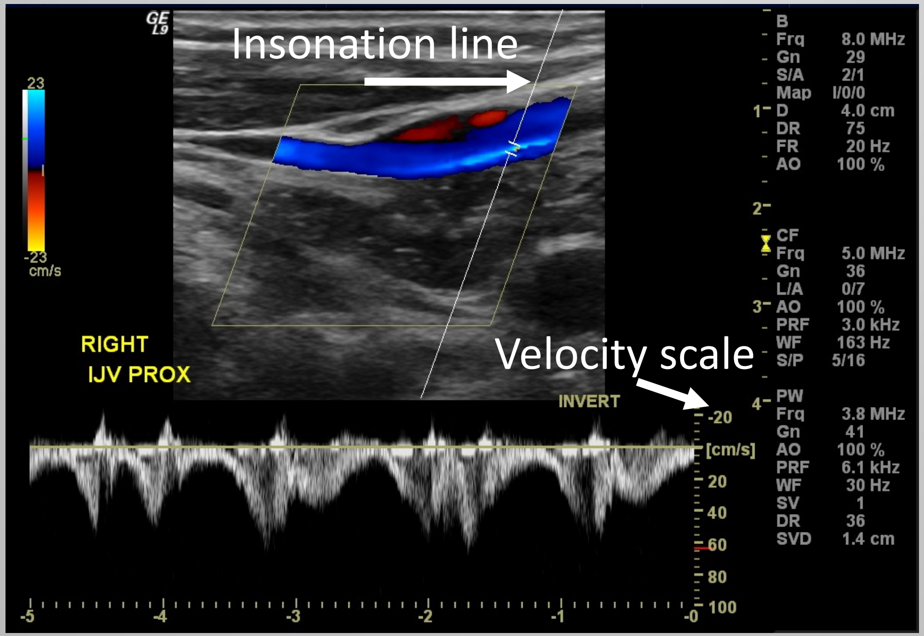


PW Doppler and angle correction



PW Doppler and angle correction

- If you are evaluating only the waveform morphology (usually veins), then the angle correction cursor does not need to be engaged and the machine assumes it is at 0˚.
- Waveform *morphology* does not change when the angle correction cursor is used---the *velocity scale* changes with changes in angle cursor adjustment.
- Note that the insonation line must be set to intersect the vessel at <u><</u>60˚ in order to get good, diagnostic waveforms.



PW Doppler and angle correction

- At insonation angles of >60˚, the cosine of that angle used in the Doppler equation yields estimates of velocity that are far removed from the criteria charts and introduces significant errors in interpretation
- The most accurate velocity estimates are made when the angle to flow is 0˚------ right down the barrel------- or near 0˚. But the blood vessels we interrogate don't *usually* lie vertically under the transducer.
- At 90˚ there is theoretically no discernable flow IF the flow is steady state and laminar------ however blood is pulsatile with helical flow patterns so some very muddled waveform pattern can be demonstrated that is not diagnostic.

Angles	Cosines of those angles
0°	1
30°	.86
45°	.70
60°	.50
90°	0

PW Doppler and angle correction

Doppler Equation: frequency shift

$$f_{Dop\Delta} = \frac{2\, f_{Oper} * v * \cos(\Theta)}{c}$$

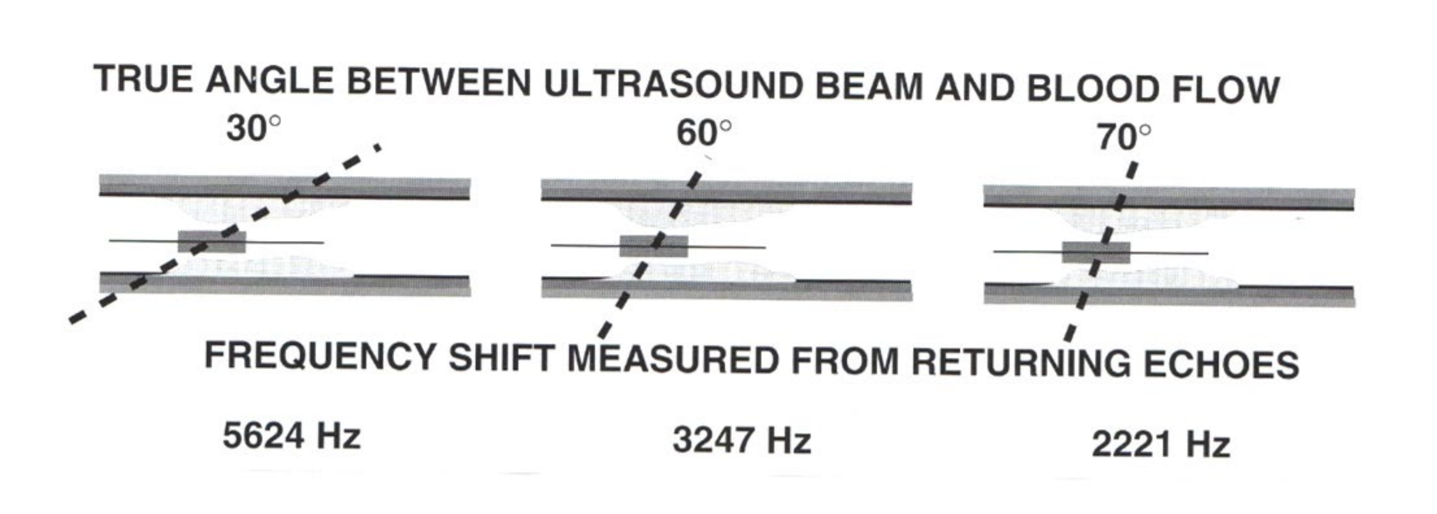


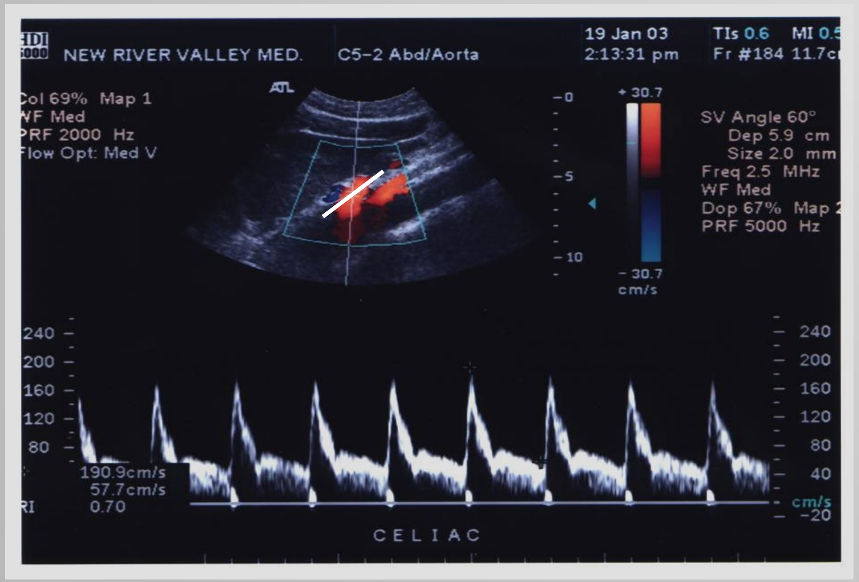
Diagram taken from J. Polak: Peripheral Vascular Sonography, second edition

PW Doppler and angle correction

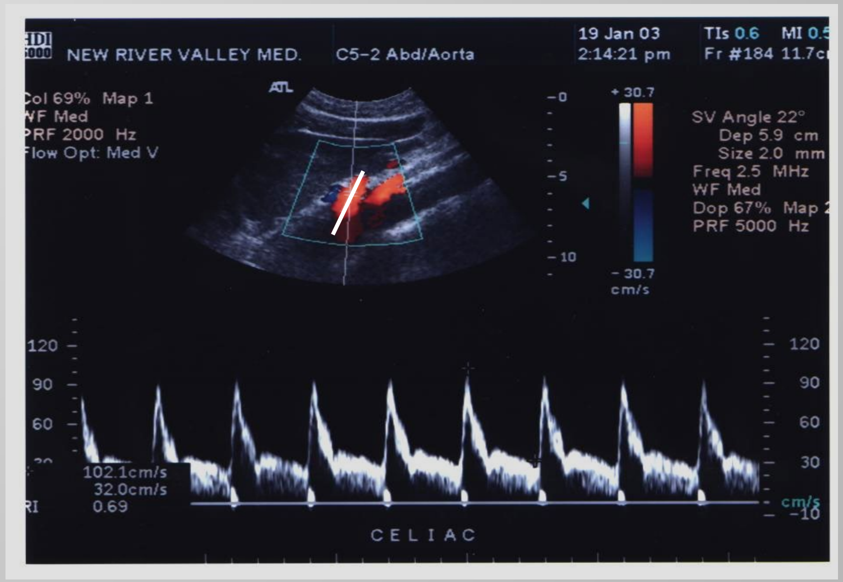
Solving for velocity

$$v = \frac{f_{Dop\Delta} * c}{2\, f_{oper} * \cos(\Theta)}$$

0°	1
30°	.86
45°	.70
60°	.50
90°	0

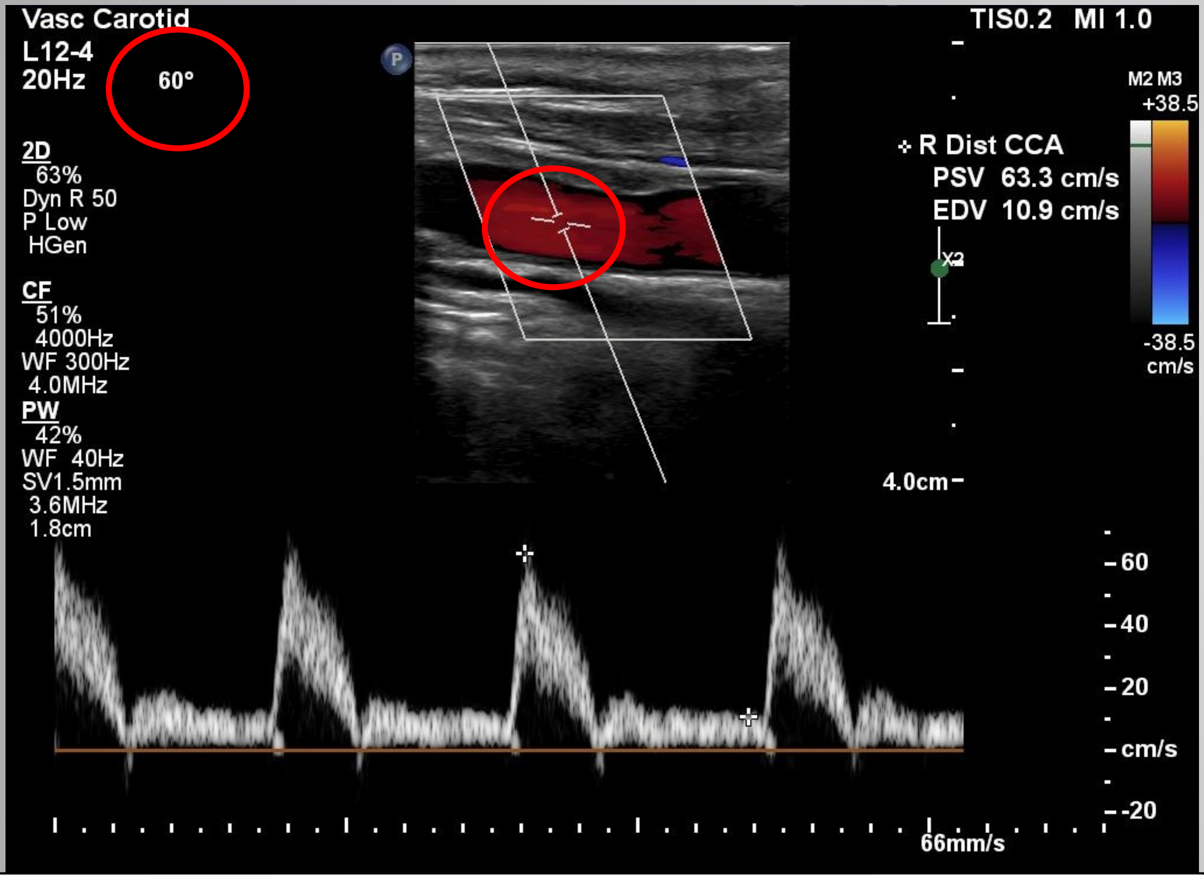


Angle 60°, vel 191/58

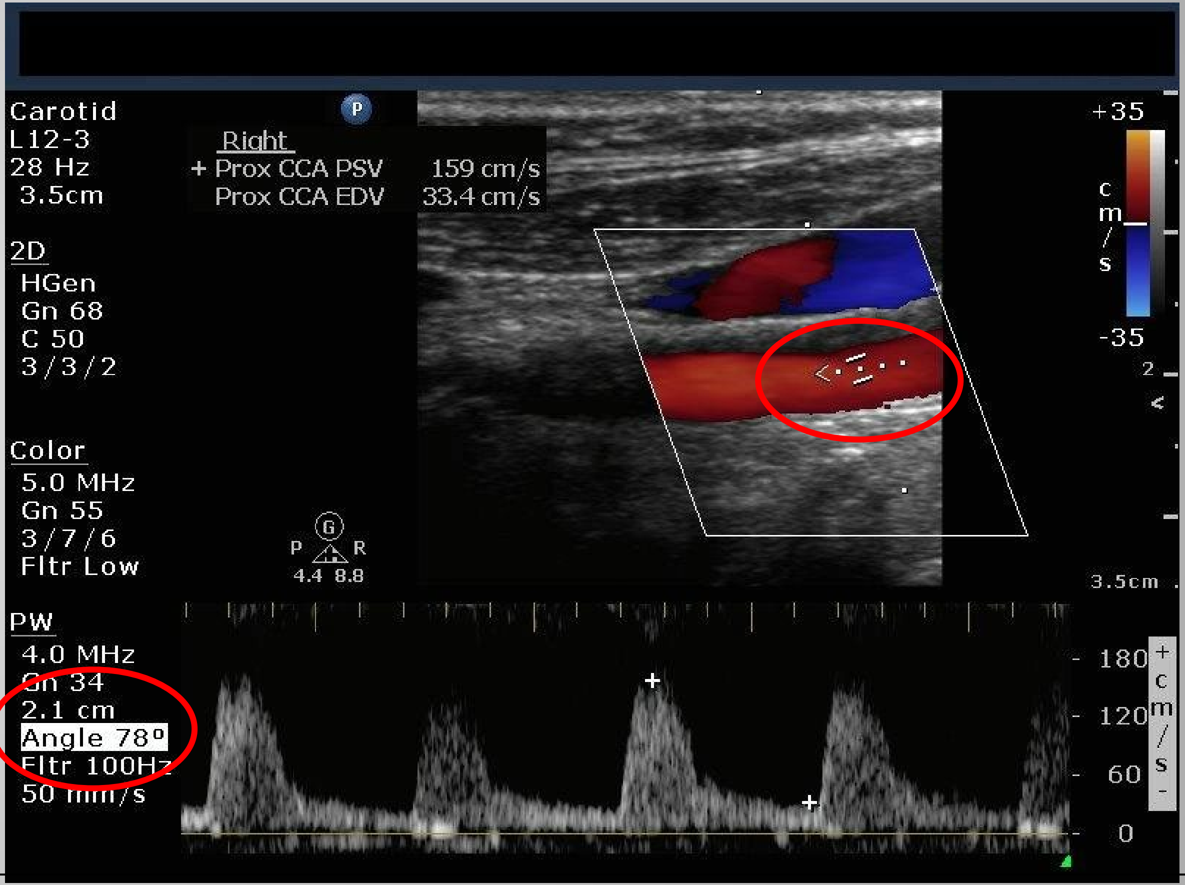


Angle 22°, vel 102/32

PW Doppler and angle correction: examples

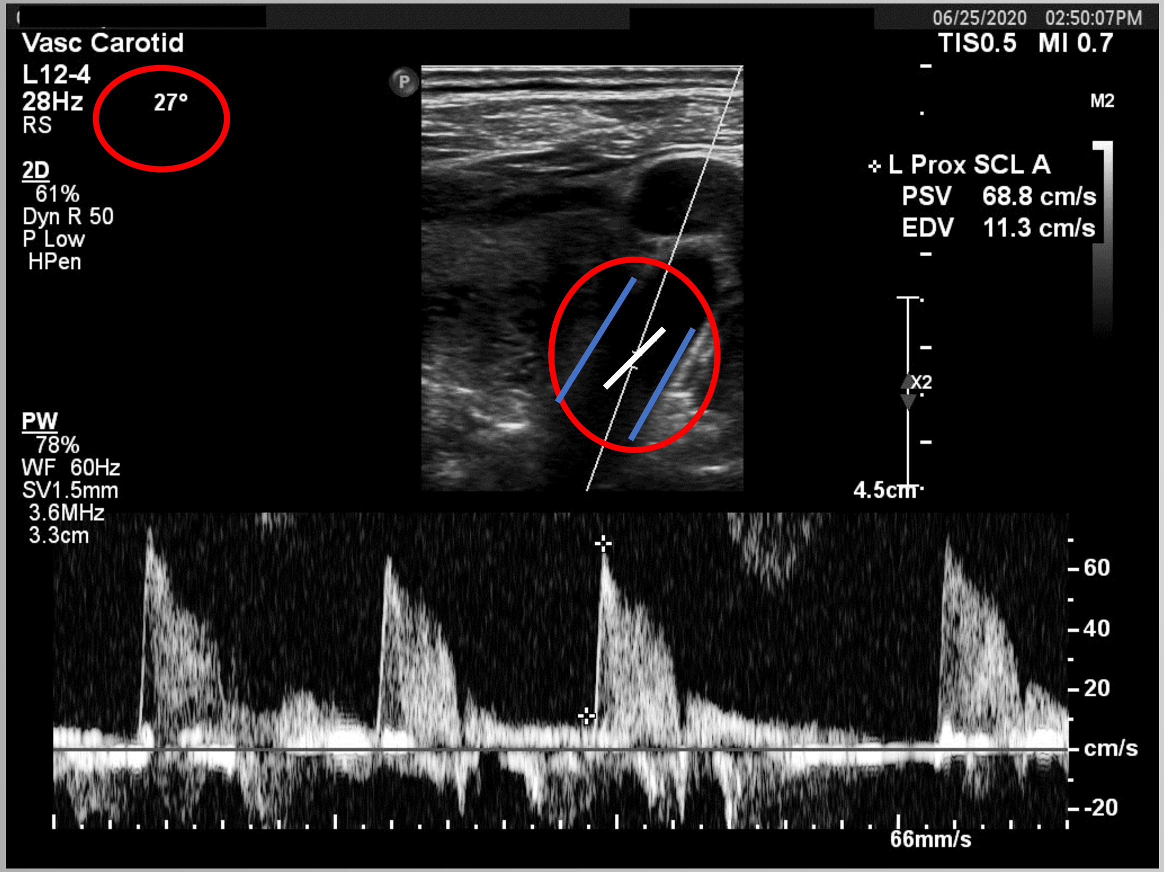


Angle correction cursor aligned parallel to vessel wall at an angle of 60˚ and sample volume center stream. Velocity estimate is “accurate” to use in interpretation.

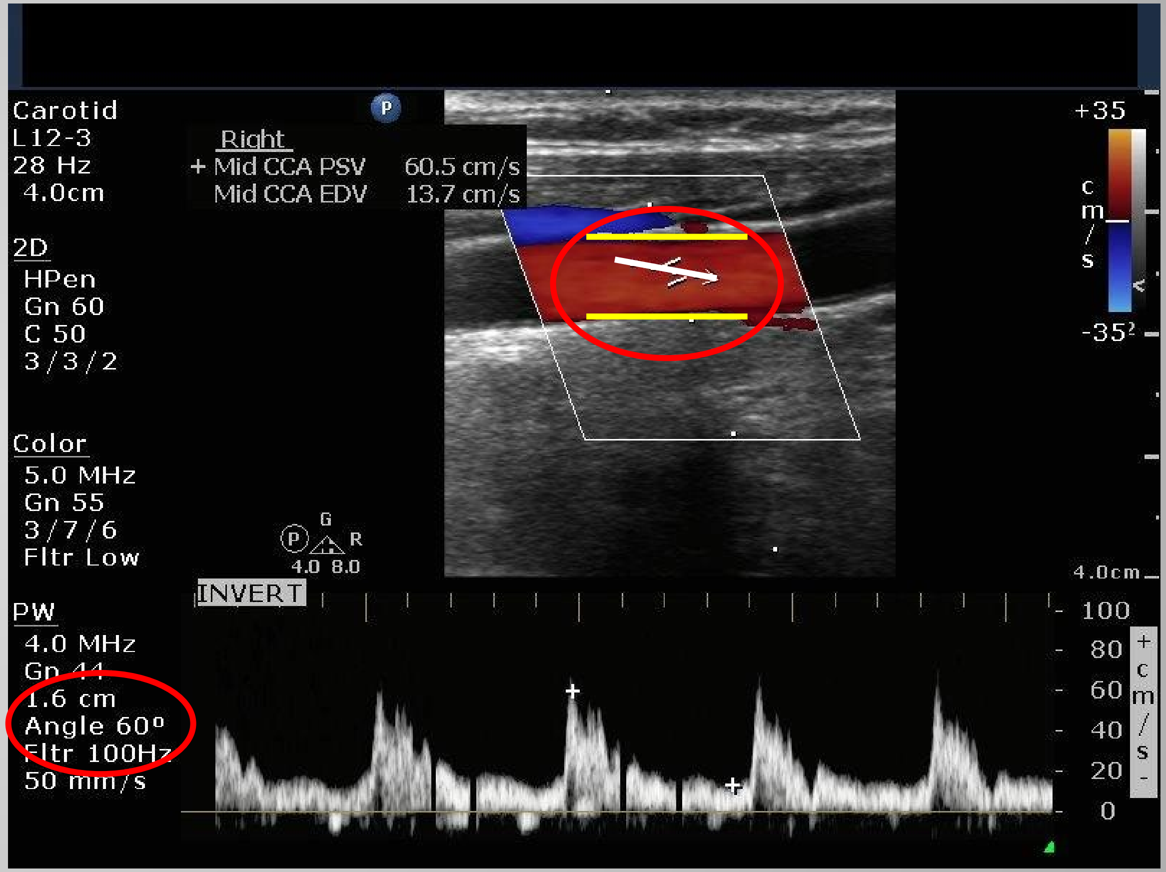


Angle correction cursor aligned parallel to vessel wall at an angle of 78˚ and sample volume center stream. Velocity estimate is “inaccurate” to use in interpretation.

PW Doppler and angle correction: examples

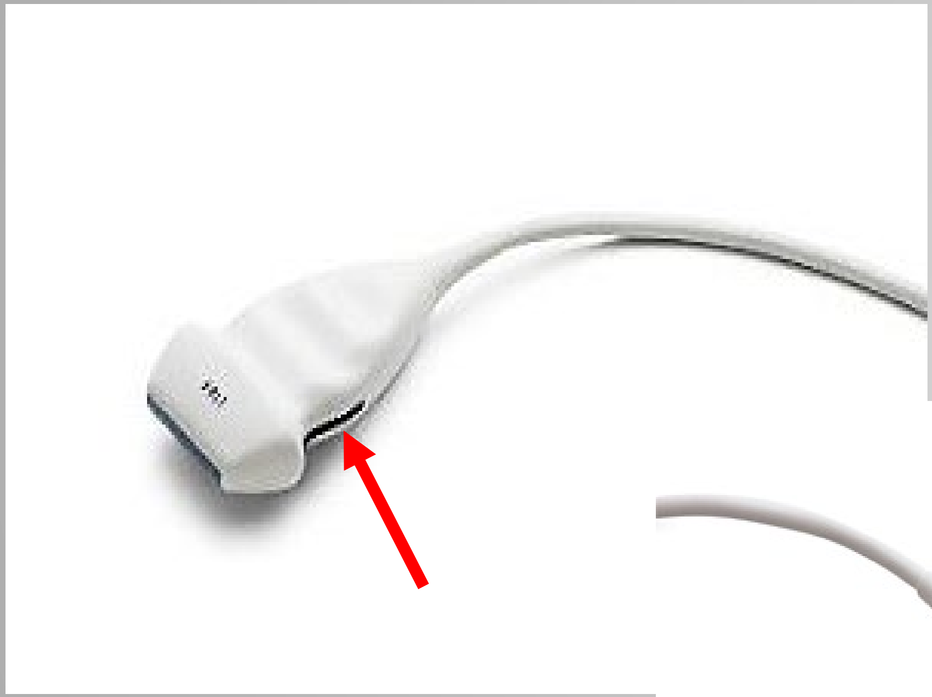


Angle correction cursor not aligned parallel to vessel wall, at an angle of ≤60˚ (27˚) and sample volume center stream. Velocity estimate is "inaccurate" to use in interpretation.



Angle correction cursor is not aligned parallel to vessel wall," angle of 60˚ and sample volume center stream. Velocity estimate is "inaccurate" to use in interpretation.

Orientation of the transducer: left side of the display screen is assumed to be the patient’s head or right side



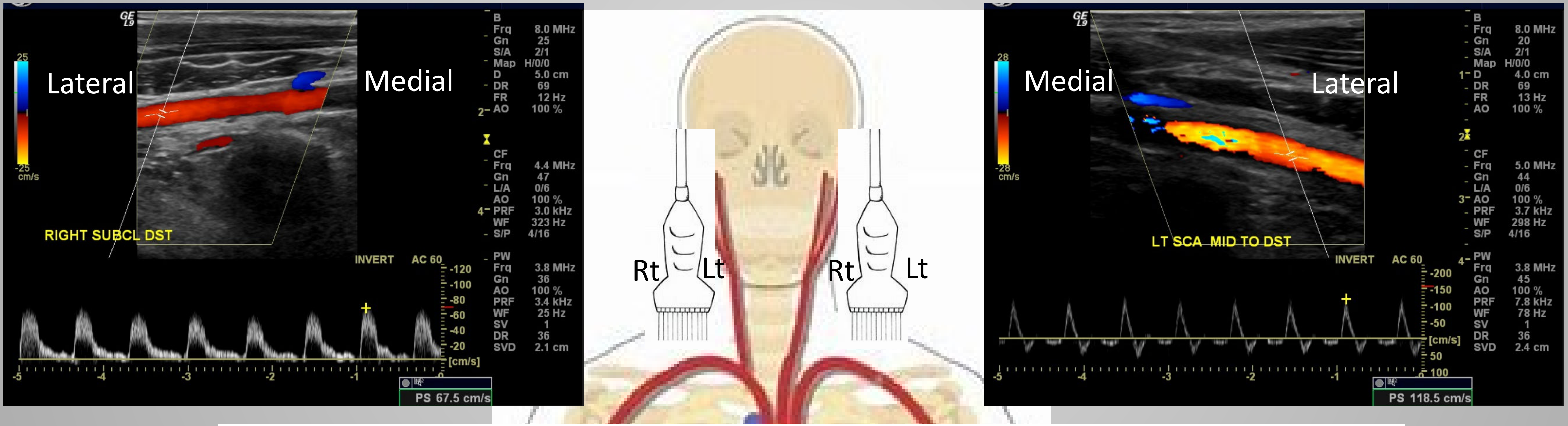
There may be a clearly designated orientation marker on the transducer

If there is not a clearly designated orientation marker, use this method to identify it

We must agree on transducer orientation to interpret direction of flow

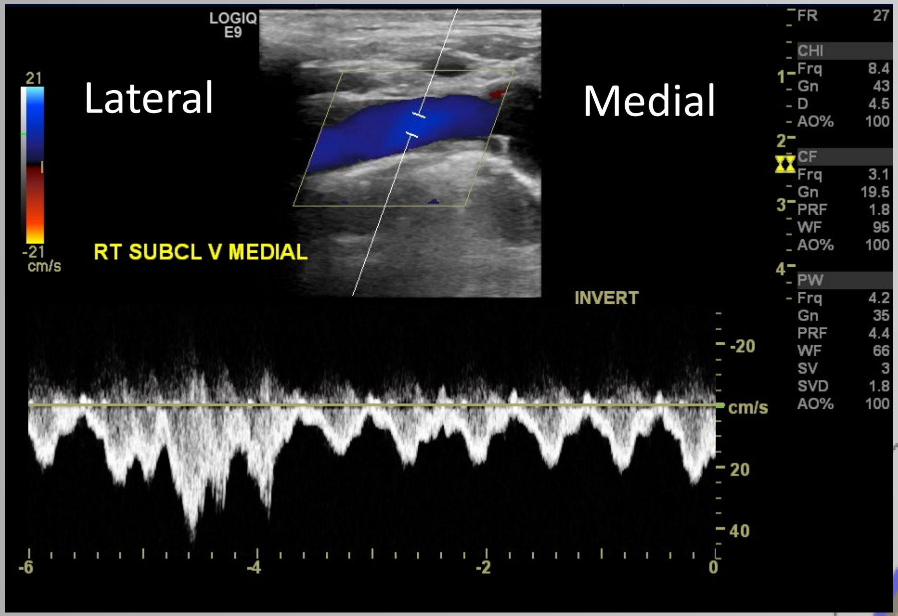
[IAC presentation on YouTube by Tish Poe](https://www.youtube.com/watch?v=VYhlgQu-JOI&feature=youtu.be)

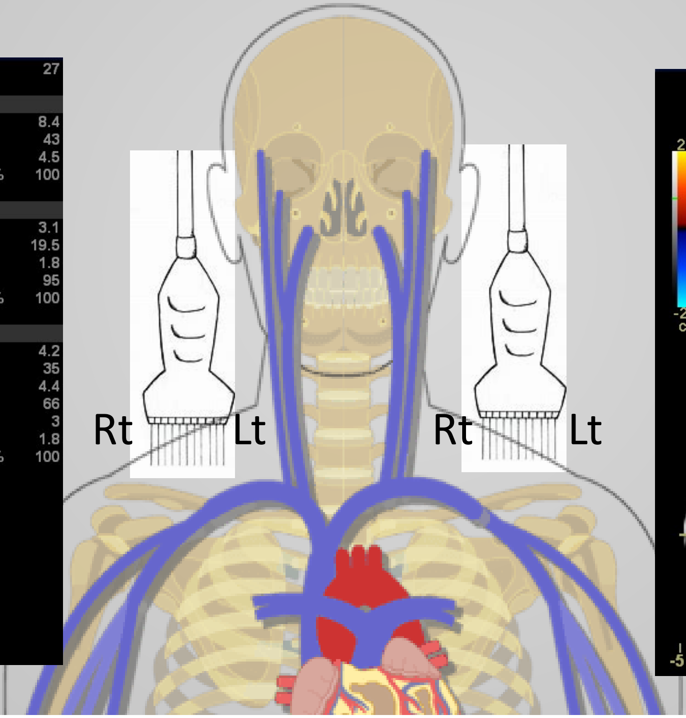
https://www.youtube.com/watch?v=VYhlgQu-JOI&feature=youtu.be

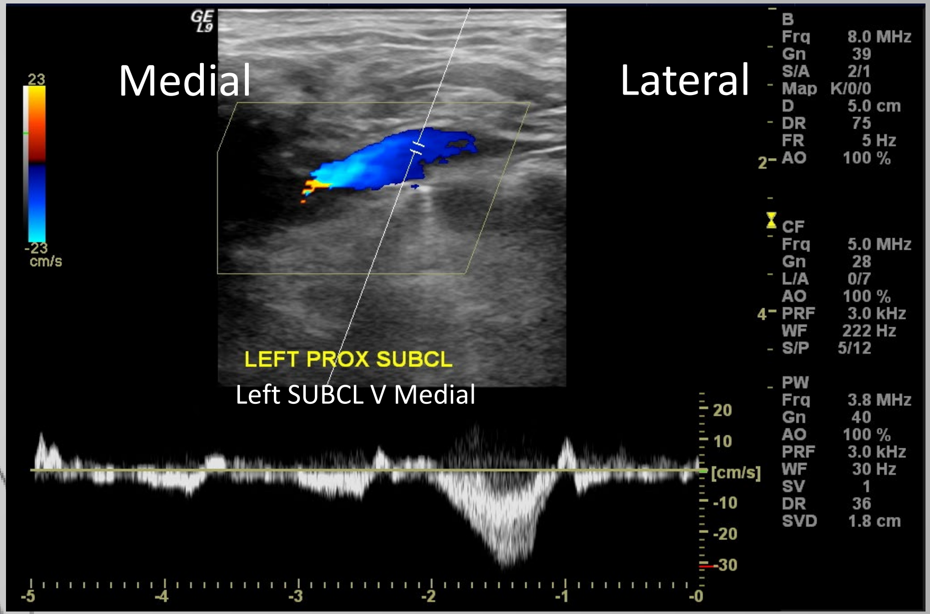


Subclavian vessels are displayed in long axis with transducer transverse to the body

We must agree on transducer orientation to accurately interpret direction of flow.





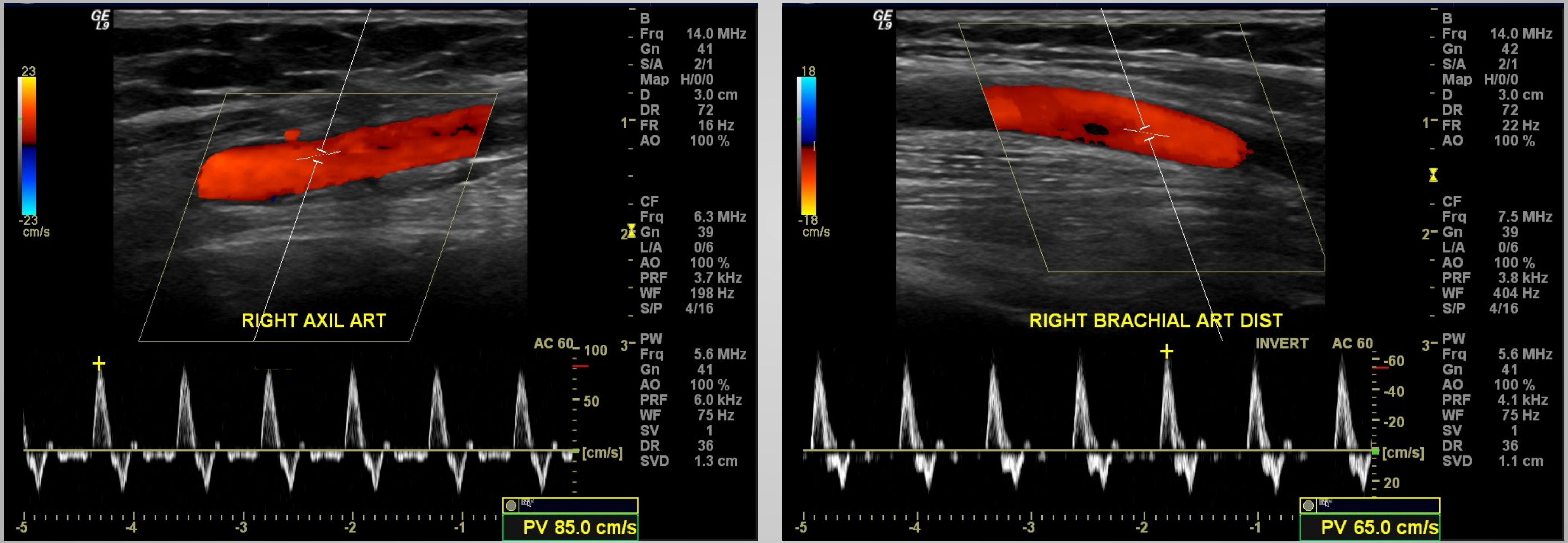


Subclavian vessels are displayed in long axis with transducer transverse to the body

Conventions

- Normal arterial flow above the baseline and normal venous flow below the baseline on spectral Doppler display
- Normal systolic arterial flow red and normal venous flow blue when color Doppler is used (this is not as strong a convention as for spectral)

So just how should we read flow direction, now that the transducer is oriented correctly?

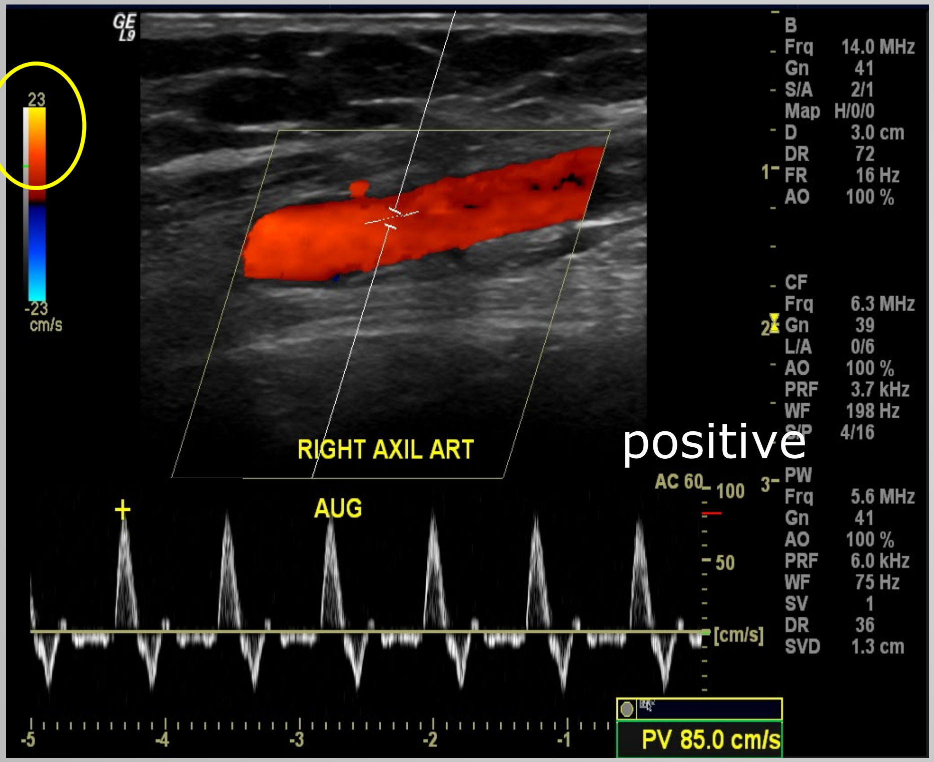


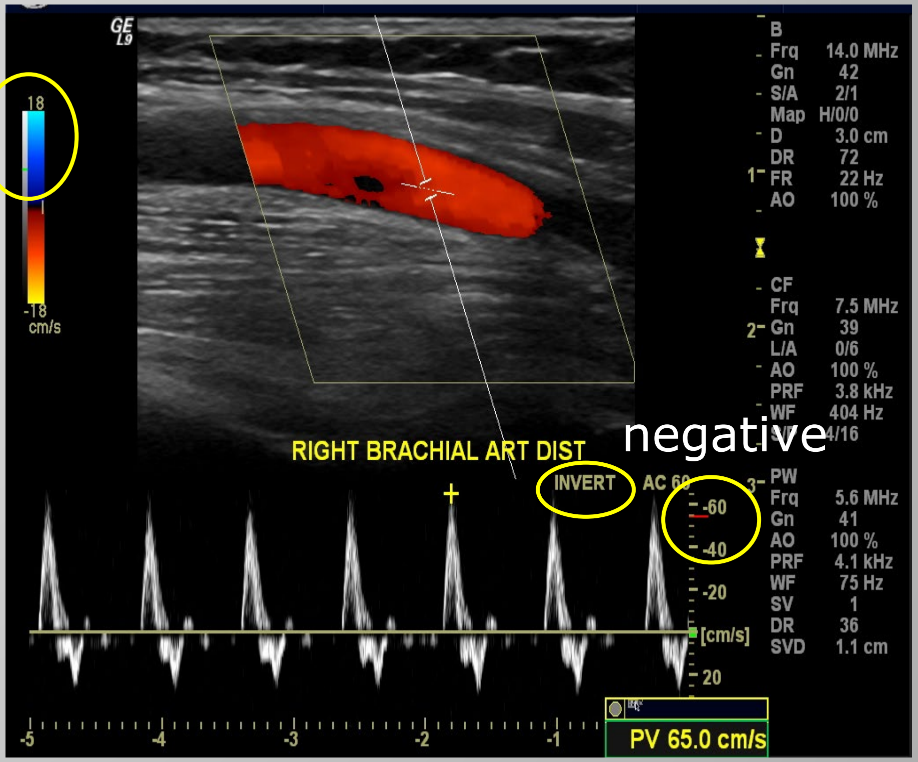
Color Doppler is a great assistant, but spectral Doppler tells the full story

So just how should we read flow direction, now that the transducer is oriented correctly?

Reading the color bar: The color on top is designated for flow approaching the line of sight.

Color below the black baseline is designated for flow receding from the line of sight.

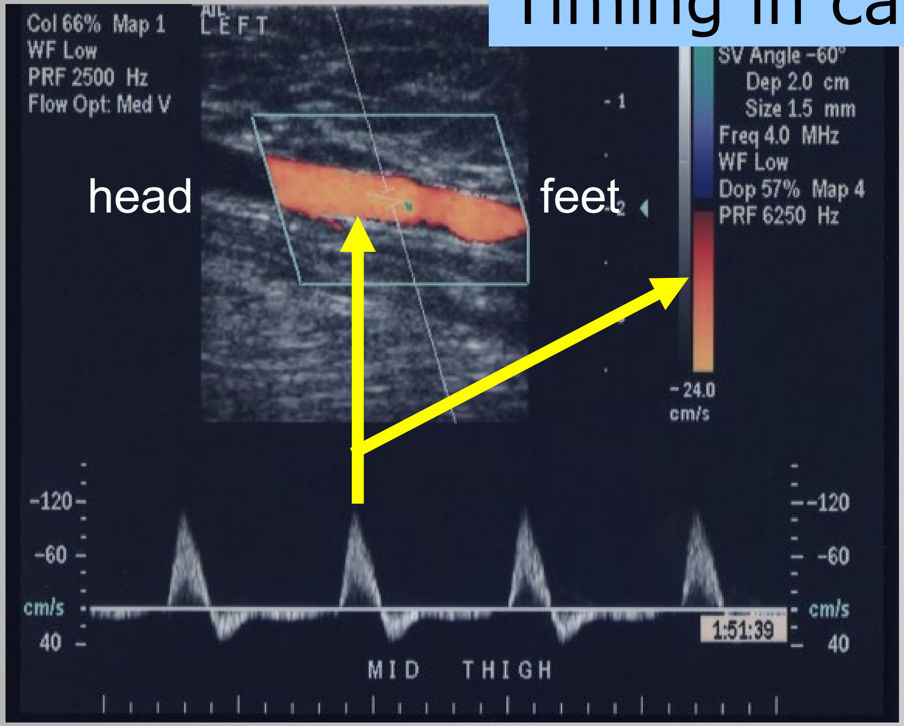


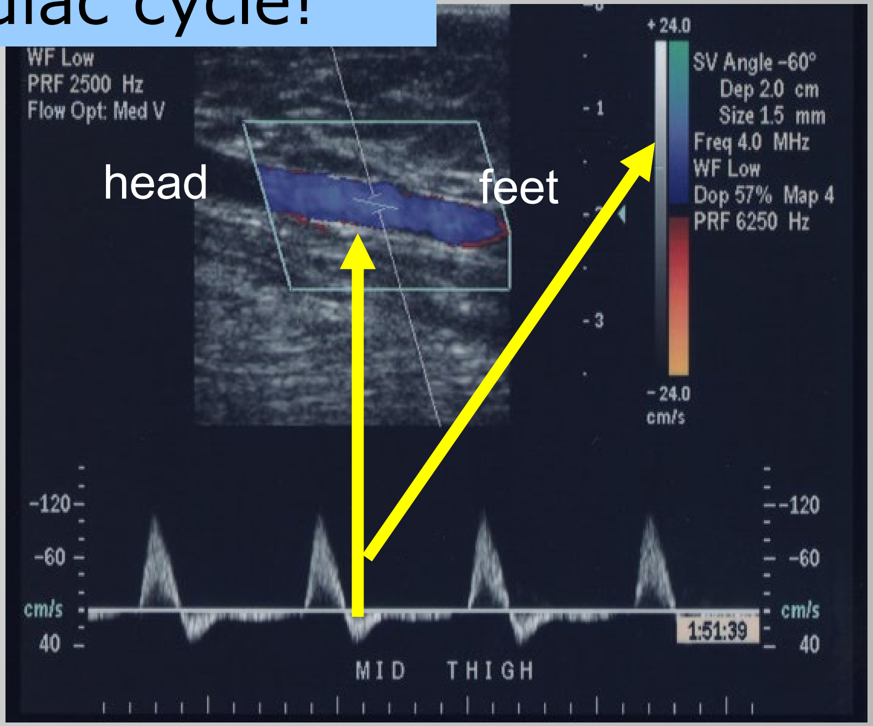


Spectral Doppler!

Why is there a difference in the color display in this vessel?

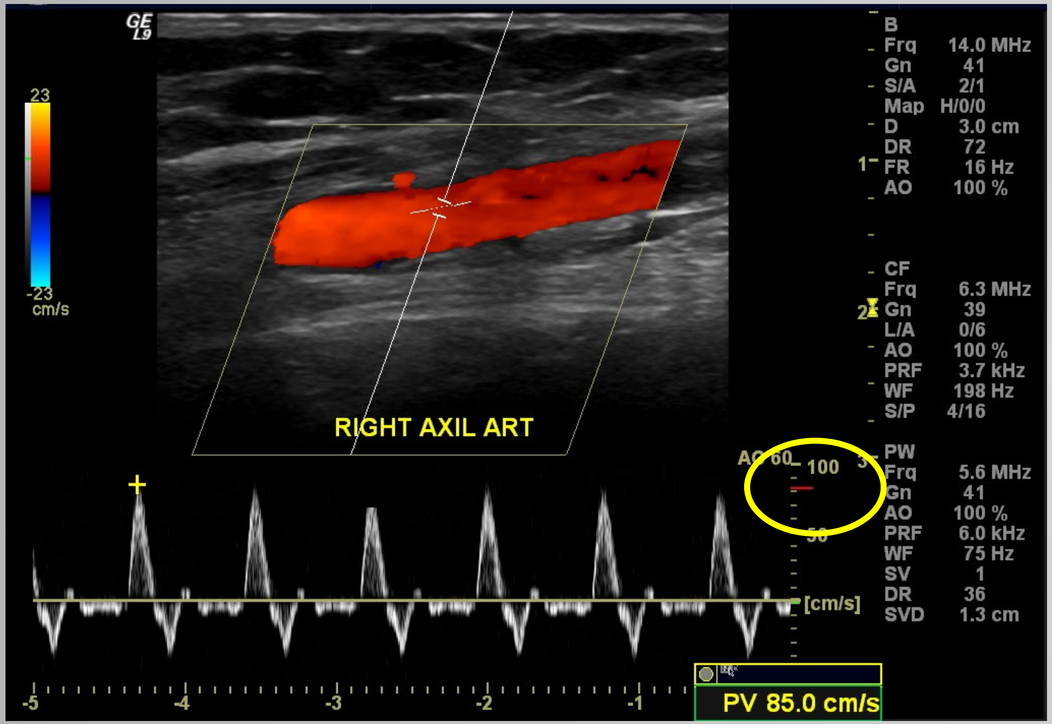
Timing in cardiac cycle!

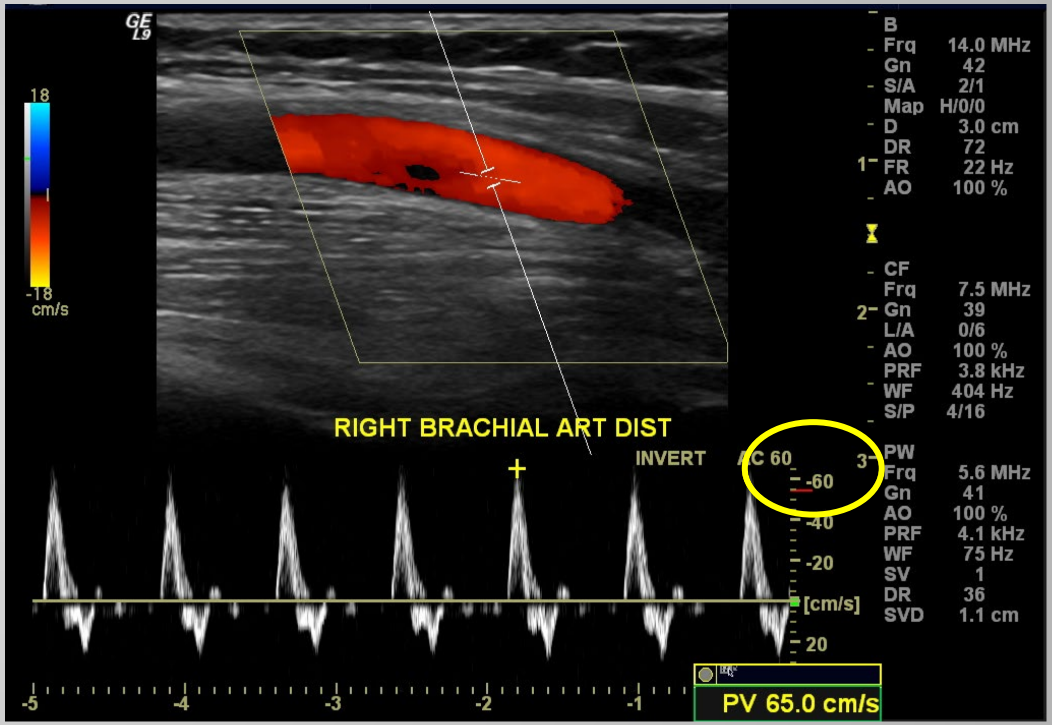




If the flow is not fully in one direction, color Doppler will change during the cardiac cycle

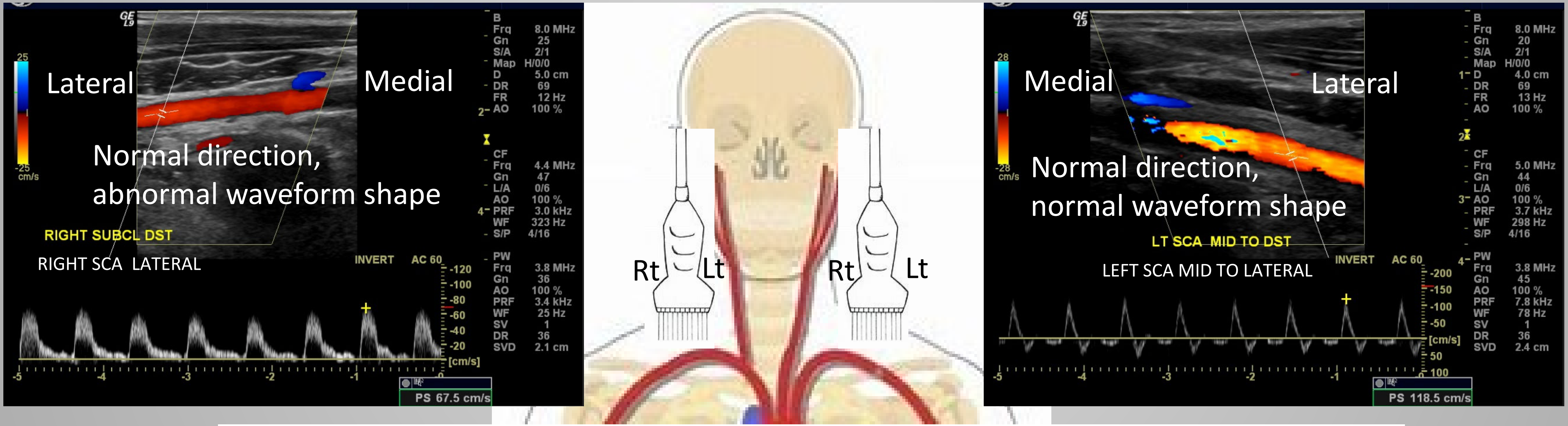
So just how should we read flow direction, now that the transducer is oriented correctly?





Always look at the orientation of the spectral Doppler scale:
Is positive (toward the line of sight) above the baseline or is negative (away from the line of sight) above the baseline

So now let's look again at the subclavian arteries: direction and are both sides symmetrical and normal?



Looking at the Doppler lines of sight:
RT SCA should be negative / away;
LT SCA should be negative / away

Consensus paper: Doppler waveform nomenclature

Interpretation of Peripheral Arterial and Venous Doppler Waveforms: A Consensus Statement From the Society for Vascular Medicine and Society for Vascular Ultrasound

Journal for Vascular Ultrasound 1–26 © 2020, Society for Vascular Ultrasound

Venous Key major descriptors

- Flow direction (antegrade, retrograde, absent)
- Flow pattern (respirophasic, decreased, pulsatile, continuous, regurgitant)
- Spontaneity (spontaneous, nonspontaneous)

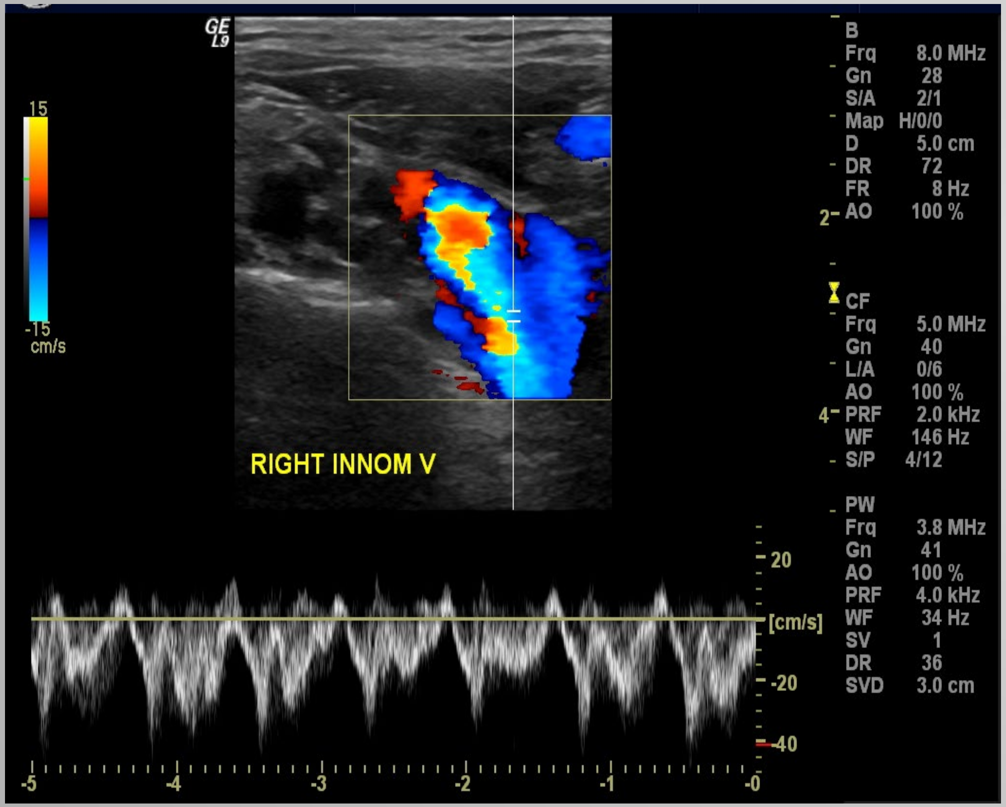
Additional modifier terms may also be used

- Augmentation (normal, reduced, absent)
- Reflux
- Fistula flow

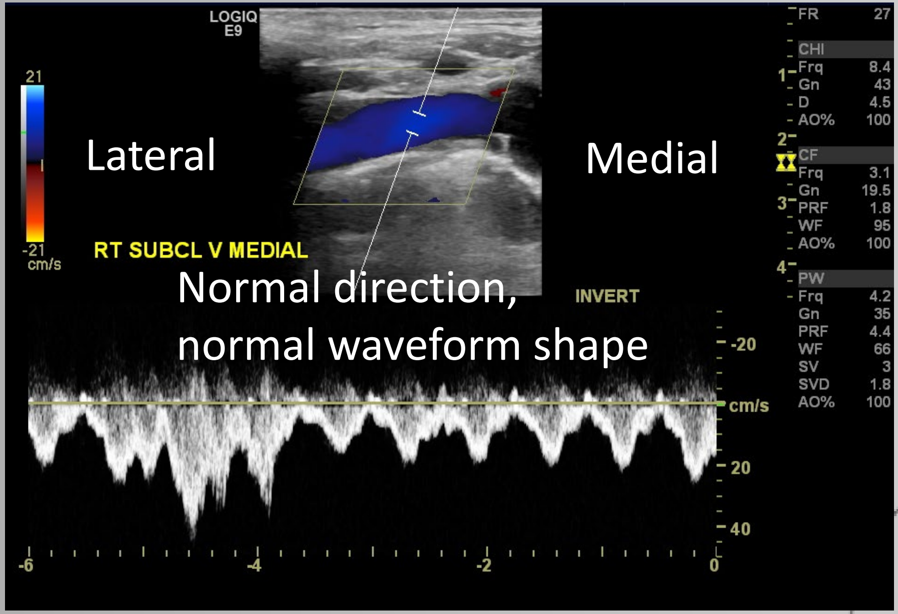
Venous Hemodynamics

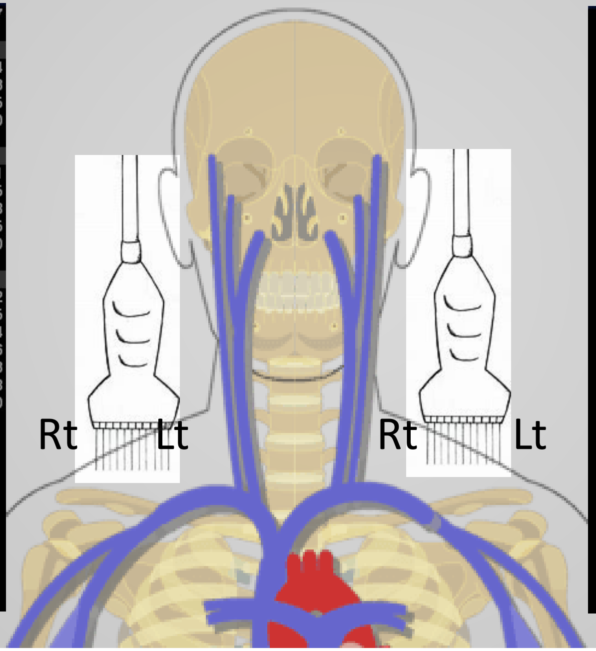
- Venous Valves
- Respiration
- Hydrostatic Pressure
- Muscle Pump

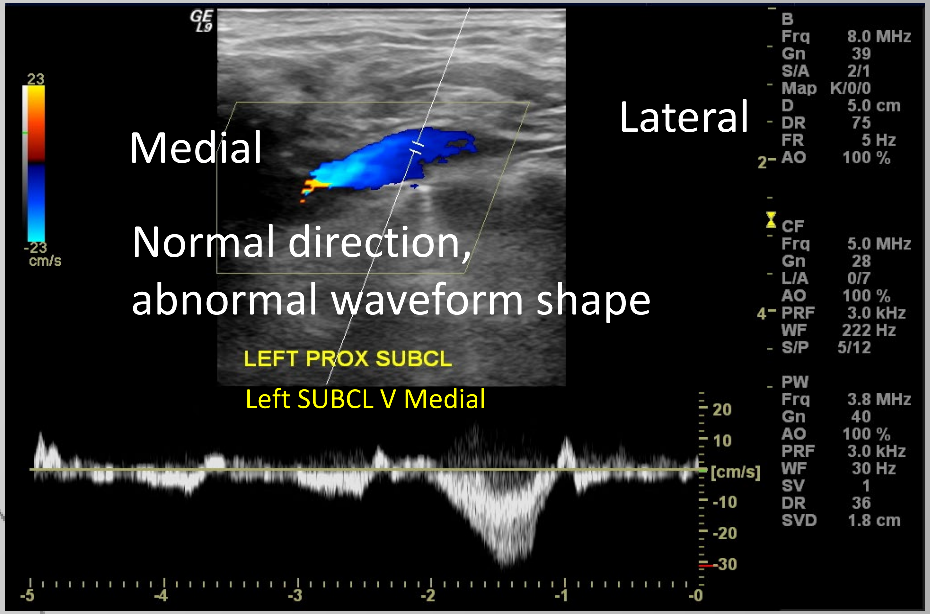
UE Central Vein Doppler Signals: normal terminology includes pulsatile, respirophasic, antegrade



So now let’s look again at the subclavian veins

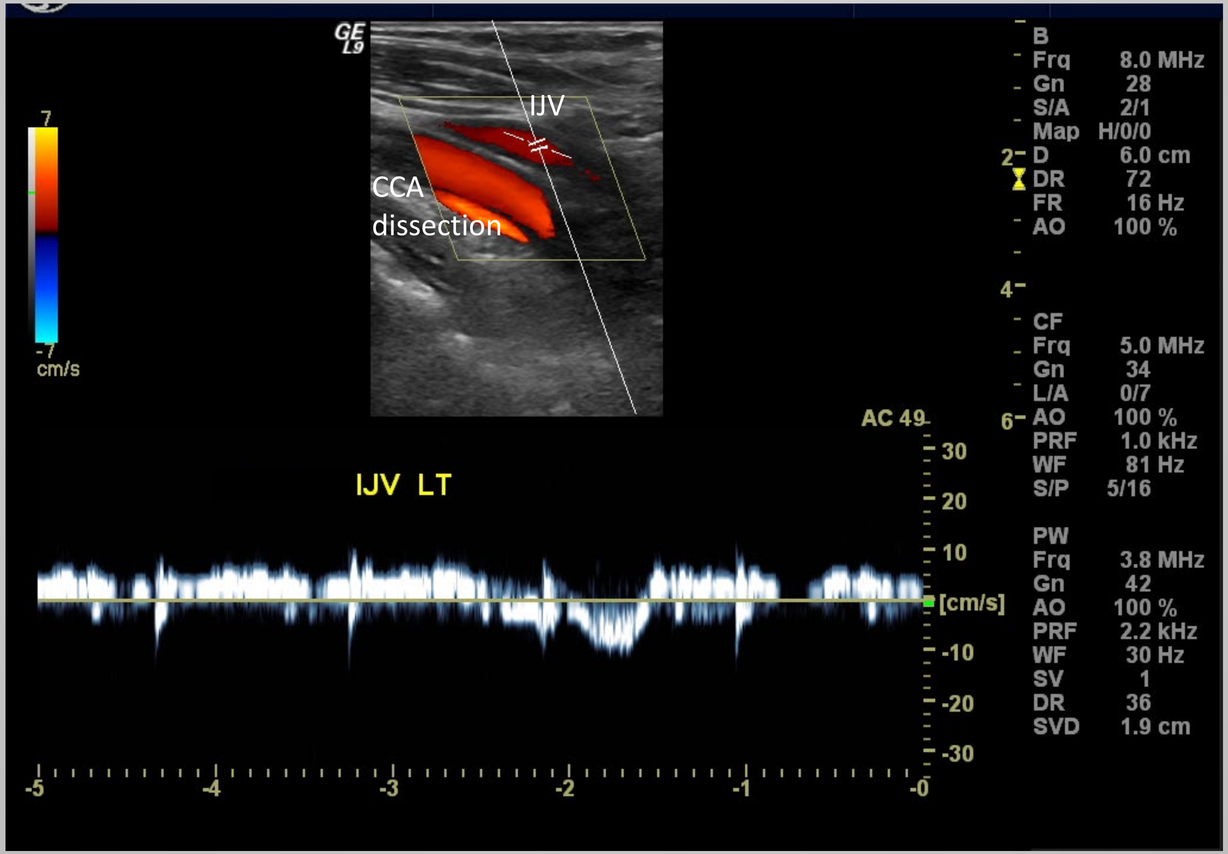






Looking at the Doppler lines of sight:
RT SCV should be positive / toward;
LT SCV should be negative / away

IJV PW Doppler: what do you think about flow direction in this image?

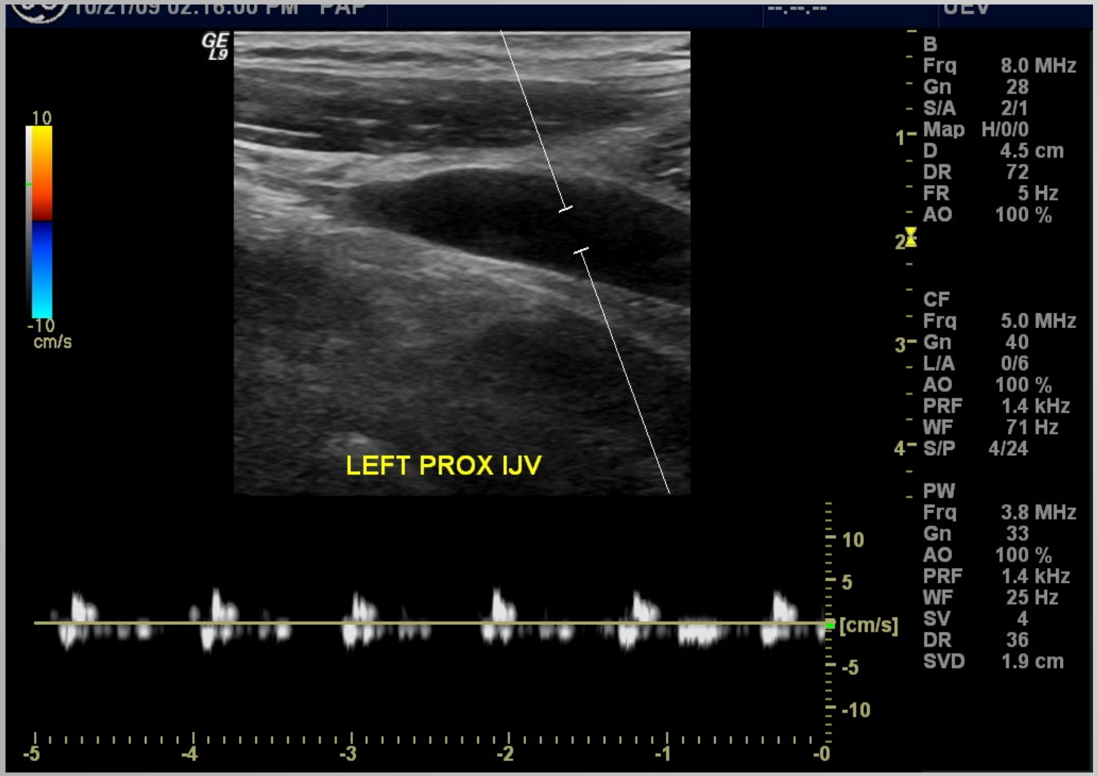


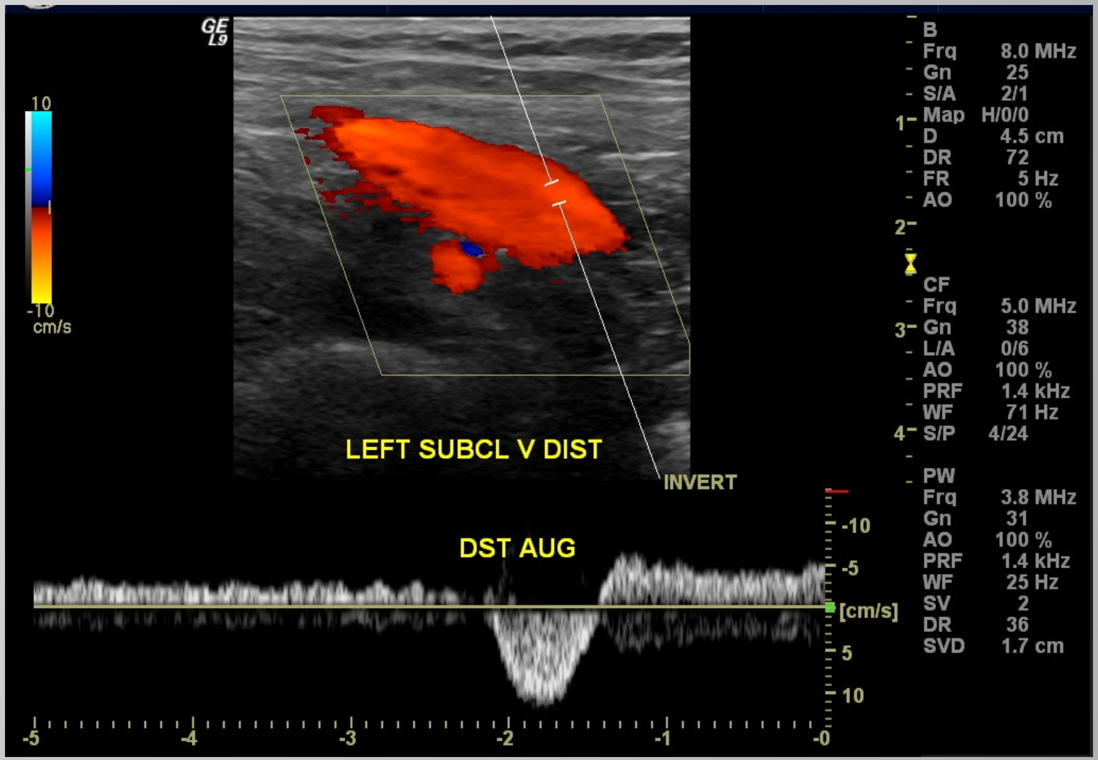
Retrograde

Spontaneous

Dampened

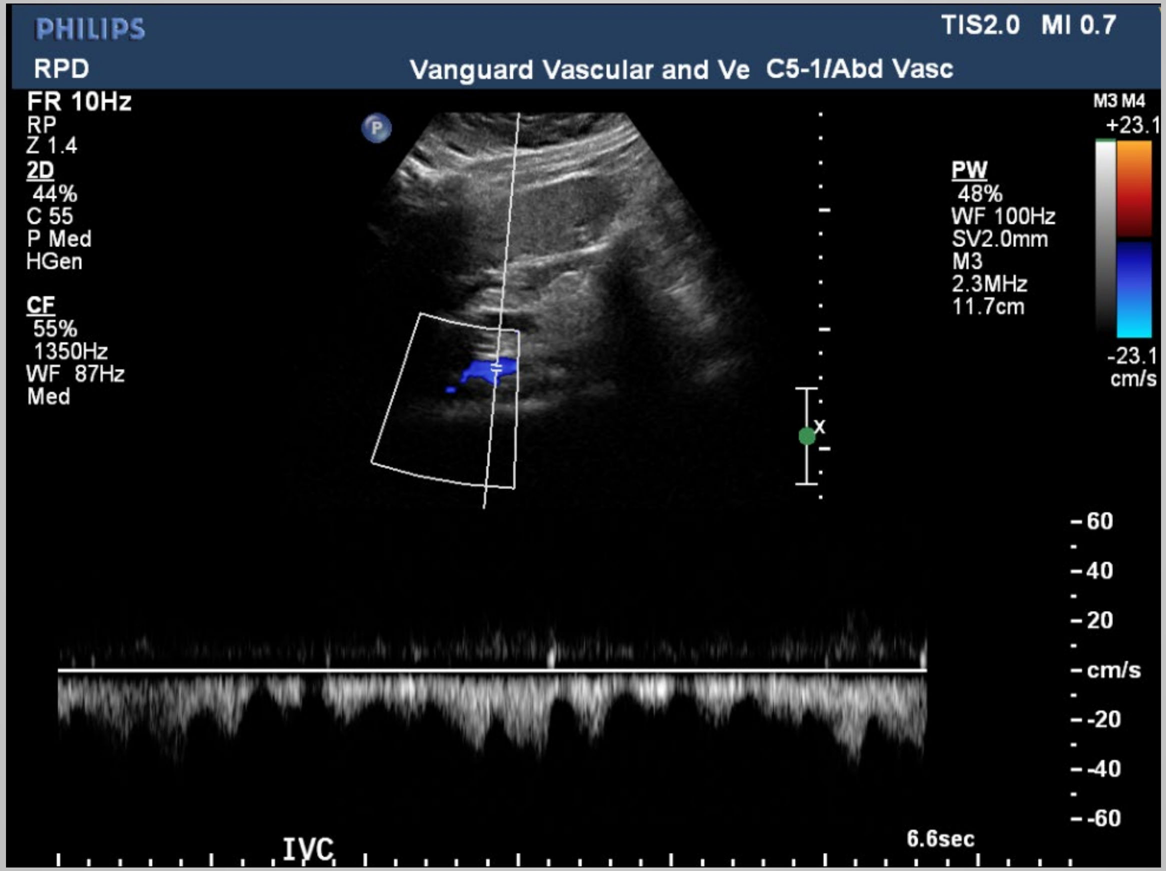
UE Central Vein Doppler Signals: abnormal terminology includes dampened, continuous, retrograde





Waveform analysis

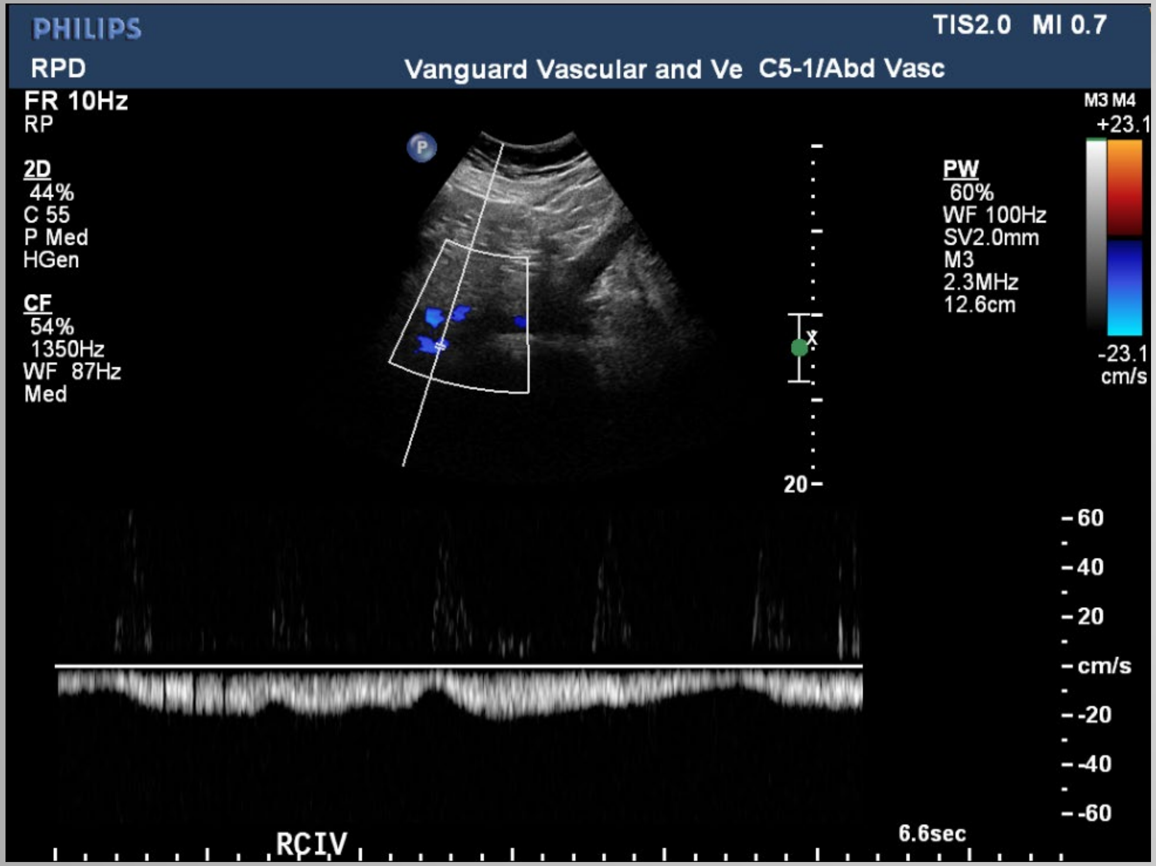
IVC: Spontaneous, pulsatile, respiro-phasic flow signals

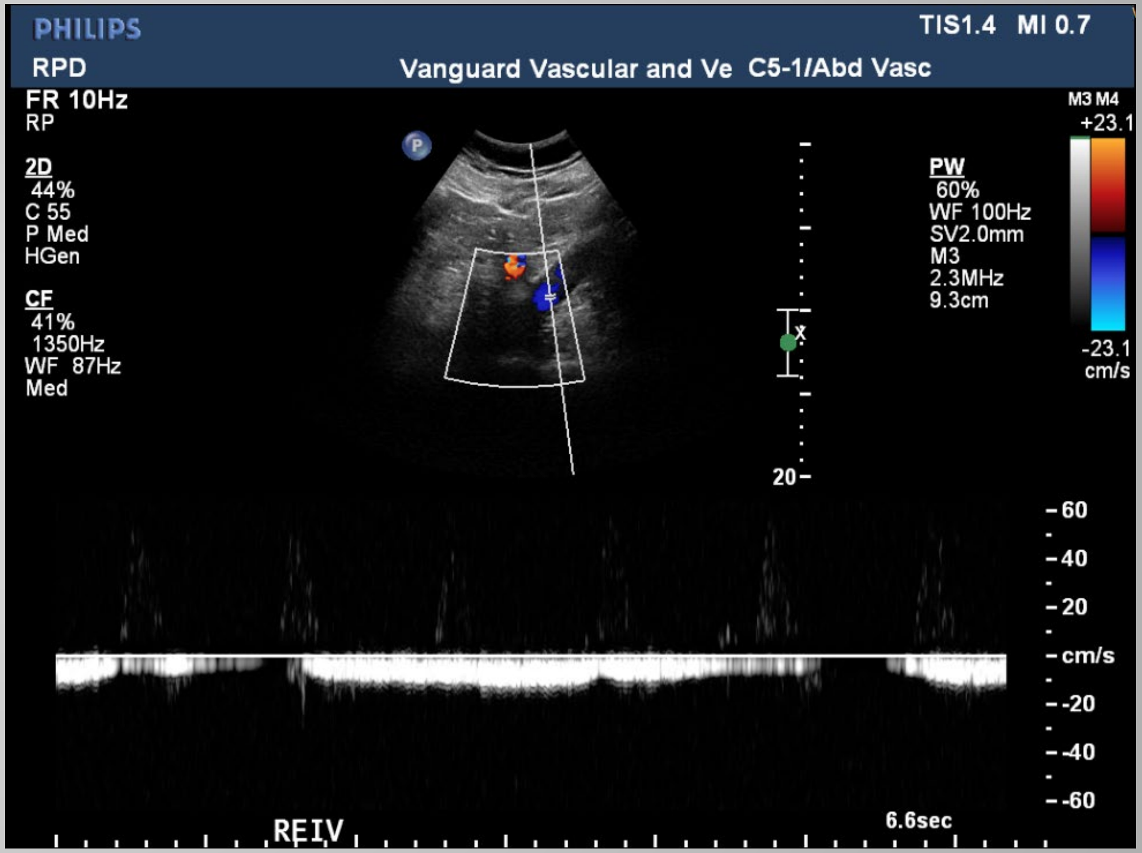


Is this normal? Yes

Waveform analysis

Normal, spontaneous, respiro-phasic flow signals LE





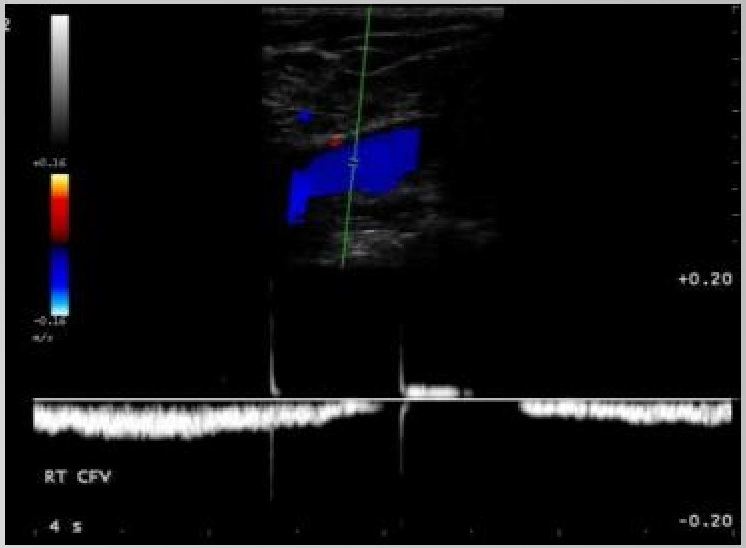
Spontaneous and Phasic Flow: LE

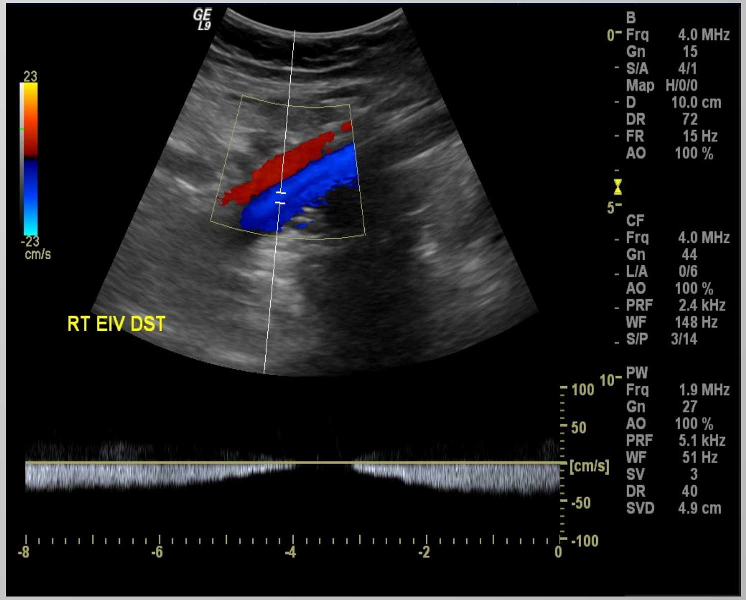
Spontaneous

- Detectable flow
- Spontaneity may be absent in the most distal veins (i.e., posterior tibial at ankle) due to decreased speed of blood
- Absence of spontaneous flow may indicate obstruction

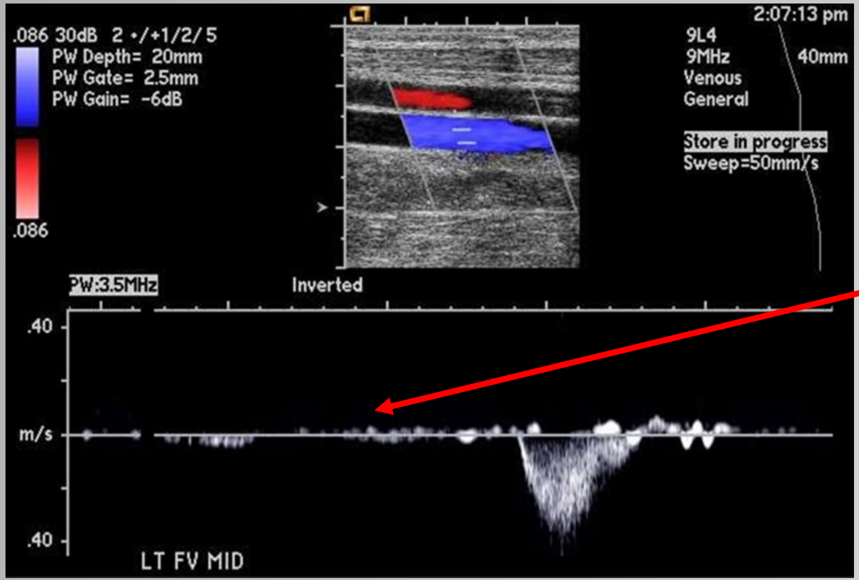
Phasic

- Inhale = decrease
- Exhale= increase



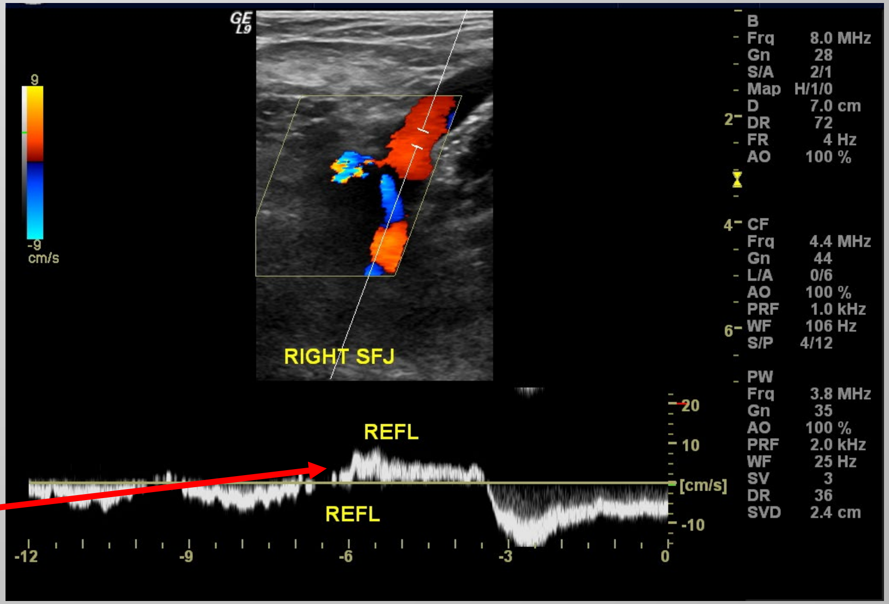


Valve competence: Flow should be move cranially (antegrade) from the lower extremity (LE) veins, iliac veins and IVC—toward the heart

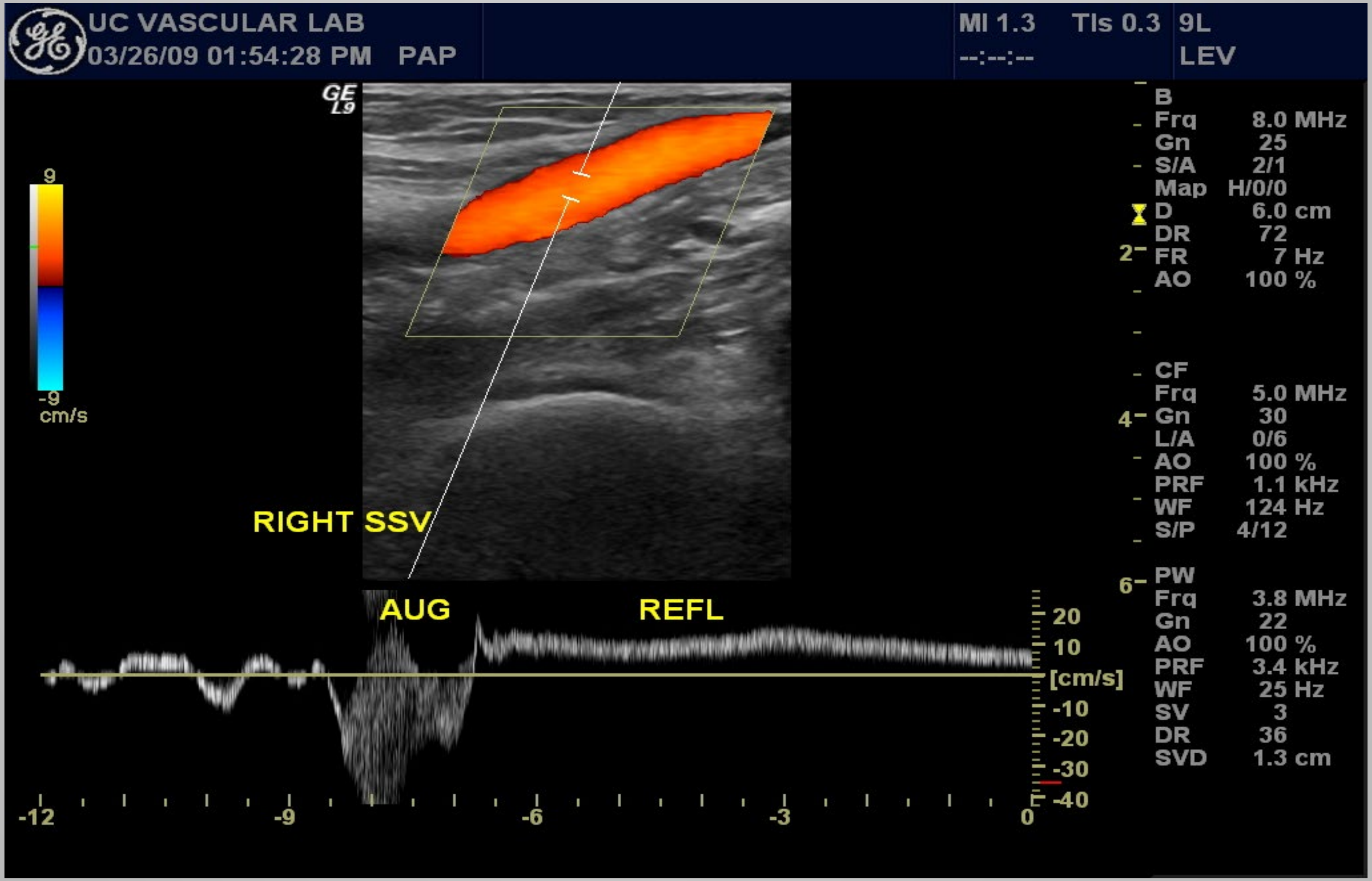


Proximal compression or Valsalva maneuver (VM), flow will normally stop antegrade flow in LE veins

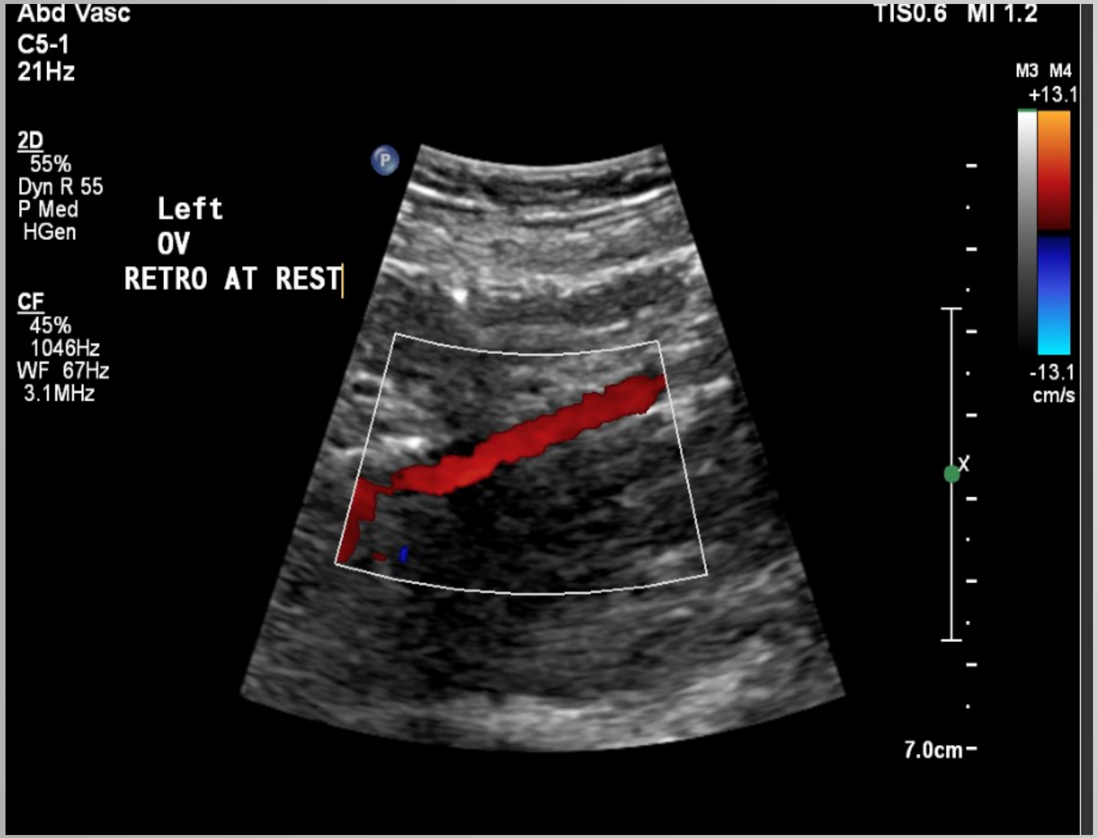
When abnormal, flow will move caudally, retrograde (reflux) during compression or VM, indicating valve incompetence

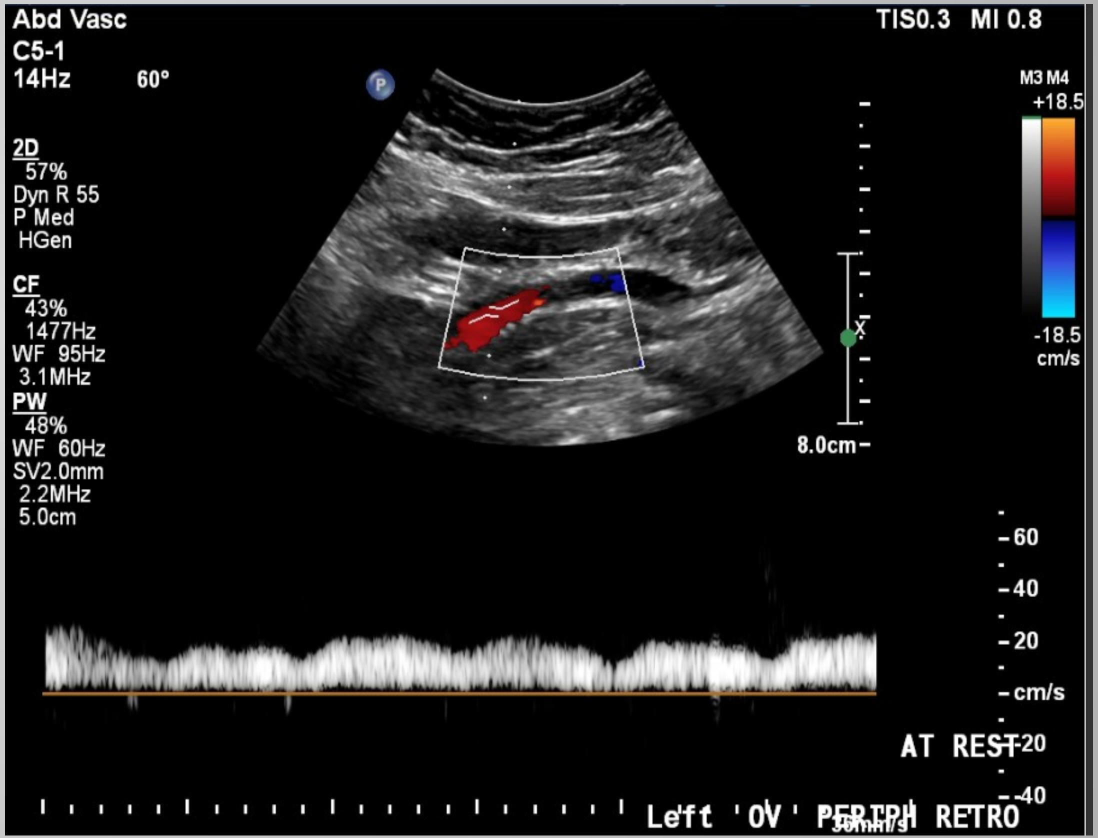


Adjust spectral Doppler scale to allow low velocity waveforms to be clearly displayed



Retrograde flow in the left OV





Thank you!
Keep those waves rolling!

Patricia A. (Tish) Poe, BA RVT FSVU
Vascular Laboratory Educator and Consultant
Philadelphia, PA
patriciapoe54@gmail.com