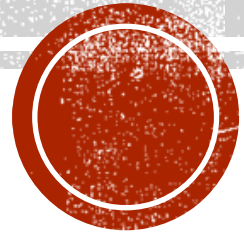
CAROTID DUPLEX SCANNING AND COLOR FLOW IMAGING

Chapter 20



CAROTID DUPLEX IMAGING

- Combines physiologic information based on Doppler-shifted frequencies with the anatomic information of real-time, high-resolution, B-mode imaging; thus "DUPLEX"

CAPABILITIES OF DUPLEX IMAGING

- Accurate in assessing and localizing the presence of arterial disease
- Differentiate occlusion from a tight stenosis
- Evaluate flow patterns associated with plaque
- Documents and follows progression of disease
- Provides surface characteristics of the vessel wall and characteristics of plaque
- Evaluate pulsatile masses in the neck region

LIMITATIONS OF DUPLEX IMAGING

- Poor visualization due to:
  - Dressings, Sutures, Skin Staples
  - Large muscular necks with deep vessels
  - Shadowing from calcifications
- ***Over-estimation*** of disease from:
  - Accelerated flow attributed to stenosis instead of:
    - Tortuous vessels
    - Collateralization
    - Inappropriate Doppler angle
  - Artifact mistaken for plaque

LIMITATIONS OF DUPLEX IMAGING

- ***Under-estimation*** of the disease process from:
  - Jet of accelerated flow is missed
  - Very low-level echoes of soft plaque is not appreciated
  - Long smooth plaque does not have accelerated or turbulent flow patterns
  - Stenosis at an area of dilatation (bulb) is not appreciated
  - Inappropriate Doppler angle

CAROTID DUPLEX IMAGING

- Remember:
  - Right CCA comes off the innominate artery, also referred to as the brachiocephalic trunk
  - Left CCA comes directly off the Aortic Arch
- CCA bifurcates into the:
  - **ICA** – Low resistant vessel
  - **ECA** – High resistant vessel

PATIENT POSITIONING

- Patient is placed in a comfortable supine position with the head slightly hyperextended and the head turned slightly away from the side being examined
  - If being scanned on a cart, you can raise the back of the cart, so the patient's upper head and chest are elevated
  - Can be performed with or without a pillow
  - Some patients are unable to lay flat
    - Try to make them as comfortable as possible without compromising your exam

TRANSDUCER SELECTION

- Linear array transducer
- Frequency ranges from 5 MHz-15 MHz depending on patient
  - 15 MHz (or higher) for extremely thin necks
  - 7.5-10 MHz for average patients
  - 5 MHz for a thick neck with deep vessels

SCANNING APPROACHES

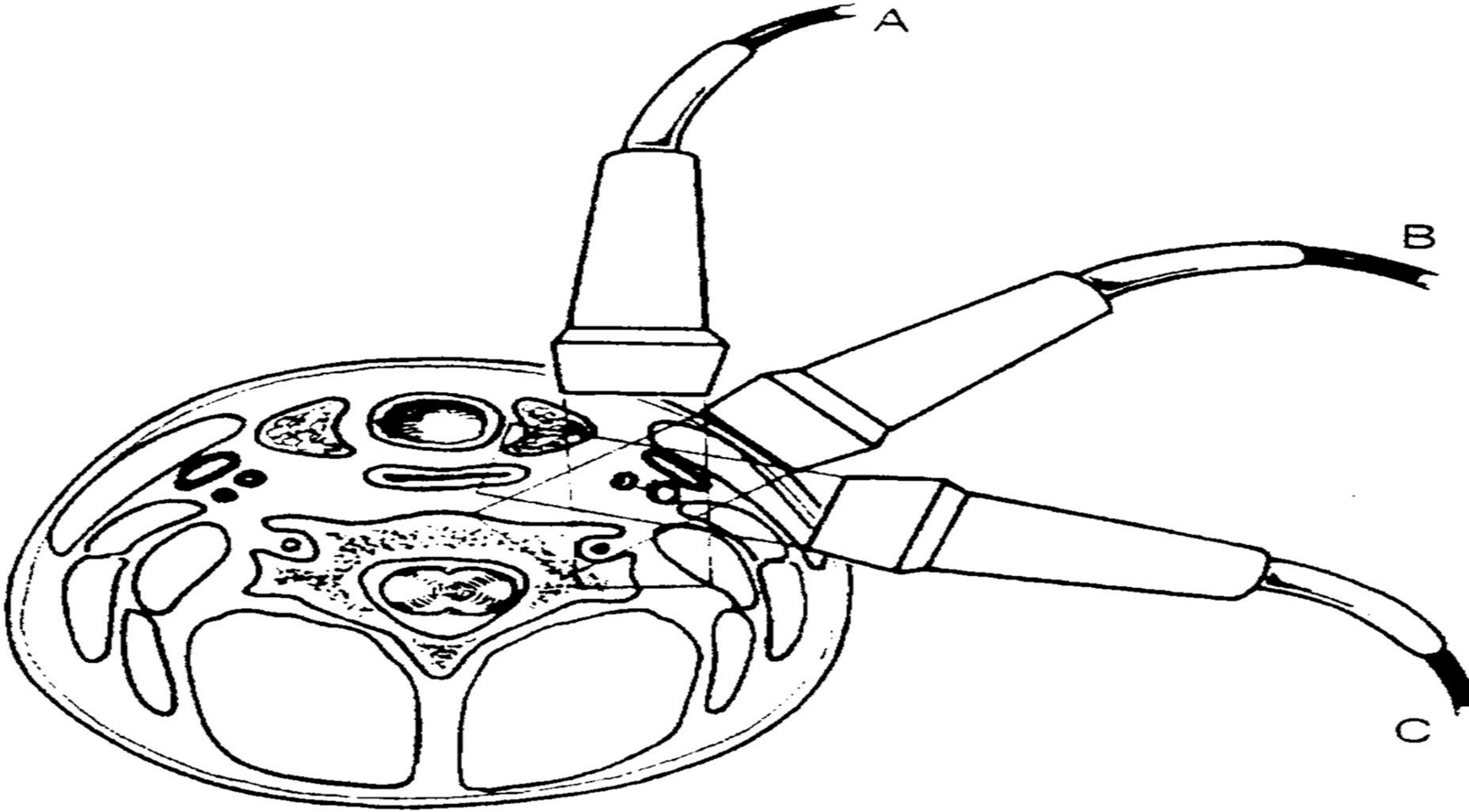
Anterior approach:

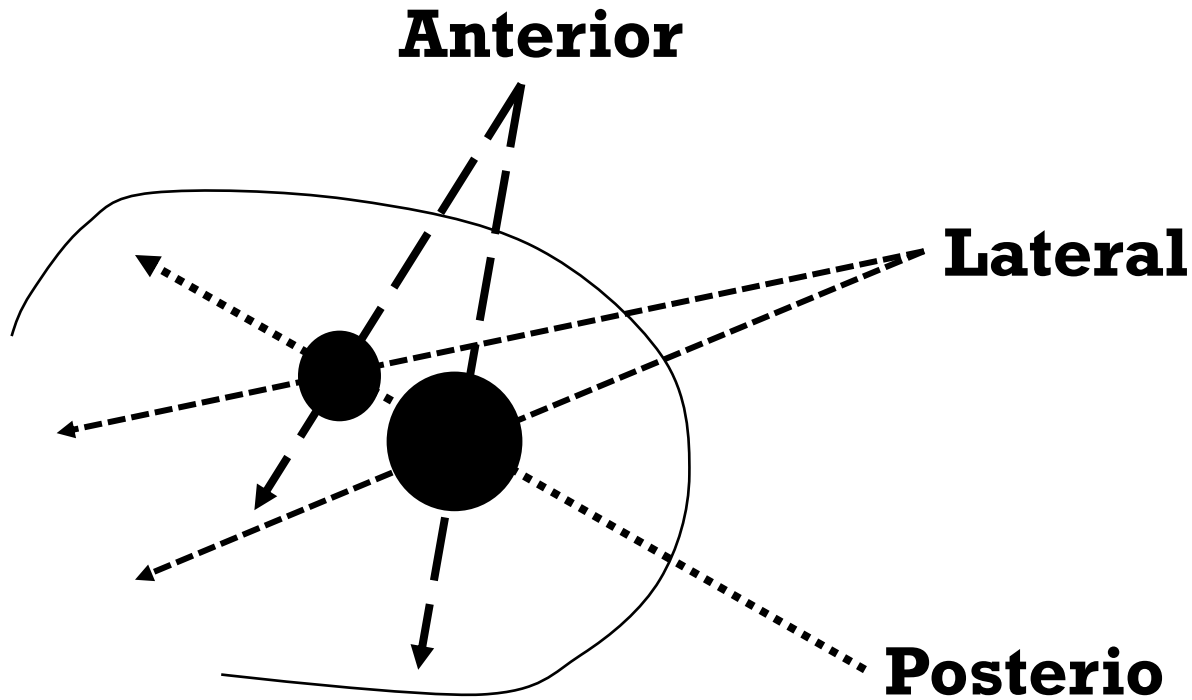
- Probe on the front of the neck; along the groove between the trachea and the Sternocleidomastoid (SCM) muscle
- Probe will be upright compared to other approaches
  - You are aiming down at the vessel, making the vessels closer to the probe (places vessels in the near field)
- Less tissue between the transducer and vessels
  - This approach may help with thick necks and deep vessels
- May be the only approach that gives useful imaging/Doppler information
- Works best with patient's head straight up, rather than turned away

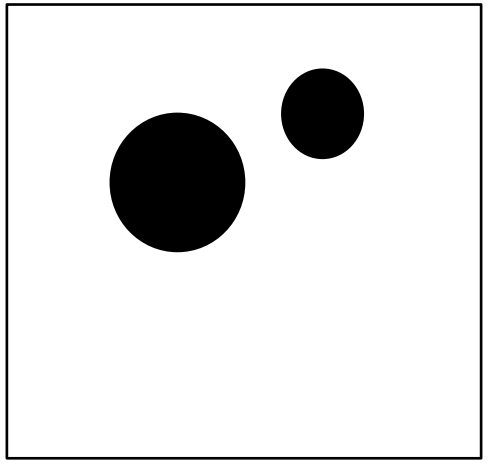
SCANNING APPROACHES

Lateral and Posterior approach:

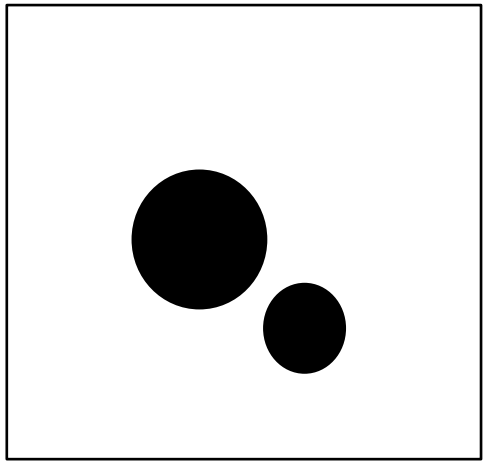
- Probe placed at the side of the SCM muscle
- Roughly perpendicular to the ear
- The wall of the vessels will tend to look much sharper
- Vessels will appear in the far-field
  - More tissues are placed between the transducer and vessels
- Patients head should be turned away from the side being evaluated


A
B
C

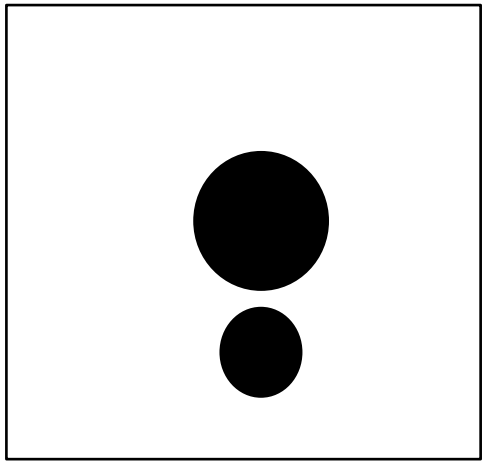




Anterior



Lateral



Posterior

PRACTICAL CONSIDERATIONS

- As with scanning anything, there are trade-offs among the different windows:
  - Fuzzier but closer with anterior
  - Clearer but deeper in the lateral and posterior
- During scanning, you should constantly vary your approach to modify/improve your image
- Three approaches are just for reference points, many others in between!

PROCEDURE

- Exam can be started in either:
  - Longitudinal
  - Transverse
- For beginning vascular technologists, transverse may be easier to start with
- There is no wrong way to begin the exam unless your facility has strict protocols

PROCEDURE

- B-mode images evaluate:
  - Presence
  - Location
  - Severity

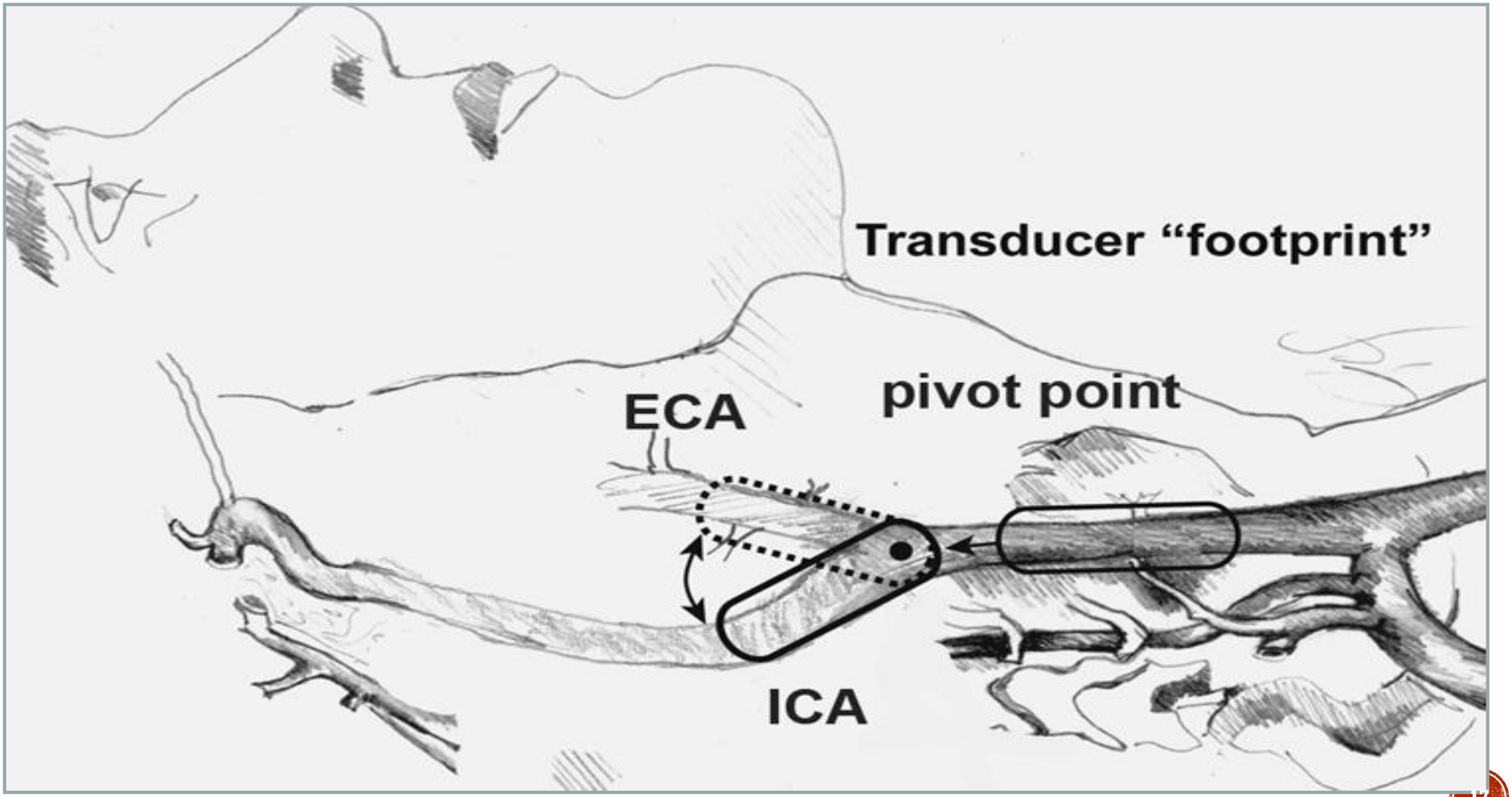
  } of plaque accumulation
  - Surface characteristics of vessel
- B-mode – **<u>Normal</u>**
  - Entire lumen should be anechoic (absence of plaque)
  - Anechoic line (endothelium) evident at vessel lumen

*** Note: document any pathology ***

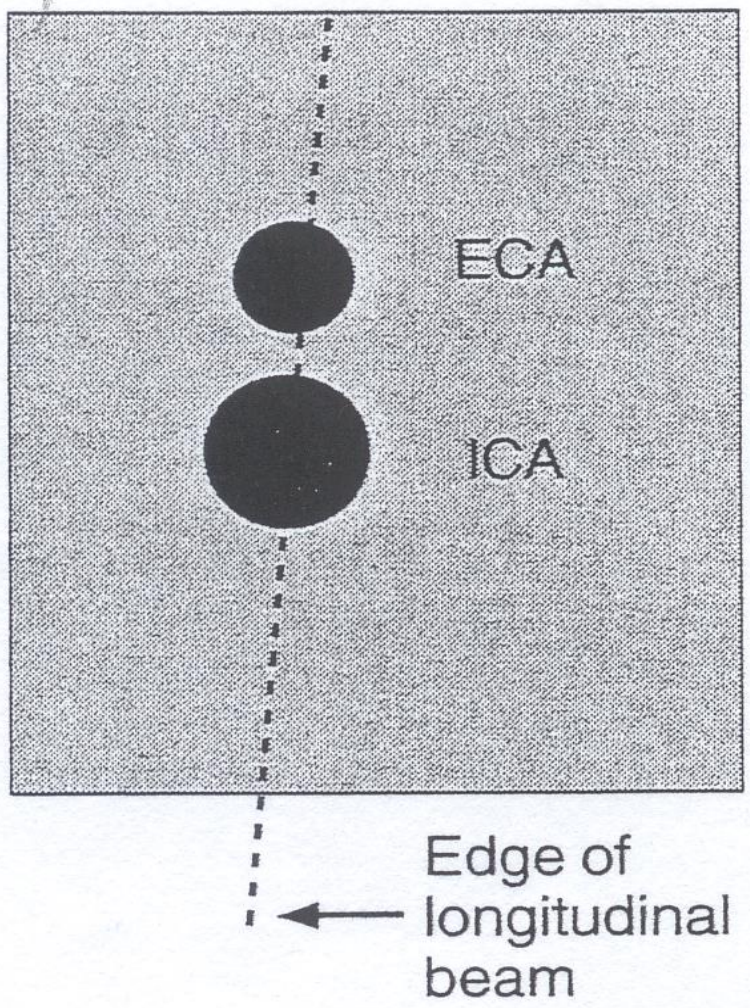
NORMAL PROCEDURE

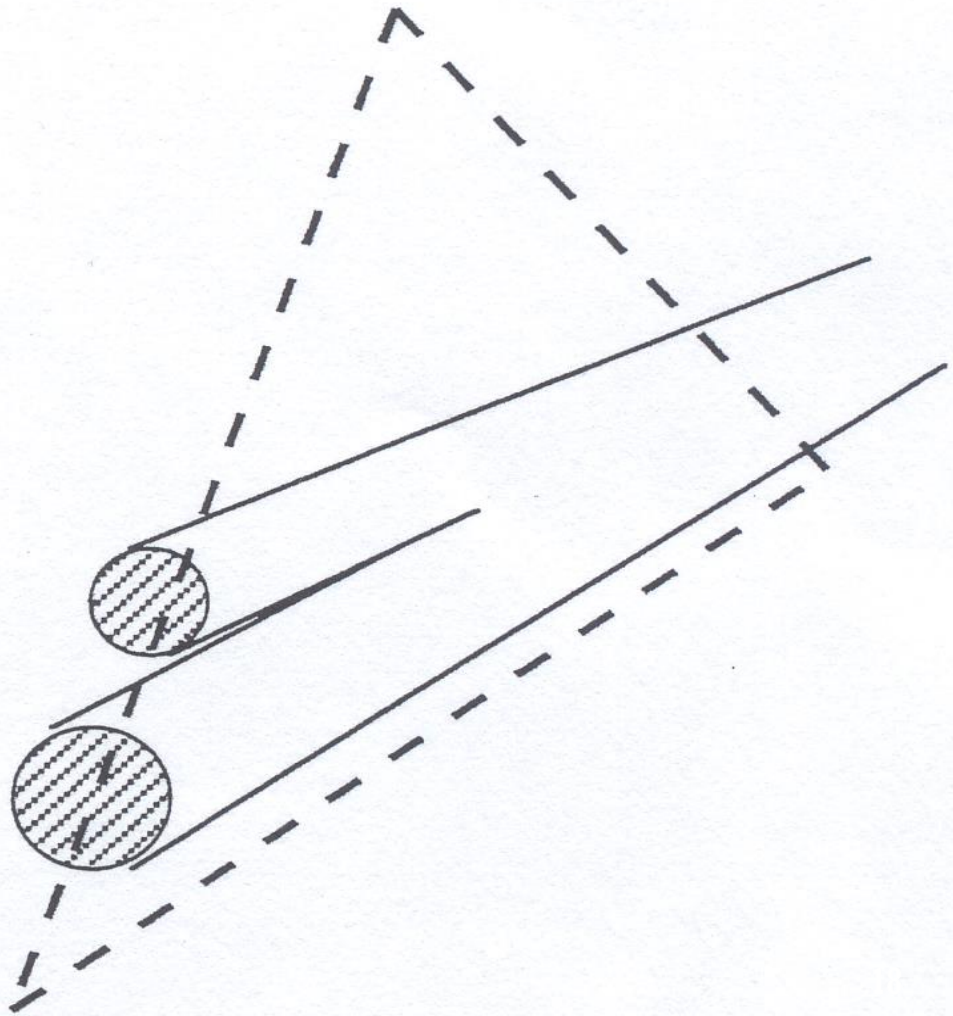
- Transducer is placed in a longitudinal view at the base of the neck and the carotid artery is assessed to the level of the mandible
- B-Mode images: (according to ACR guidelines)
  - ***Longitudinal*** Images:
    - CCA
    - Bifurcation
    - ICA to include the bulb (origin)

This is a *very* minimal grayscale requirement!

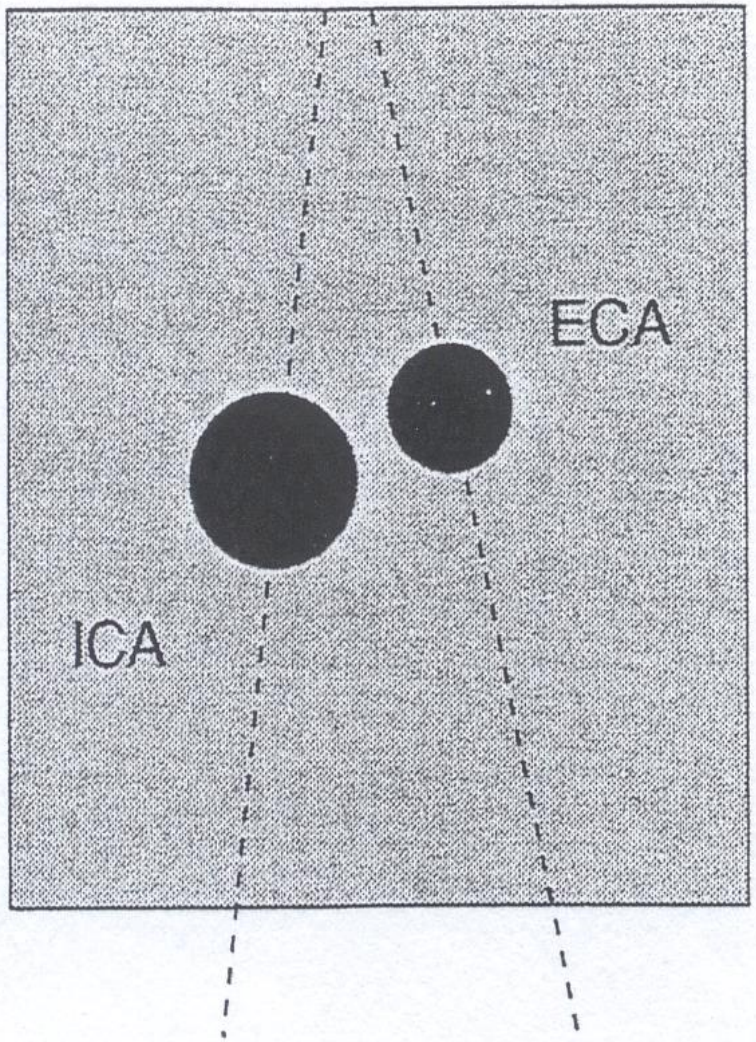

Transducer “footprint”
pivot point
ECA
ICA

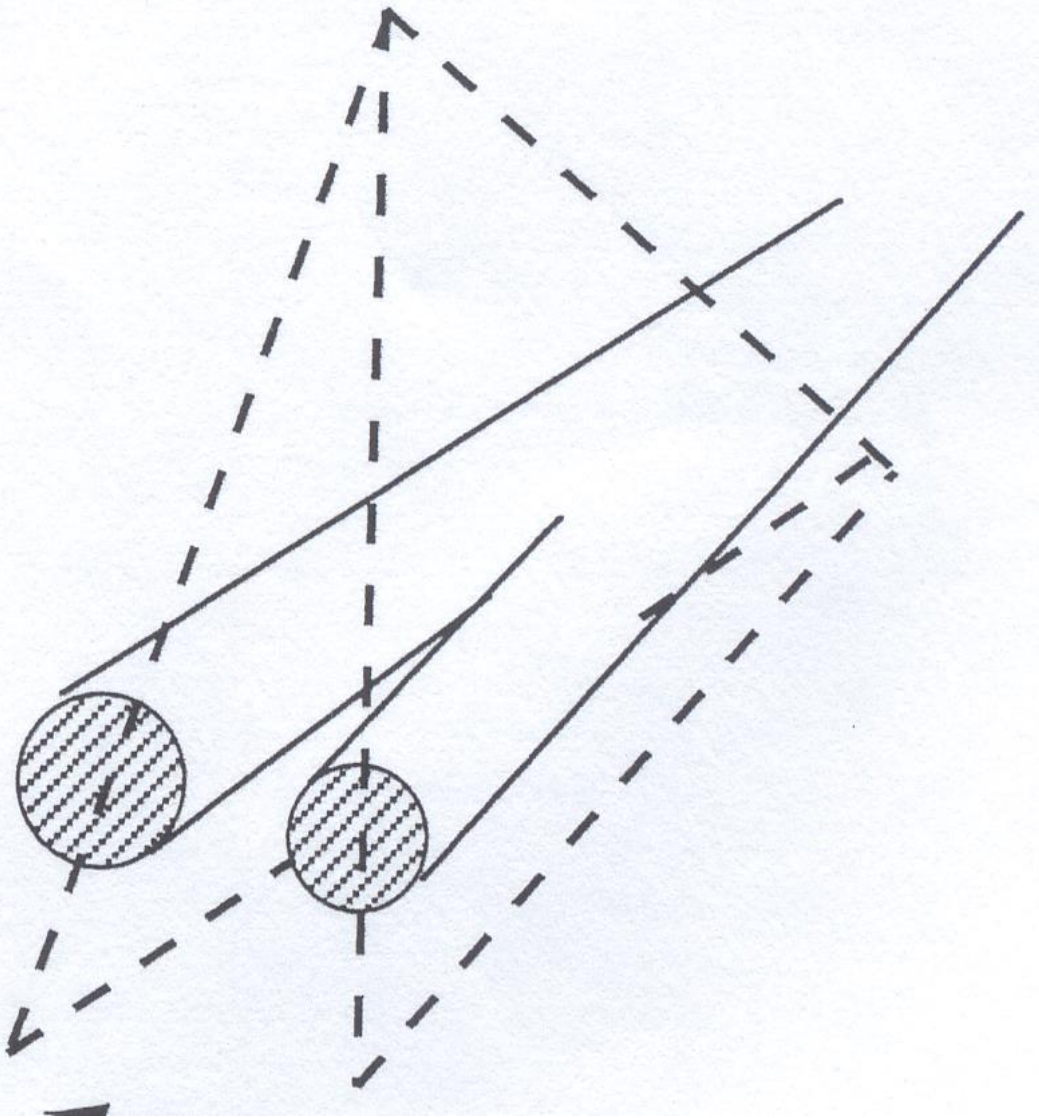
BIFURCATION IMAGING

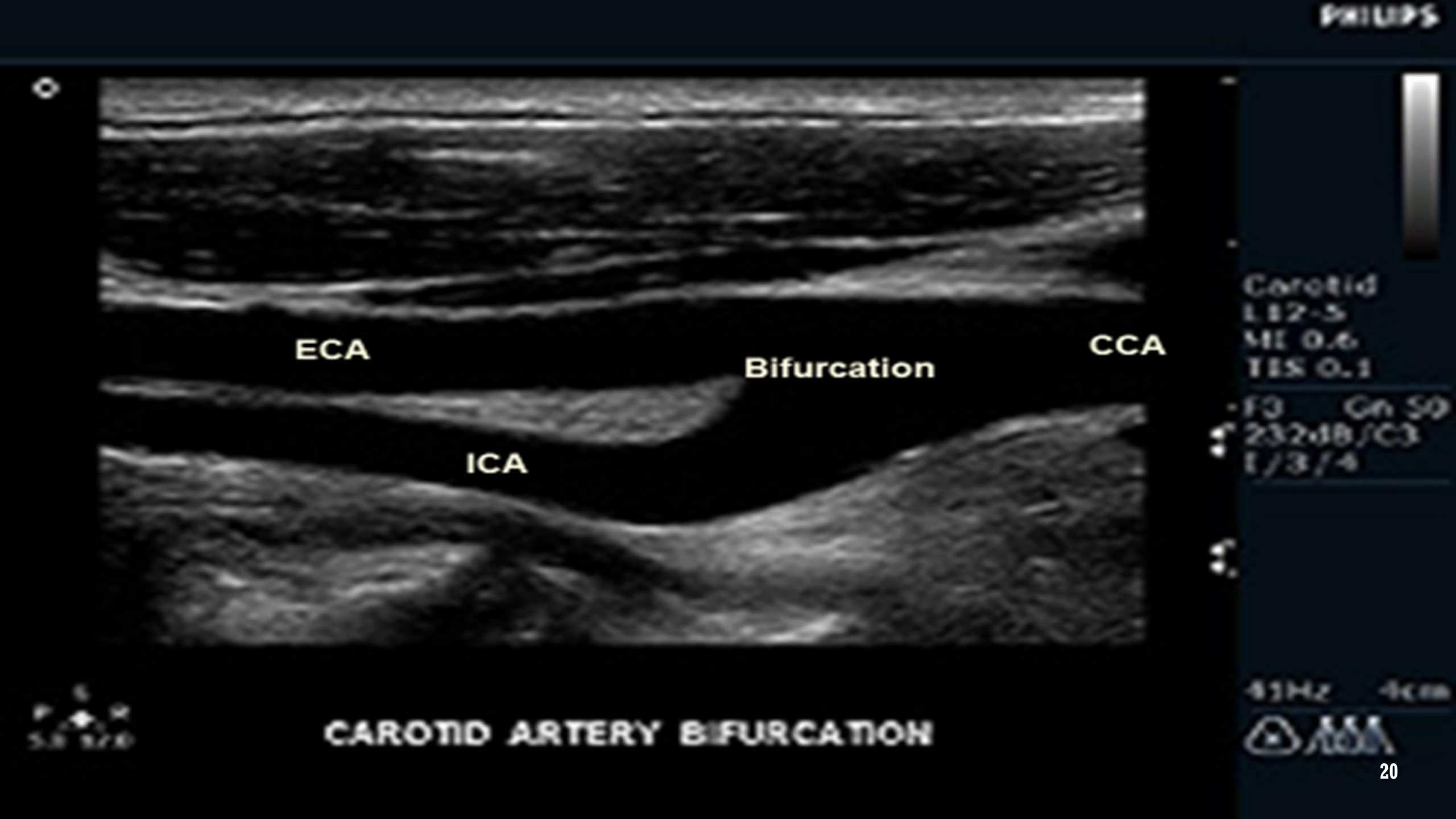




BIFURCATION IMAGING



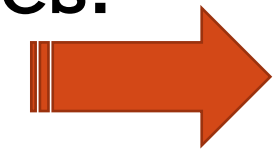



PHILIPS
ECA
Bifurcation
CCA
ICA
Carotid
L12-5
MI 0.6
TIS 0.1
F3 Gn 50
232dB/C3
1/3/4
41Hz 4cm
CAROTID ARTERY BIFURCATION

NORMAL PROCEDURE

- Transducer is placed in a transverse view at the base of the neck and the carotid artery is assessed to the level of the mandible

- B-Mode Images: (according to ACR guidelines)
  - ***Transverse*** Images:
    - ICA - Proximal



This is a *very* minimal grayscale requirement!

NORMAL PROCEDURE

- After evaluation of B-mode, Color Doppler is used to evaluate Color Flow characteristics (hemodynamics)
- Color Doppler Images: (ACR guidelines)
  - Long axis of distal CCA
  - Long axis of Proximal ICA
  - Long axis of Mid ICA
  - Long axis of ECA (with identification of a branch if possible)
  - Long axis of vertebral artery

NORMAL PROCEDURE

- After evaluation of B-Mode, Pulsed Wave Doppler is used to evaluate spectral analysis (frequencies of the blood flow)
- Spectral Doppler images measures maximal peak systolic velocities at the following levels: (ACR Guidelines)
  - Proximal CCA
  - Mid or Distal CCA
  - Proximal ICA
  - Mid to distal ICA
  - Proximal ECA
  - Vertebral Artery

VISUALIZATION OF ABNORMALITIES

- If atherosclerotic plaque(s) are present:
  - The location, extent, and characteristics should be documented with grayscale imaging in both planes
  - The extent and effect on the lumen should be recorded with Color Doppler (same with occlusion – Power Doppler)
  - The maximum velocity should be recorded at the site of the stenosis and distal to the stenosis to demonstrate presence/ absence of disturbed flow

PLAQUE CHARACTERISTICS

- *Fatty streaks:* homogeneous, low-level echoes
- *Fibrous (soft) plaque:* low-to-medium level echoes
- *Complex plaque:* low, medium and high-level echoes, heterogeneous
- *Calcification:* very bright, highly reflective echoes, often demonstrating an acoustic shadow

PLAQUE CHARACTERISTICS

- *Thrombosis:* appears isoechoic to flowing blood, must use color Doppler and spectral Doppler to ensure there is no hemodynamically significant stenosis
- *Stenosis:* plaque should be visible in two scan plans
- *Occlusion:* plaque morphology may demonstrate the occlusion as anechoic or echogenic, utilize Power Doppler to determine a significant stenosis vs. total occlusion
  - Vessel may demonstrate piston-like motion on B-mode

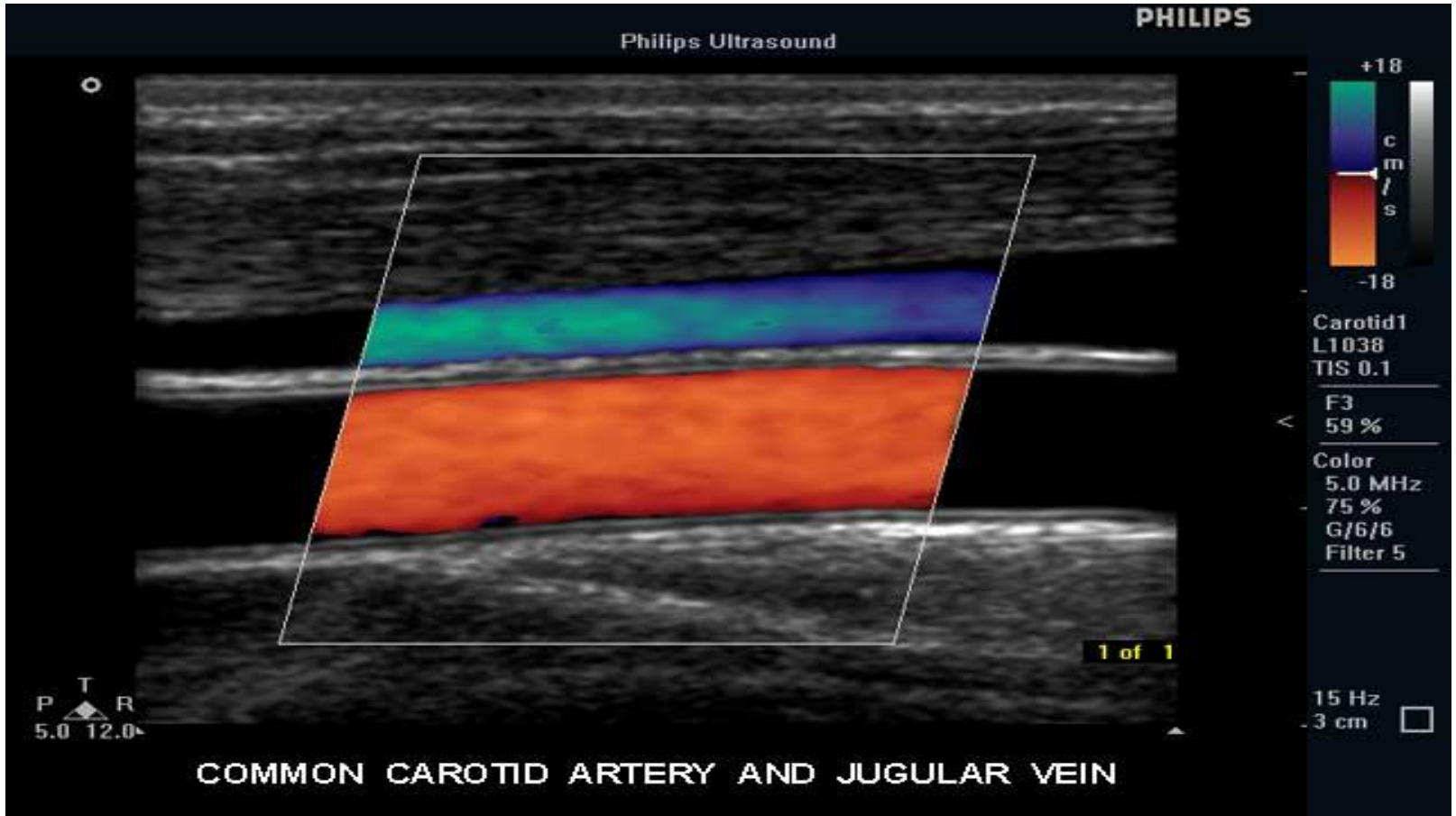
COLOR DOPPLER

- Normally combined with pulsed Doppler
- Helps assess for the presence of:
  - Turbulence
    - Disorganized flow chaotically going in many directions simultaneously
  - Flow separation zones
    - Where high momentum blood separates from the laminae of surround fluid (Blood from tight stenosis running into somewhat normal flow)
  - Movement disturbances at vessel wall
  - Variations in hemodynamics

COLOR BEAM STEERING

- Color Doppler Beam should be steered in the direction that provides the smallest angle of incidence to the blood flow

If the vessels slant to the left, the color box should also slant to the left



Avoid a 90° angle to the blood flow

COLOR BOX

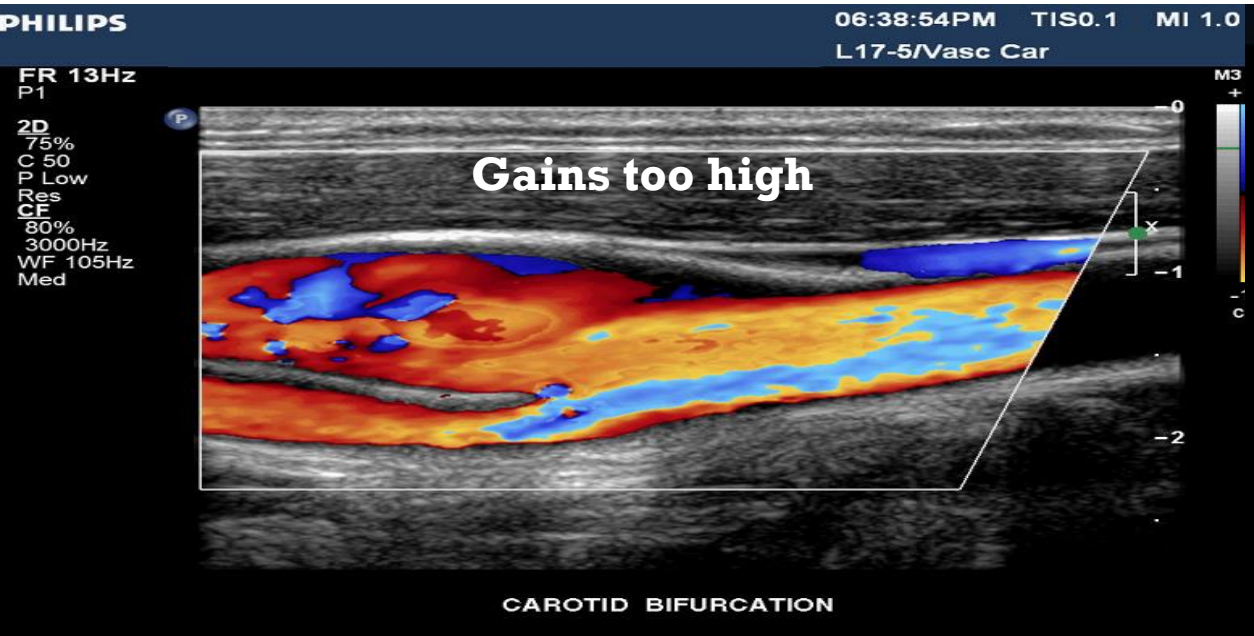
- Frame rate is related to color box size
  - Large Color Box:
    - Reduces frame rate
  - Smaller Color Box:
    - Increases frame rate
- Always try to use the smallest color box possible to optimize color
- If penetration is an issue, direct the color box straight down (do not steer)

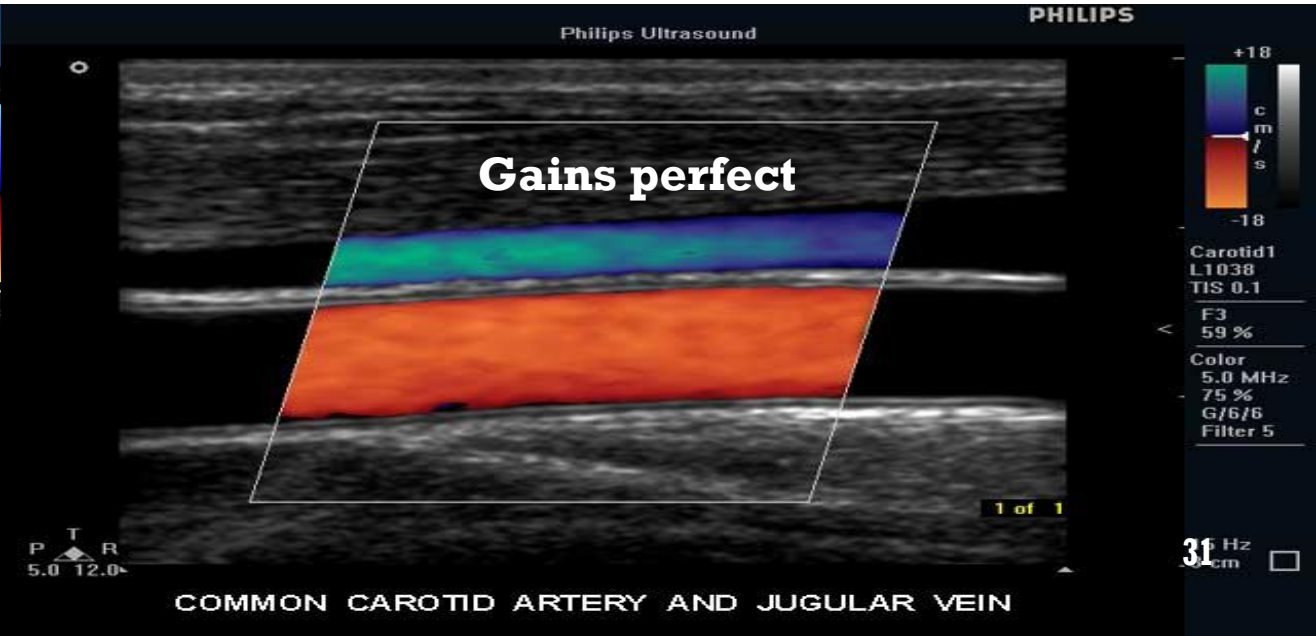
COLOR SCALE

- High Velocity Flow:
  - Increases pulse repetition frequency (PRF) to minimize aliasing
    - Aliasing – the situation that arises when the Nyquist sampling limit is exceeded by the frequency of the input signal
- Low Velocity Flow:
  - Decreases PRF to improve sensitivity

COLOR GAIN

- Must be careful to set your color gain properly
  - Too high – may appear "turbulent"
  - Too low – may appear "low" or "no flow"
- Increase color gain until "speckling" occurs, then reduce gain slightly until speckling disappears





CONTINUOUS WAVE DOPPLER

- Operates with 2 crystals
  - 1 continuously transmits
  - 1 continuously receives
- **Disadvantage**:
  - Impossible to determine discrete points of interest
- **Advantage**:
  - Detect very high velocities without aliasing
- Not routinely used with Duplex Imaging
  - *Range ambiguity*

PULSED WAVE DOPPLER

- Normally combined with color Doppler
- Specific depths are processed:
  - Controls sample size
  - *Range resolution*
    - 2 vessels located directly above one another can be evaluated separately

PULSED WAVE DOPPLER

- Spectral Analysis
  - Individual frequencies make up returning signal
  - Intensity of spectrum is available:
    - Narrow, well-defined spectrum – limited number of frequencies are evident
    - *Spectral broadening* – variety of frequencies
      - Often associated with turbulent flow

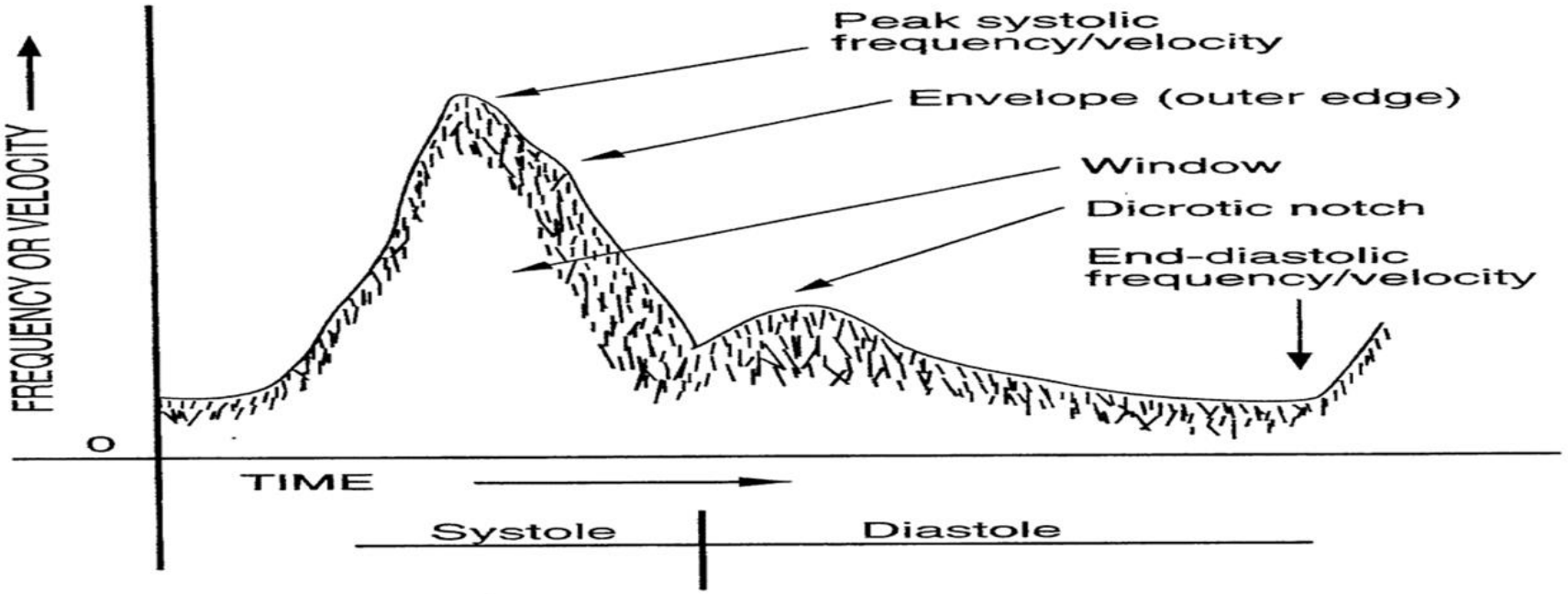
PULSED WAVE DOPPLER

- Remember:
  - Doppler angle of **45-60°** should be maintained for each signal obtained
    - **Angles above 60° should never be used**
      - Cosine values change very rapidly
      - Small errors in angles cause large errors in peak velocity

PULSED WAVE DOPPLER

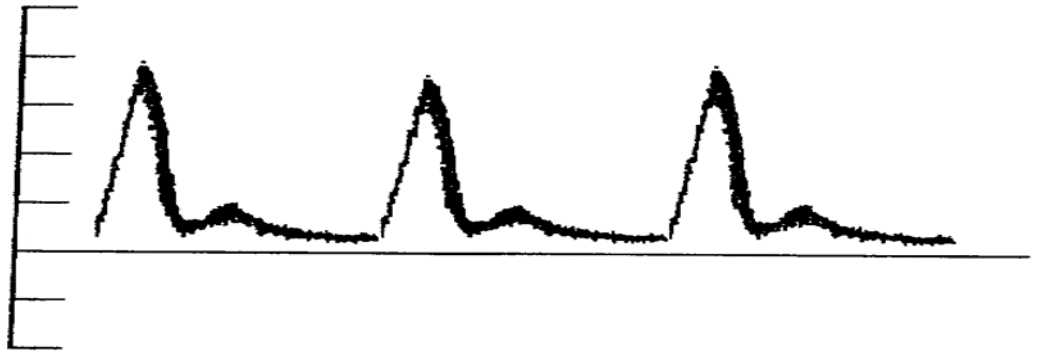
- Sample volume gate size should be kept as small as possible to detect discrete changes
  - Sample volume size should be increased when searching for a small jet or occlusion
- Sample volume should be placed near the center of the vessel to minimize the spectral broadening
  - Lower velocities found near the walls of the vessels
  - Color flow can help identify the flow profiles in the vessel

SPECTRAL ANALYSIS OF A PULSED DOPPLER WAVEFORM



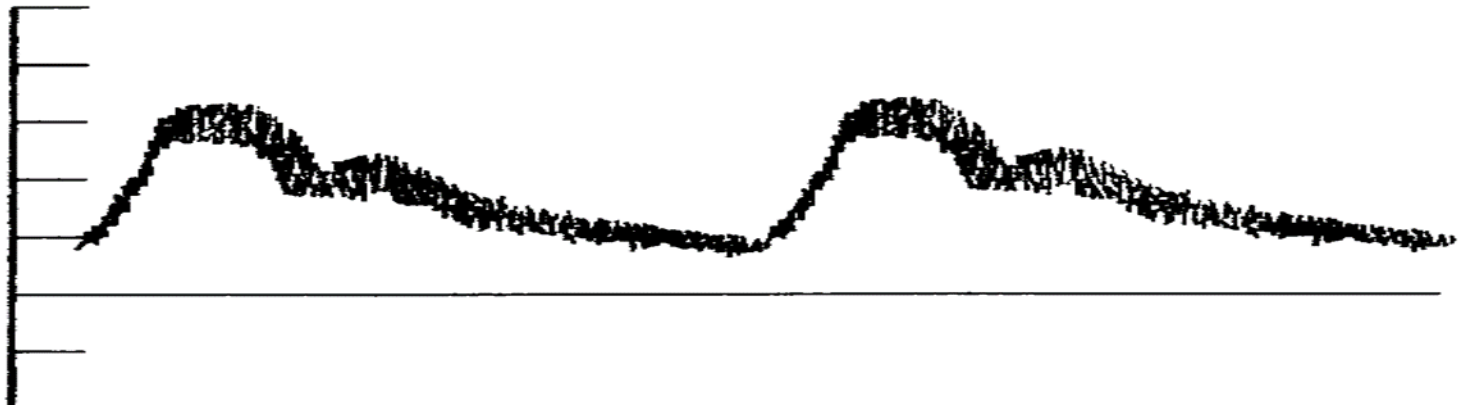
SPECTRAL ANALYSIS

- CCA – flow characteristics of both:
  - ICA
  - ECA
  - CCA waveform is of a low resistance vessel
  - End-diastolic velocity should be above the baseline



SPECTRAL ANALYSIS

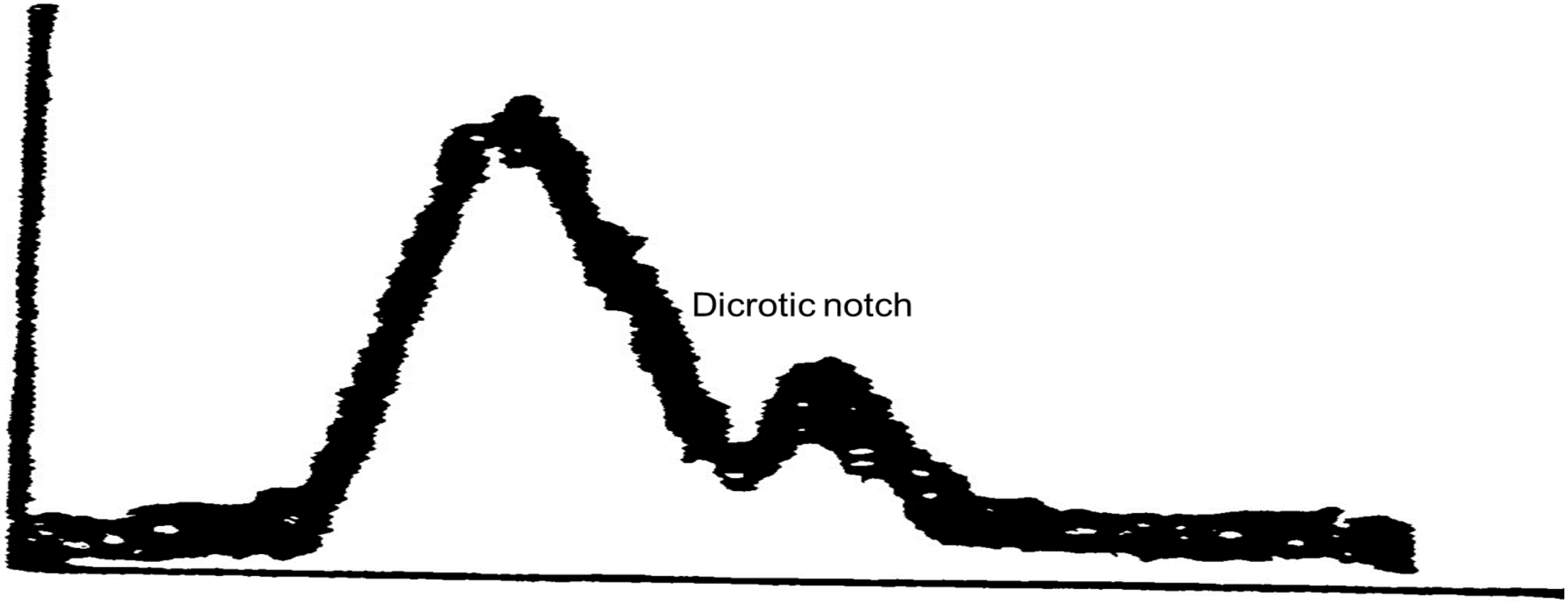
- ICA – slightly more high-pitched and continuous than the ECA
  - Feeds a low-resistance vascular bed (brain)
  - Less pulsatile than ECA
    - Rapid upstroke and down-stroke with high diastolic component
    - Dicrotic notch not clearly seen



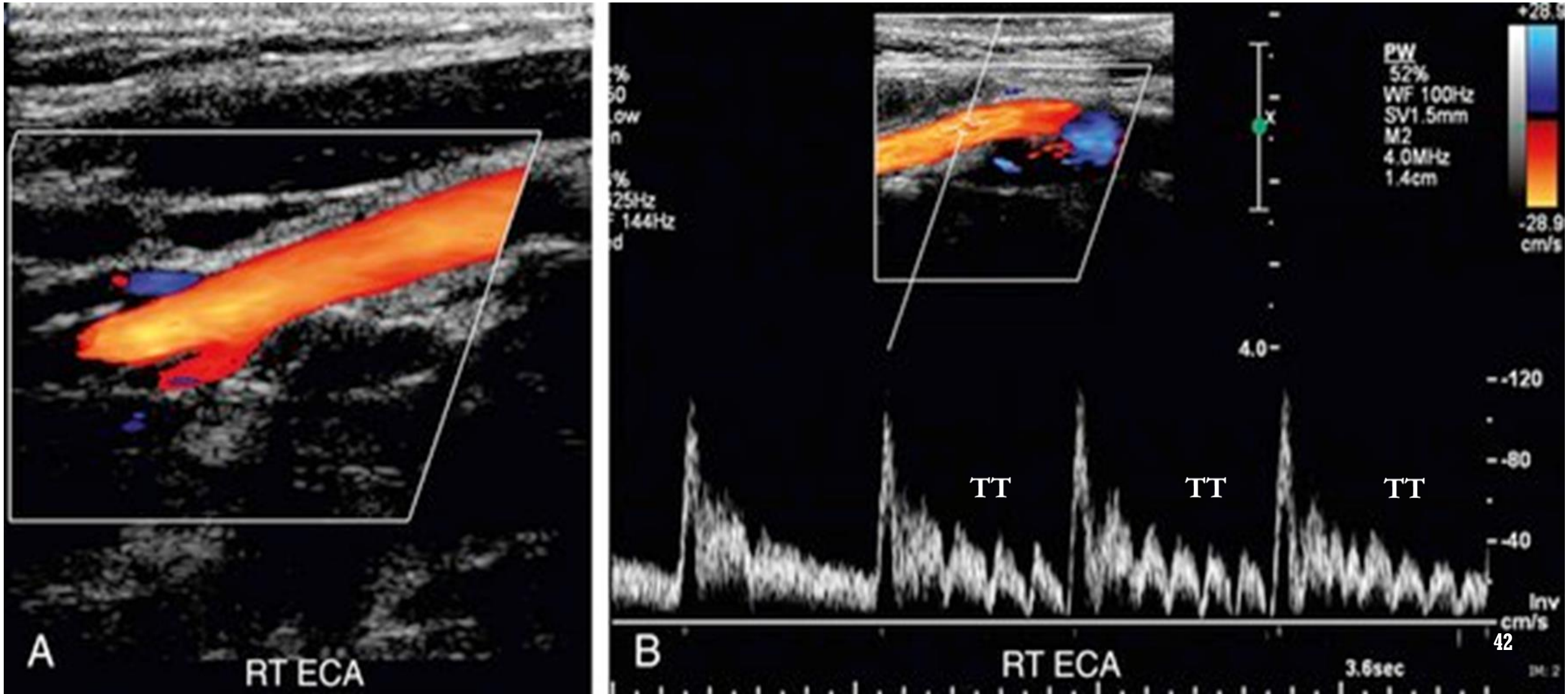
SPECTRAL ANALYSIS

- ECA
  - Feed high-resistance vascular beds (face, scalp, etc)
  - More pulsatile than ICA
    - Rapid upstroke and down-stroke with very low diastolic
    - Dicrotic notch is clearly seen
- *Temporal Tap*
  - Tapping on the superficial temporal artery will cause oscillations of the waveform
  - This is one way of verifying ECA vs. ICA

ECA SPECTRAL ANALYSIS

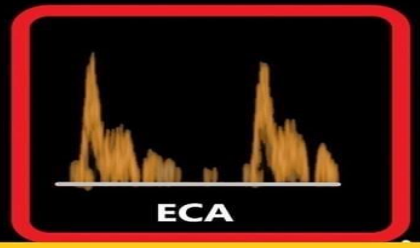


ECA – TEMPORAL TAP

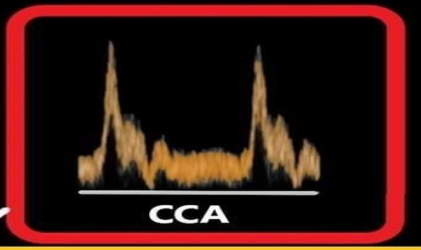


Extracranial Cerebrovascular Arteries

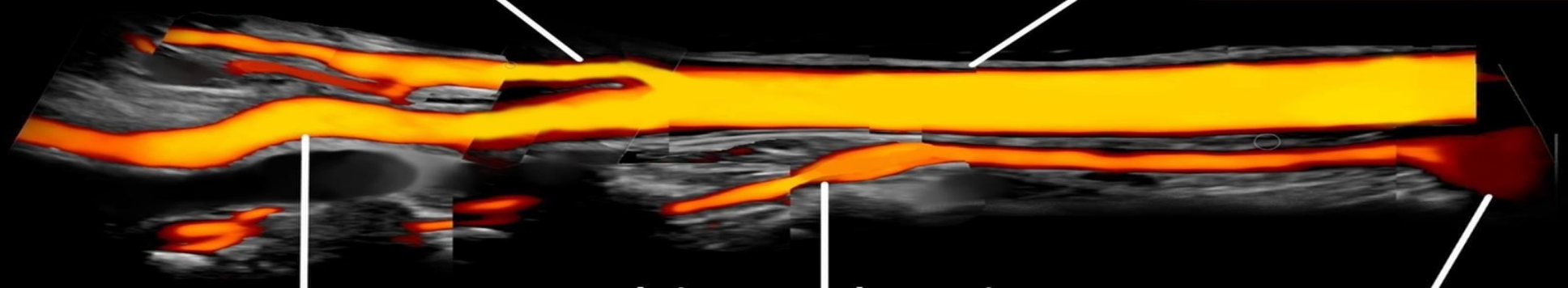
ST



External Carotid Artery



CommonCarotid Artery



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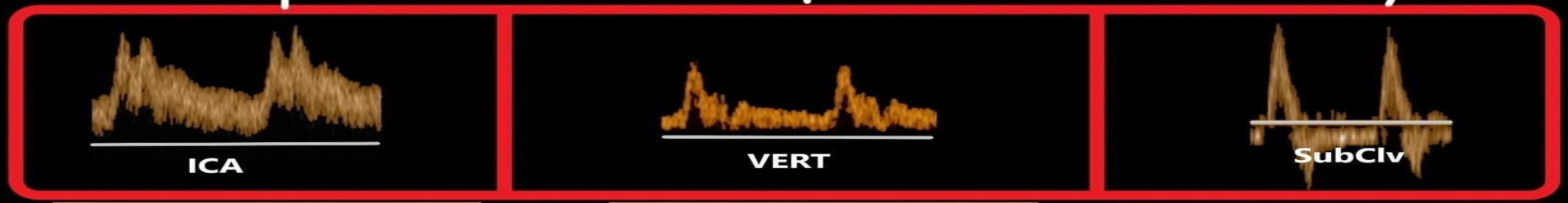


Internal Carotid Artery

Vertebral Artery

Subclavian Artery

DOPPLER SAMPLES

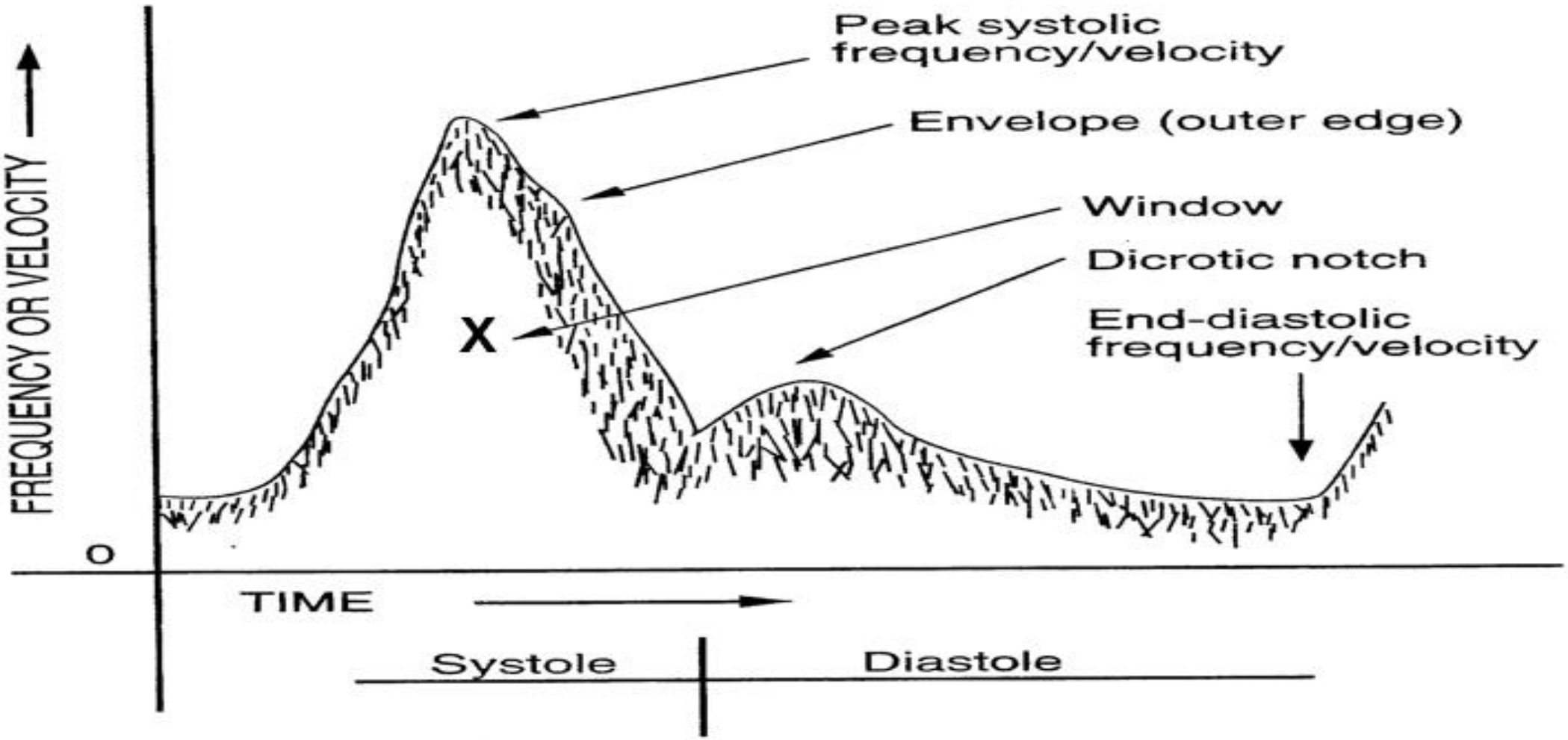
- Utilize the color to assist you in placing the sample volume
  - Look for normal flow
  - Look for abnormal flow
    - **Abnormalities can be missed if you don't know the normal/abnormal appearance**
    - **If you only sample normal flow, you will miss a stenosis**

FYI:

- Velocity increases during and after a stenosis – drag the sample volume through the narrowed area and evaluate distal also
- Velocity can decrease in a very tight stenosis

SAMPLE VOLUME

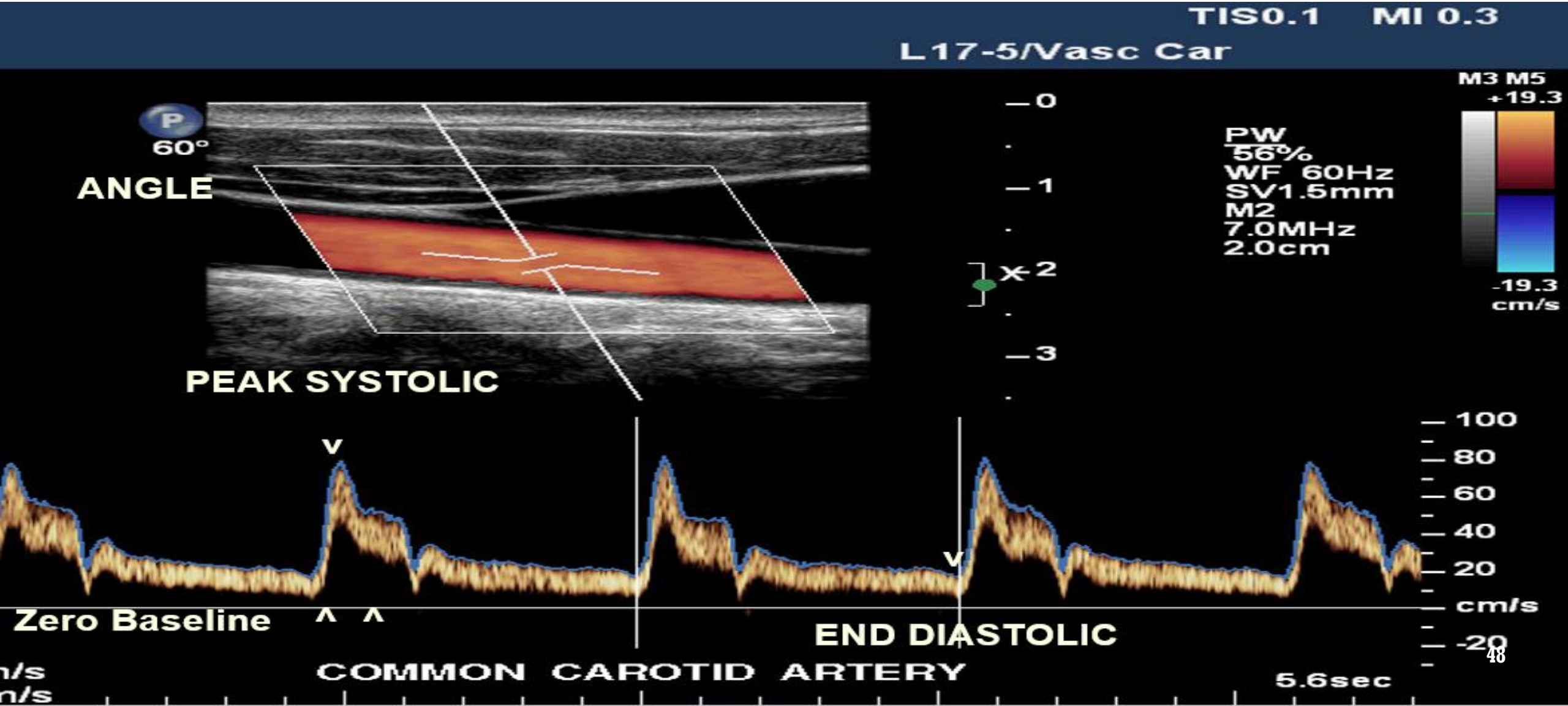
- Pulsed wave sample volume is more precisely placed in the center of the blood flow
- Laminar flow will have the presence of 2 features:
    1. Signals have a narrow band of frequencies in systole
        - Narrow band – called spectral envelope
    2. "Blank" area in the spectral envelope


Peak systolic
frequency/velocity
Envelope (outer edge)
Window
Dicrotic notch
End-diastolic
frequency/velocity
X
FREQUENCY OR VELOCITY
0
TIME
Systole
Diastole

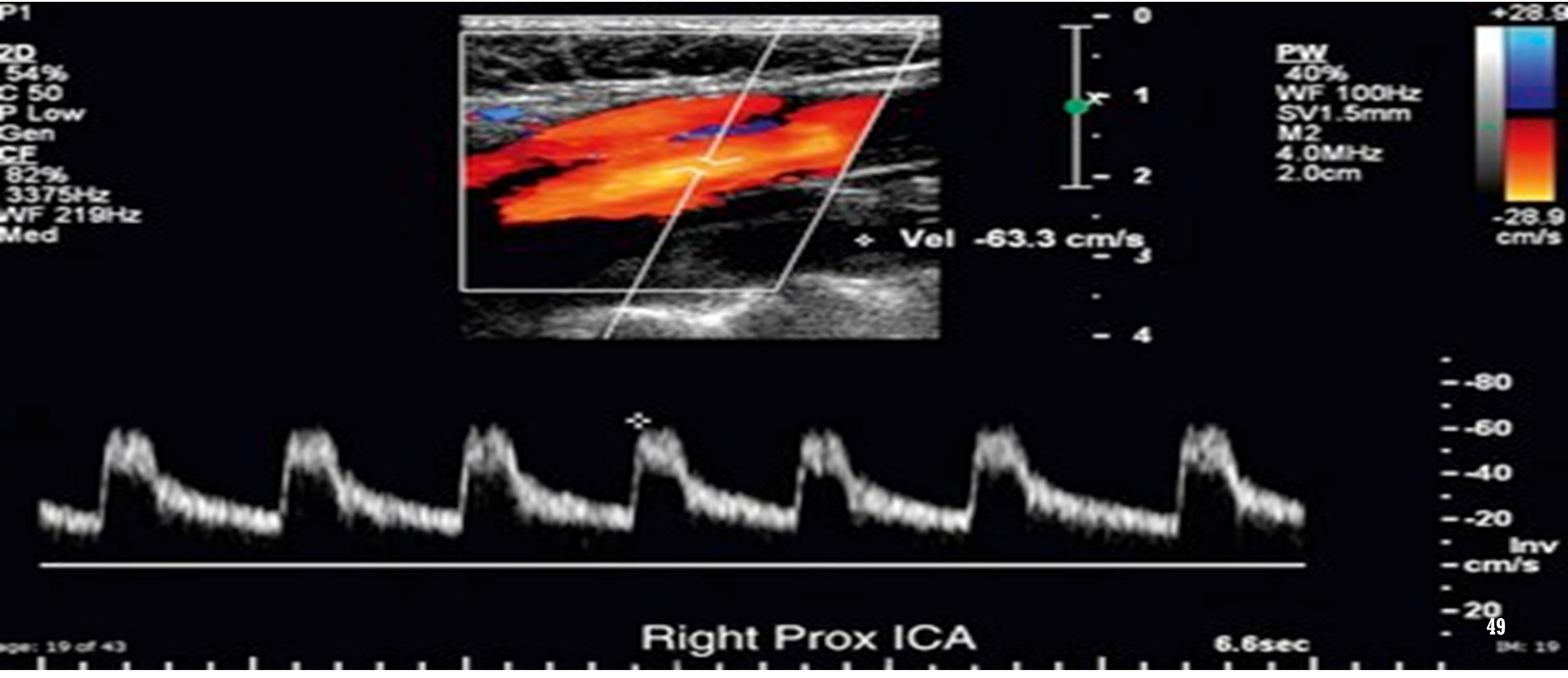
DOPPLER MEASUREMENTS

- Measure each vessel:
  - **PEAK systolic velocity**
  - **END diastolic velocity**
    - CCA – Proximal
    - CCA – Distal
    - Bulb
    - ICA – Proximal, Mid, Distal
  - **PEAK Systolic Velocity**
    - ECA – Proximal
      - Some protocols include EDV of the ECA also!

NORMAL CCA WAVEFORM



NORMAL ICA WAVEFORM

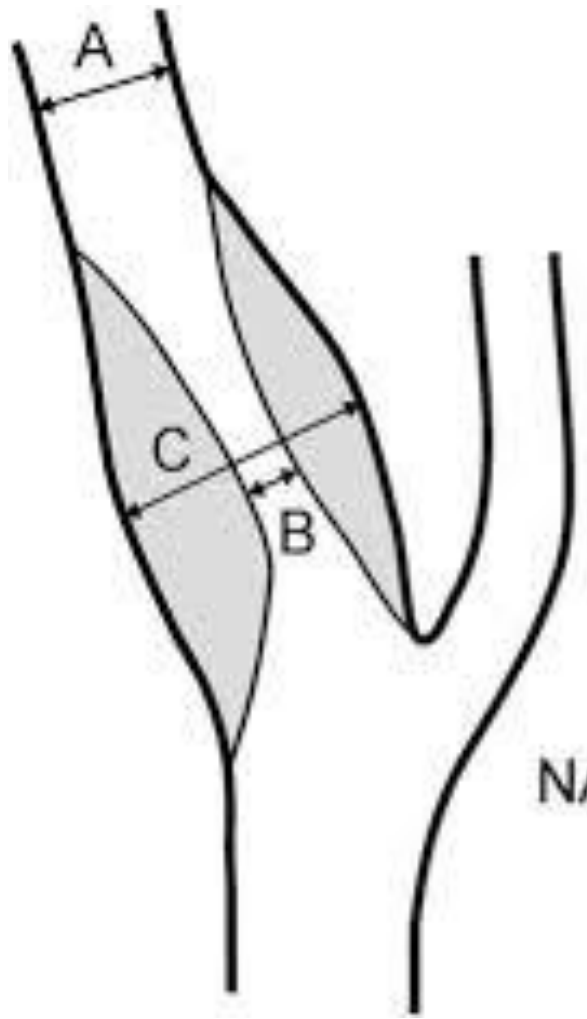


NORMAL ICA DIAGNOSTIC CRITERIA

- Normal ICA:
  - PSV <125 cm/sec
  - EDV <40 cm/sec
  - ICA/CCA ratio <2.0
  - Absence of visible plaque accumulation
  - No or minimal spectral broadening in the decelerating phase of systole
  - Spectral window present

DIAMETER REDUCTION

- NASCET (North American Symptomatic Carotid Endarterectomy Trial)
  - Evaluates the distal ICA lumen(A) in comparison to the residual lumen of the carotid bulb (B)
  - (C) investigates the actual diameter of the carotid bulb using the ECST method



$$\text{NASCET} = \frac{A-B}{A}$$

$$\text{ECST} = \frac{C-B}{C}$$

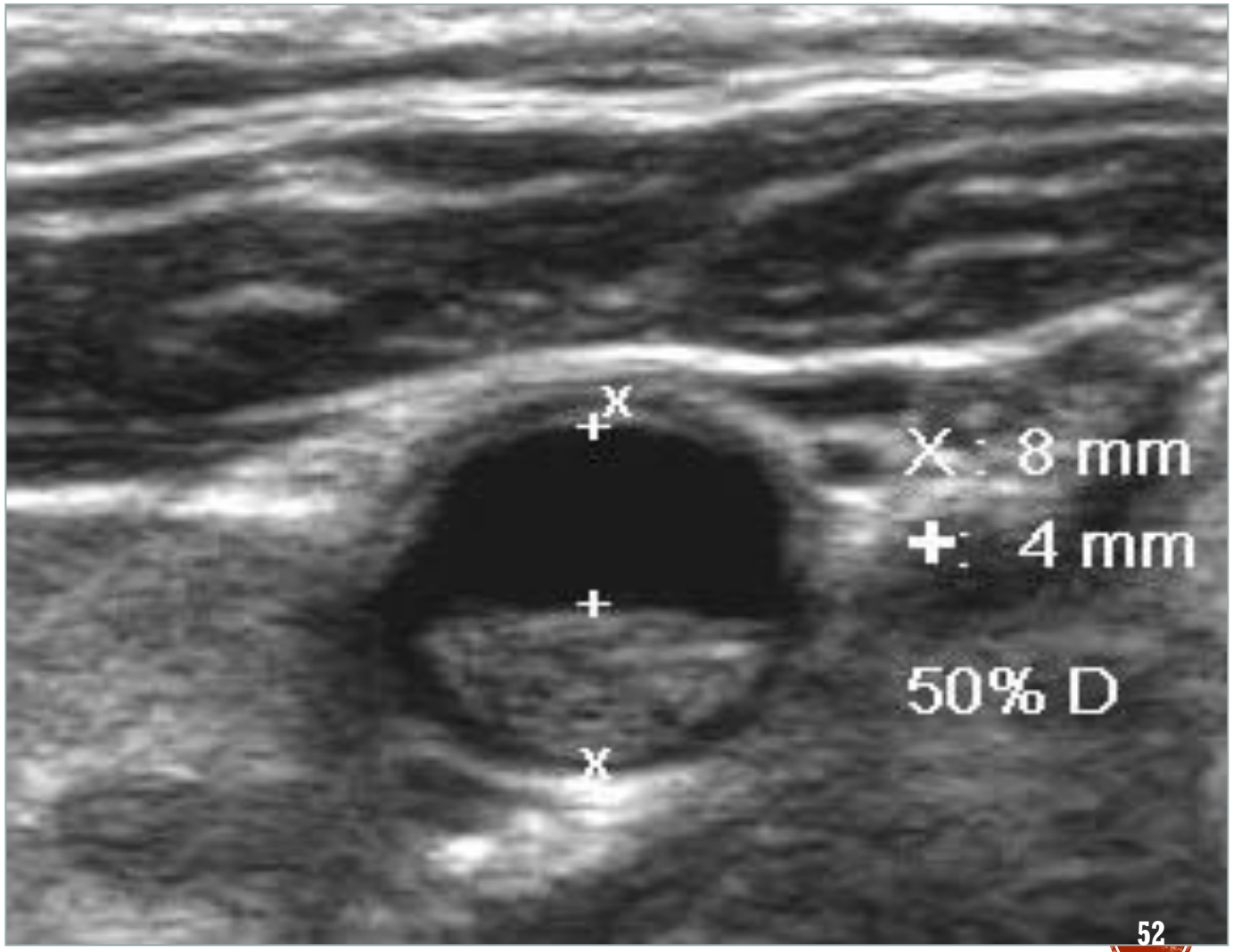
DIAMETER REDUCTION

% D stenosis =

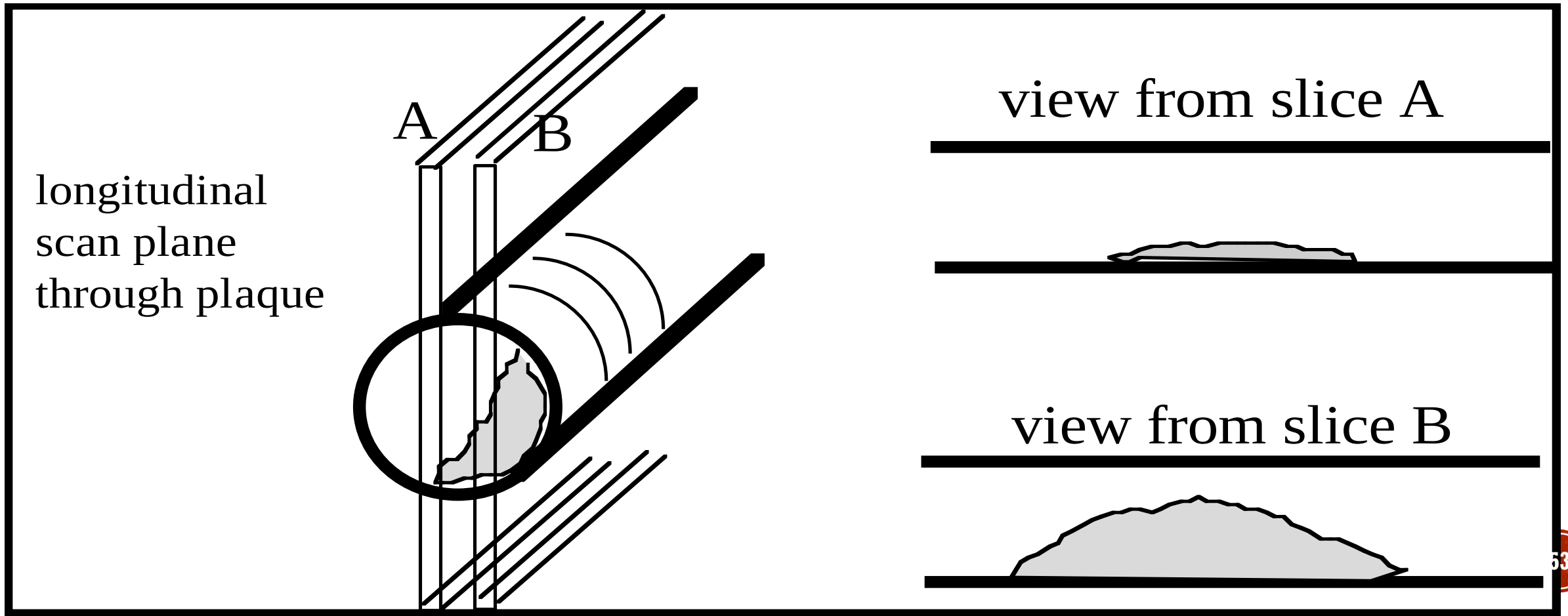
$$\frac{TL - RL}{TL} \times 100\%$$

or

$$1 - \frac{RL}{TL} \times 100\%$$



LONGITUDINAL ESTIMATION OF STENOSIS FROM B-MODE MAY BE UNRELIABLE, USE TRANSVERSE IMAGE



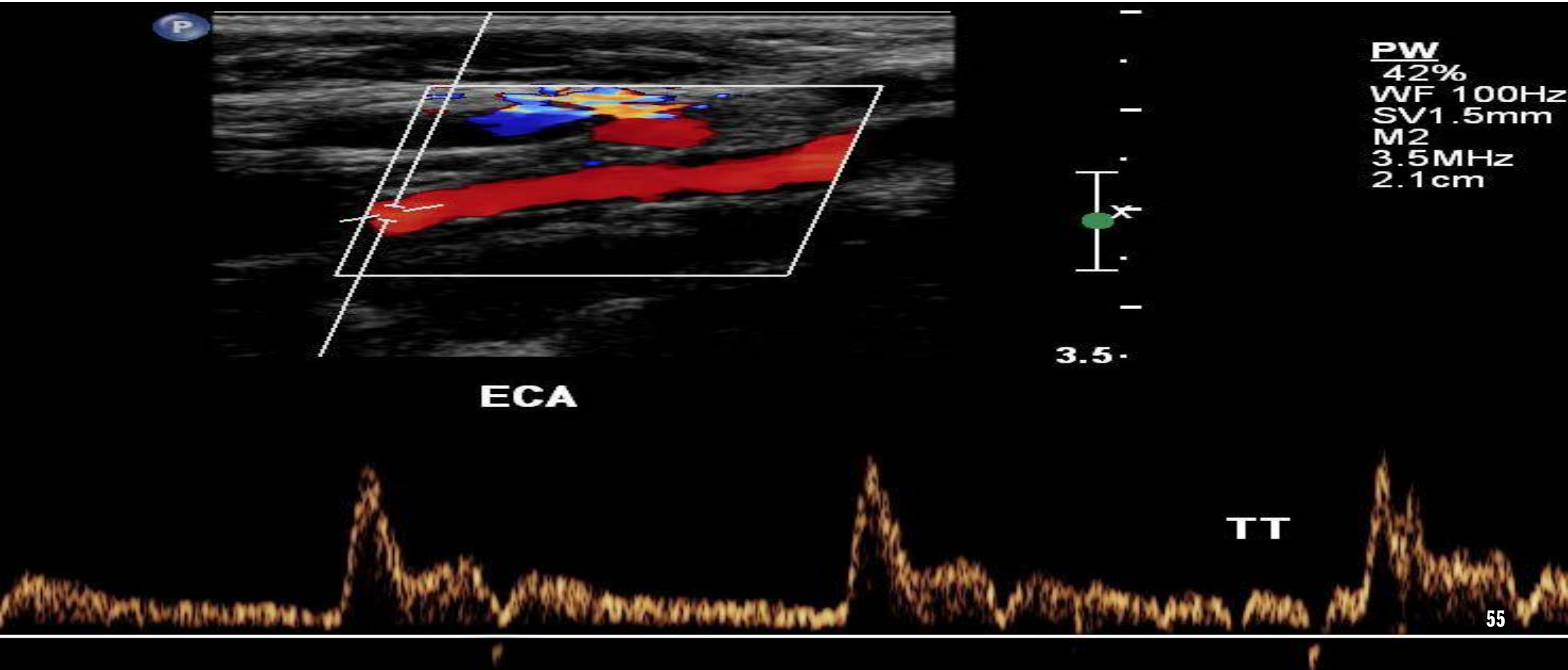
ICA/CCA RATIO

- Velocity ratios between the ICA and CCA have been developed to help the radiologist quantify the stenosis:

$$\frac{\text{ICA}}{\text{CCA (}\textit{distal segment}\text{)}} = \text{Ratio}$$

- Systolic velocity ratio (ICA/CCA)
  - 2.0-4.0 indicates a 60% diameter stenosis
  - >4.0 indicates 80% diameter stenosis
    - Systolic velocity ratio normally used
    - Diastolic velocity ratio can also be used according to the facility

NORMAL ECA WAVEFORM



VERTEBRAL

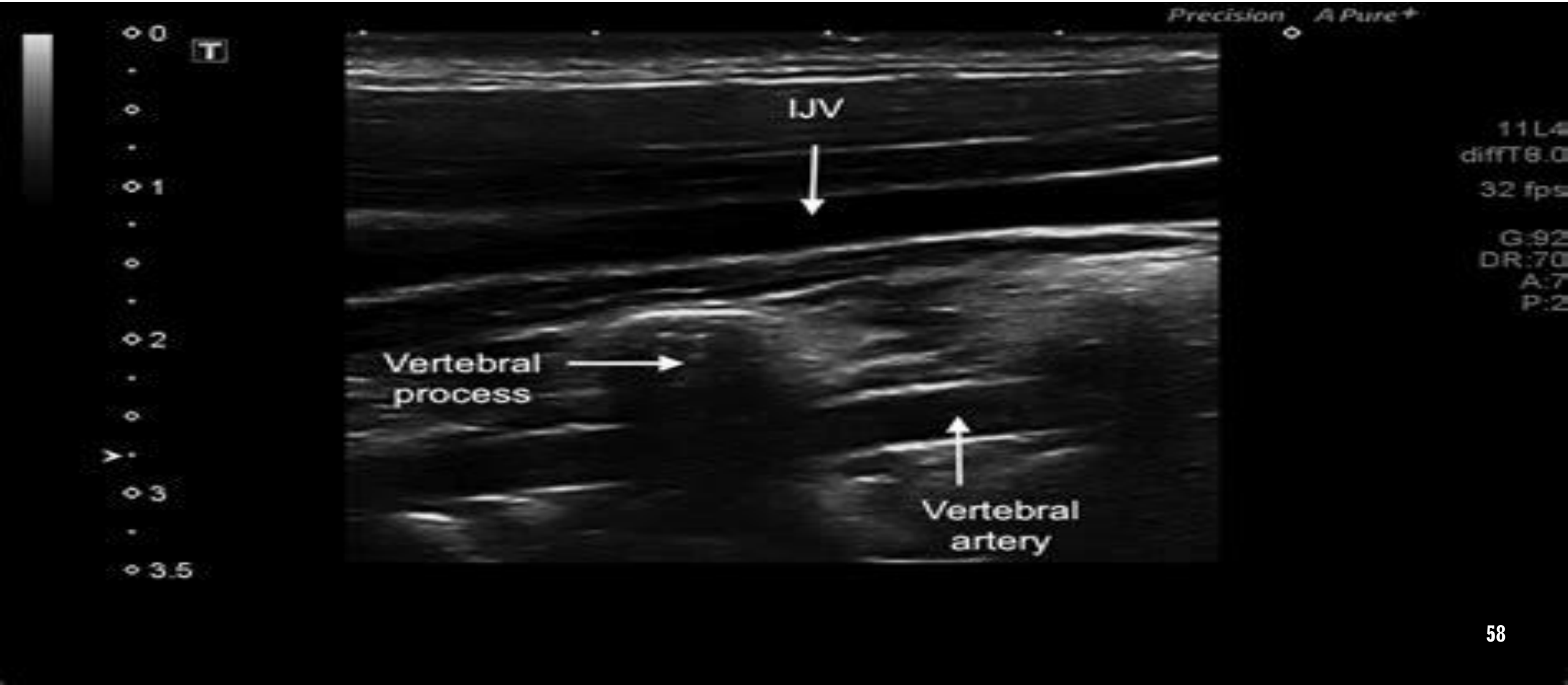
- When the right carotid system has been completely evaluated:
  - Image the right vertebral artery
- When the left carotid system has been completely evaluated:
  - Image the left vertebral artery
- Normally one image to document direction of flow is sufficient (again, depends on facility)

Why is the vertebral system important?

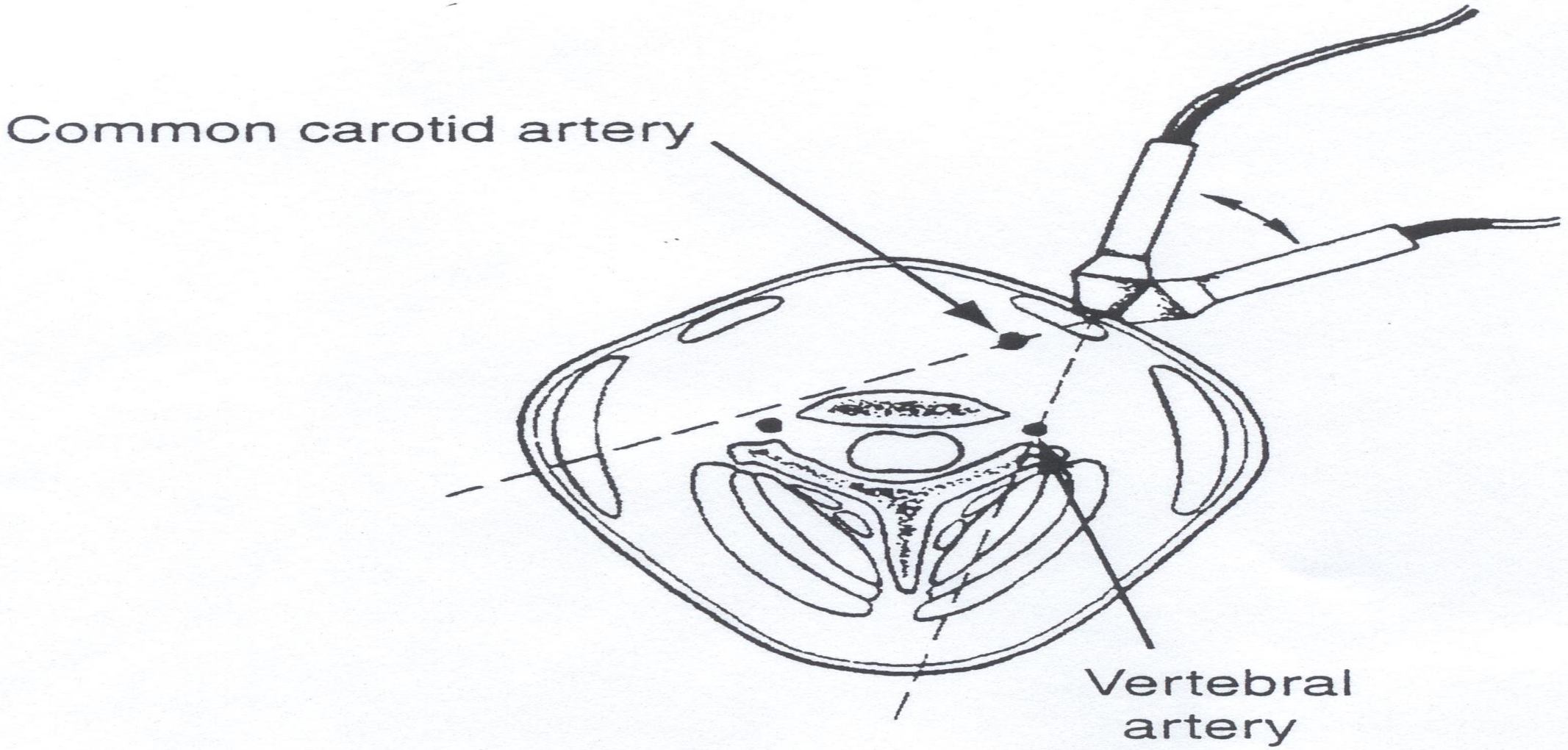
VERTEBRAL

- To image the vertebral artery:
  - While scanning the CCA in longitudinal, angle the probe posterior-laterally
  - Vertical shadows will run through it – spinous process of the cervical spine
- Document direction of flow:
  - Antegrade (towards the head) – Normal
    - Spectral analysis is above the baseline
  - Retrograde (towards the feet) – Abnormal (Subclavian Steal)
    - Spectral analysis is below the baseline
- Document absence of flow if applicable

VERTEBRAL



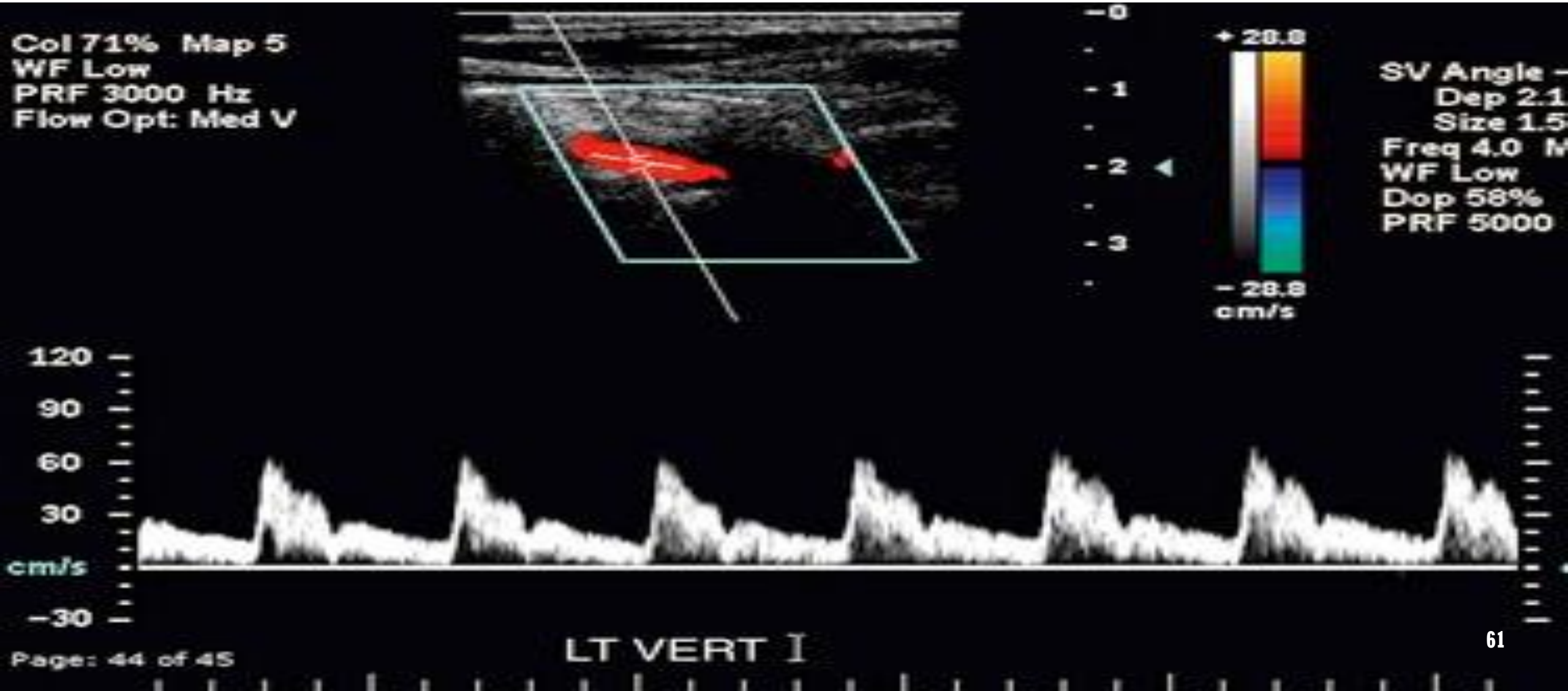
ANGLE POSTERIOR-LATERAL FROM CCA



VERTEBRAL WAVEFORM

- Appears as a scaled down version of the ICA waveform
- Directly supplies the low-resistance intracranial system
- Well-defined systolic peak with sustained flow throughout diastole

NORMAL VERTEBRAL WAVEFORM



ABNORMAL FINDINGS DURING A CAROTID EXAM

DOPPLER – ABNORMAL FINDINGS

- A stenosis will create a higher-pitched sound compared to a normal vessel
  - Waveform will demonstrate higher velocities
- Spectral broadening is indicative of turbulent flow
- Distal to a stenosis, the waveform patterns are dampened with an increased acceleration time
- A tight stenosis might not demonstrate an appreciable waveform, don't confuse it for an occlusion
  - Power Doppler can be used to identify the trickle flow and properly place your sample gate in this area

DOPPLER – ABNORMAL FINDINGS

- If the ICA is completely occluded:
  - 1. Ipsilateral CCA waveforms takes on the appearance of the ECA
  - 2. Contralateral ICA and CCA will act as collaterals, demonstrating increased systolic and diastolic velocities
- Cardiac output will influence waveforms
- Fibromuscular dysplasia (FMD) has cyclic changes in velocities as flow moves through the wall irregularities of the mid-distal ICA

DOPPLER – ABNORMAL FINDINGS

- Abnormal ICA Doppler findings:

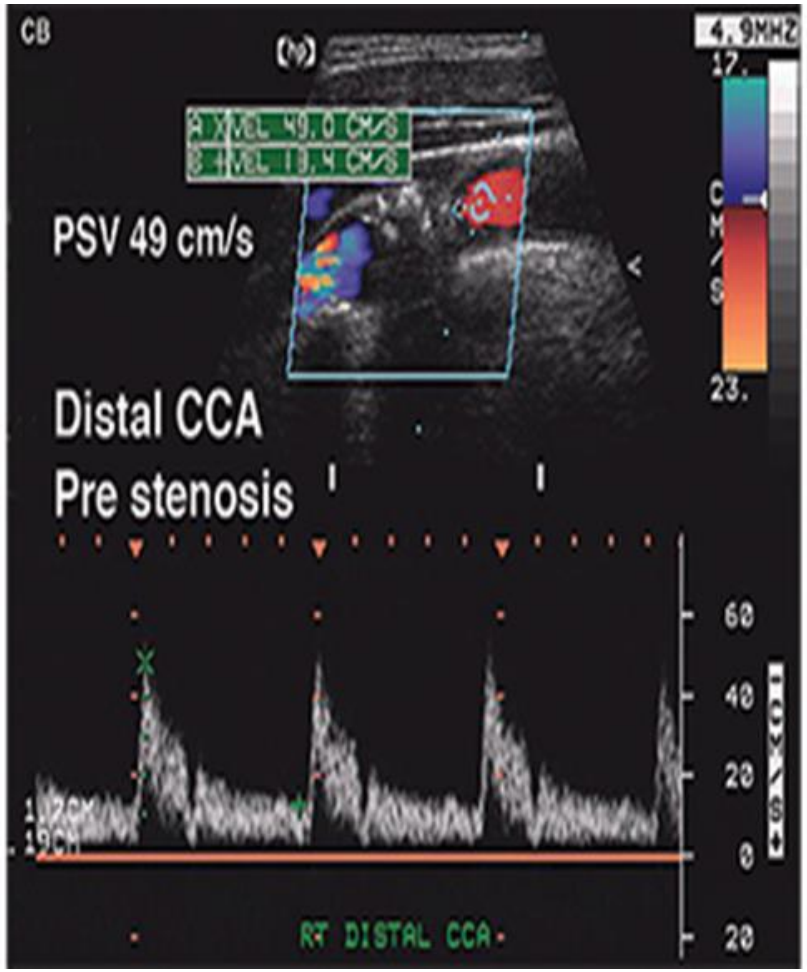
Degree of stenosis:	PSV (cm/sec)	EDV (cm/sec)	ICA/CCA Ratio
50-69% DR	125-230	40-100	2.0-4.0
≥ 70% DR	>230	>100	>4.0
Near Occlusion	High, Low, or Undetectable	Variable	Variable
Total Occlusion	Undetectable	N/A	N/A

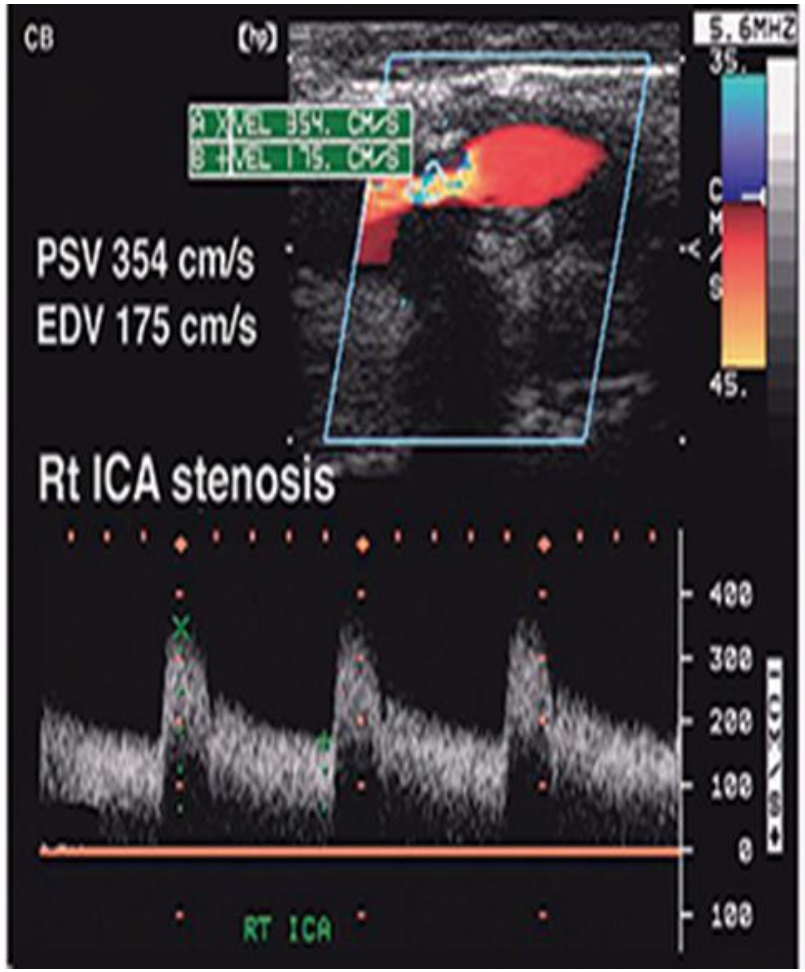
DOPPLER – ABNORMAL FINDINGS

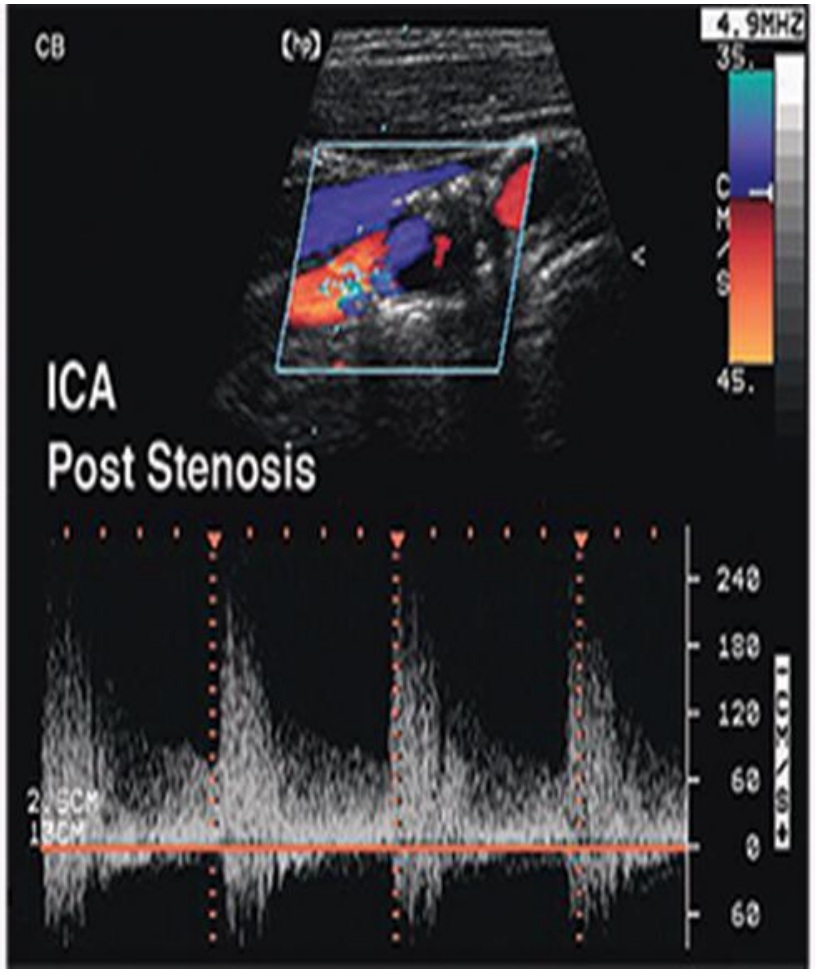
- Three conditions should exist in order to use carotid criteria:

1. You see the plaque in the artery
2. There is demonstrable velocity acceleration in the area of the plaque
3. Post-stenotic turbulence exists distal to the plaque

TRACING THROUGH A STENOSIS

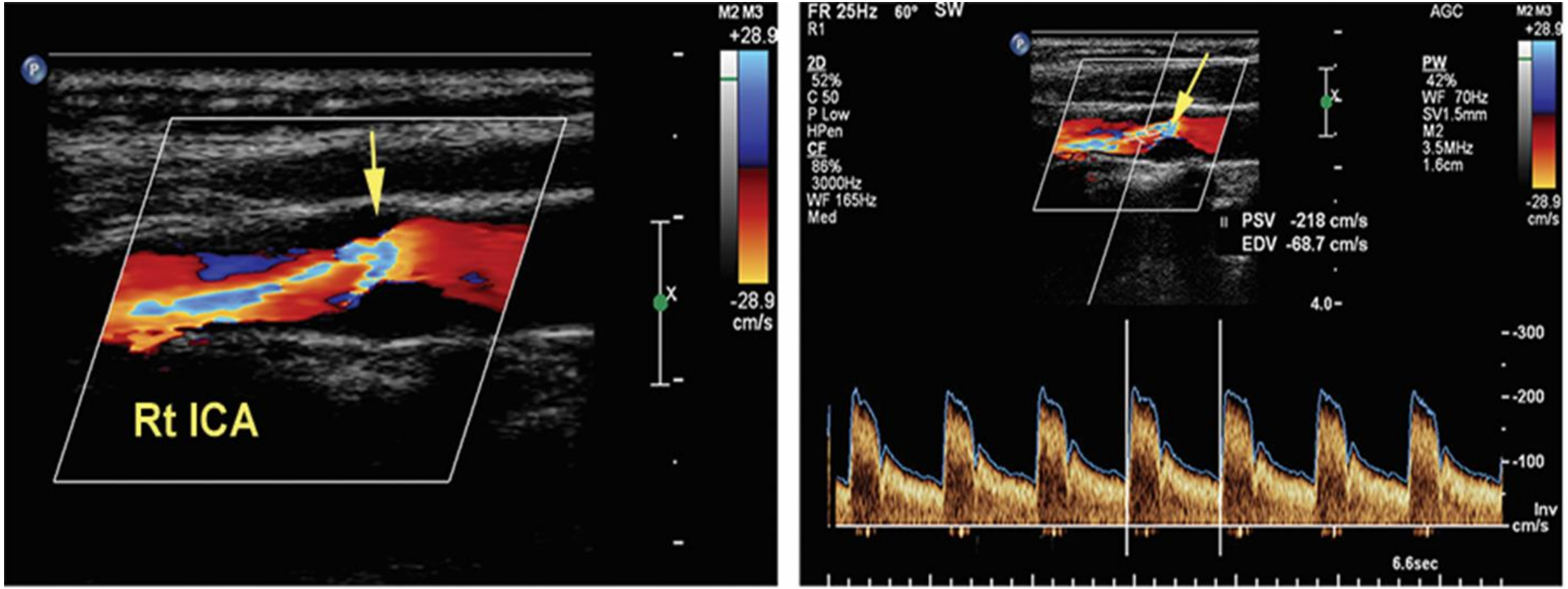






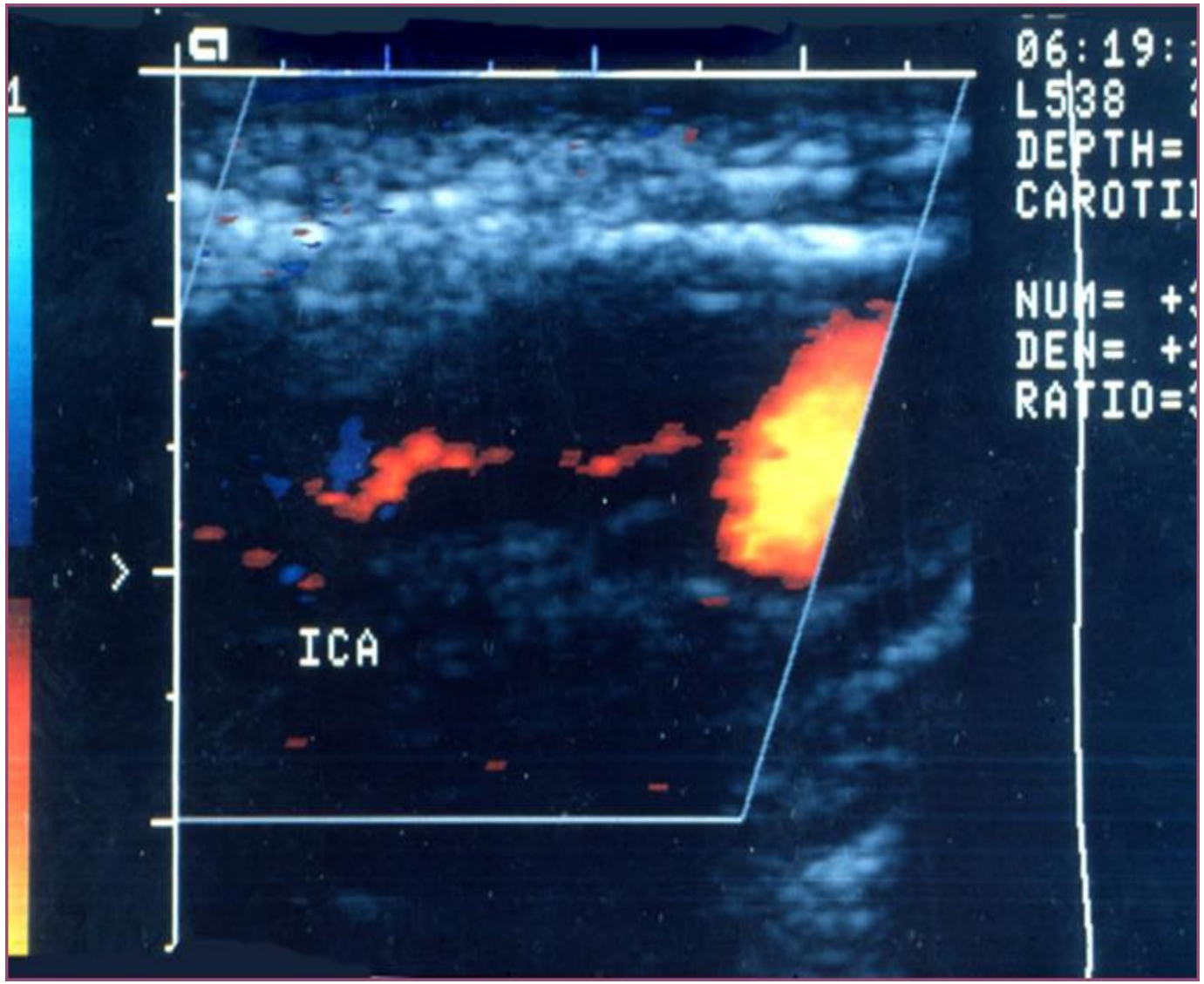
Pre-stenotic area **Maximum stenosis** **Post stenotic region**

DON'T MAKE THIS MISTAKE!



The yellow arrow indicates the region of maximum stenosis, note that the sample volume is incorrectly placed distal to the plaque.

IMAGING A NEAR TOTAL OCCLUSION IN ICA

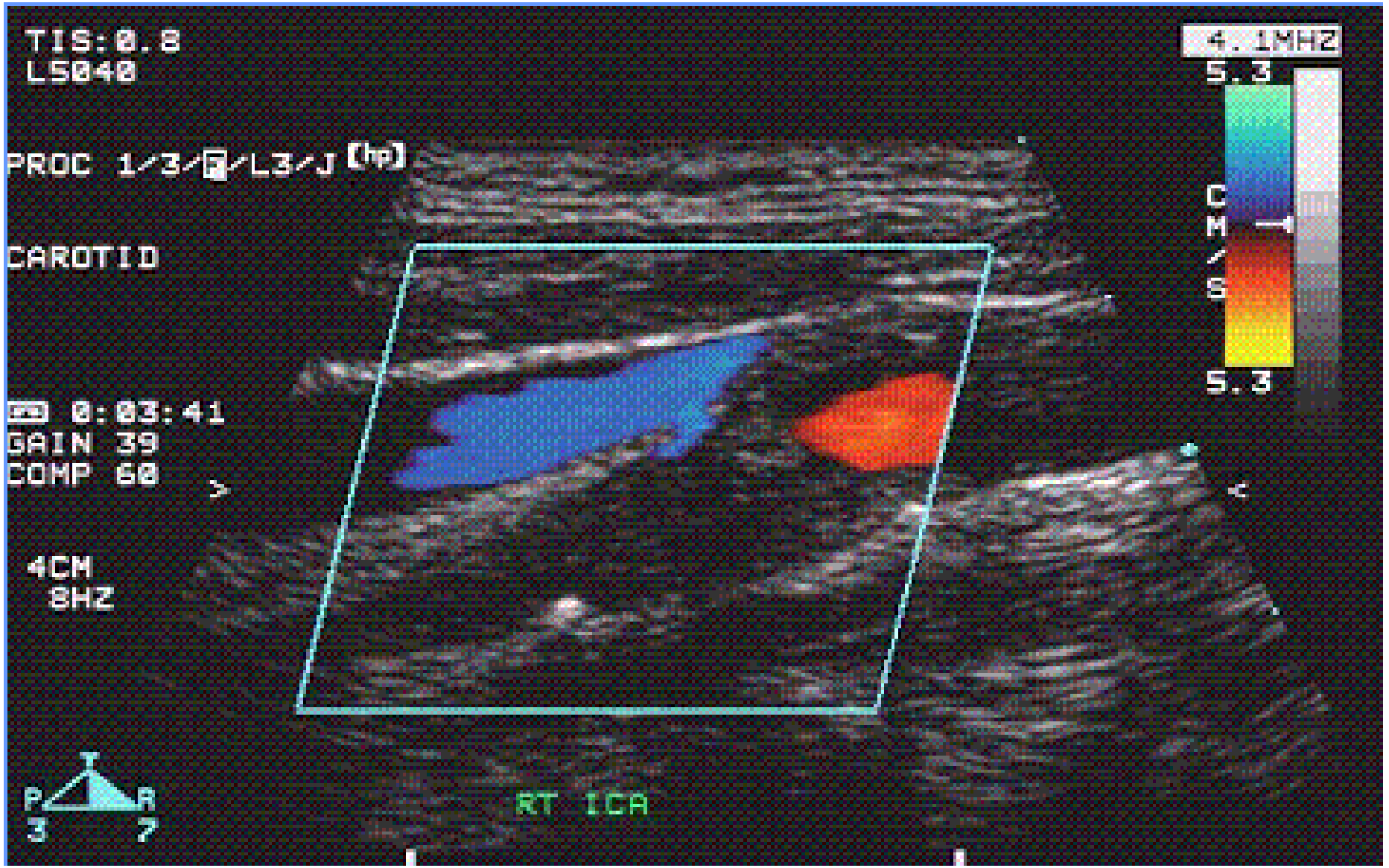


- Use low PRF color scale
- Use power Doppler
- May demonstrate *very low* velocity flow
- STAT reporting to referring physician

IMAGING A TOTAL OCCLUSION IN ICA

- Visualize plaque filling the lumen
- Determine absence of flow
  - Use color Doppler (and power Doppler) to rule out "trickle flow" or "string sign"
  - Take several samples of spectral Doppler at multiple locations to demonstrate lack of arterial pulsations
- Be cautious of technical problems such as inappropriate color Doppler gains, PRF, and steering angle
- "Water Hammer" Effect may be demonstrated with a totally occluded ICA

IMAGING A TOTAL OCCLUSION IN ICA

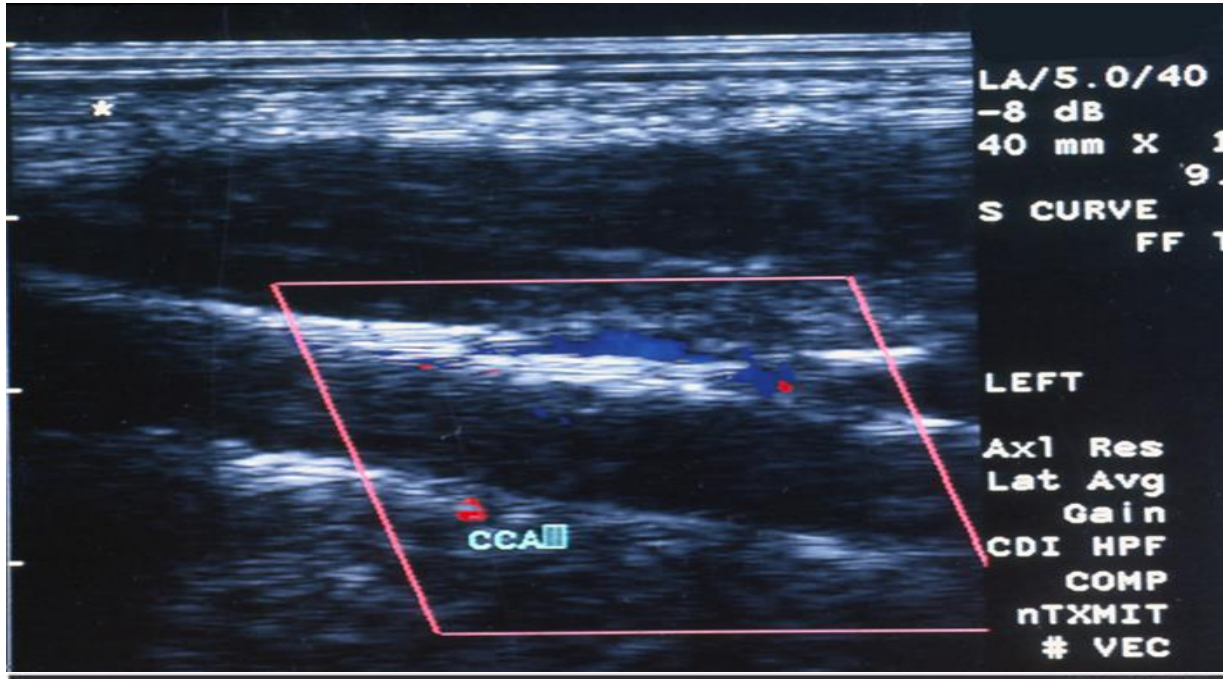


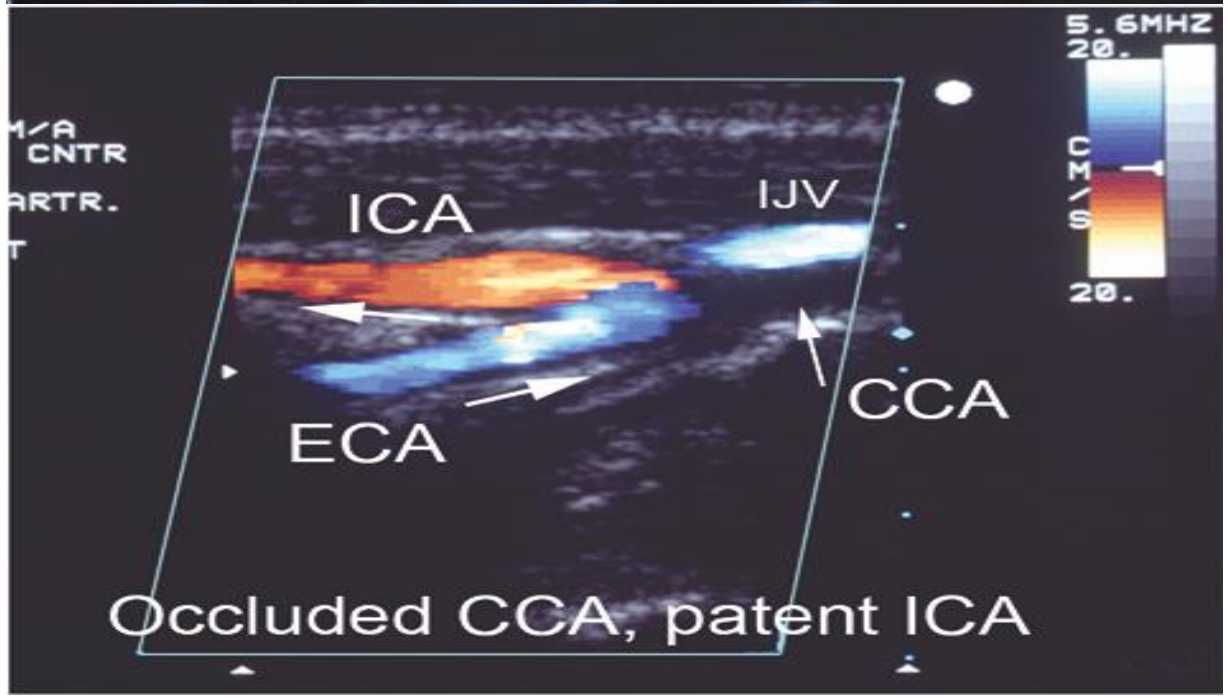
CCA STENOSIS

- No established criteria
- If velocities double over a stenotic region, it is likely a >50% stenosis

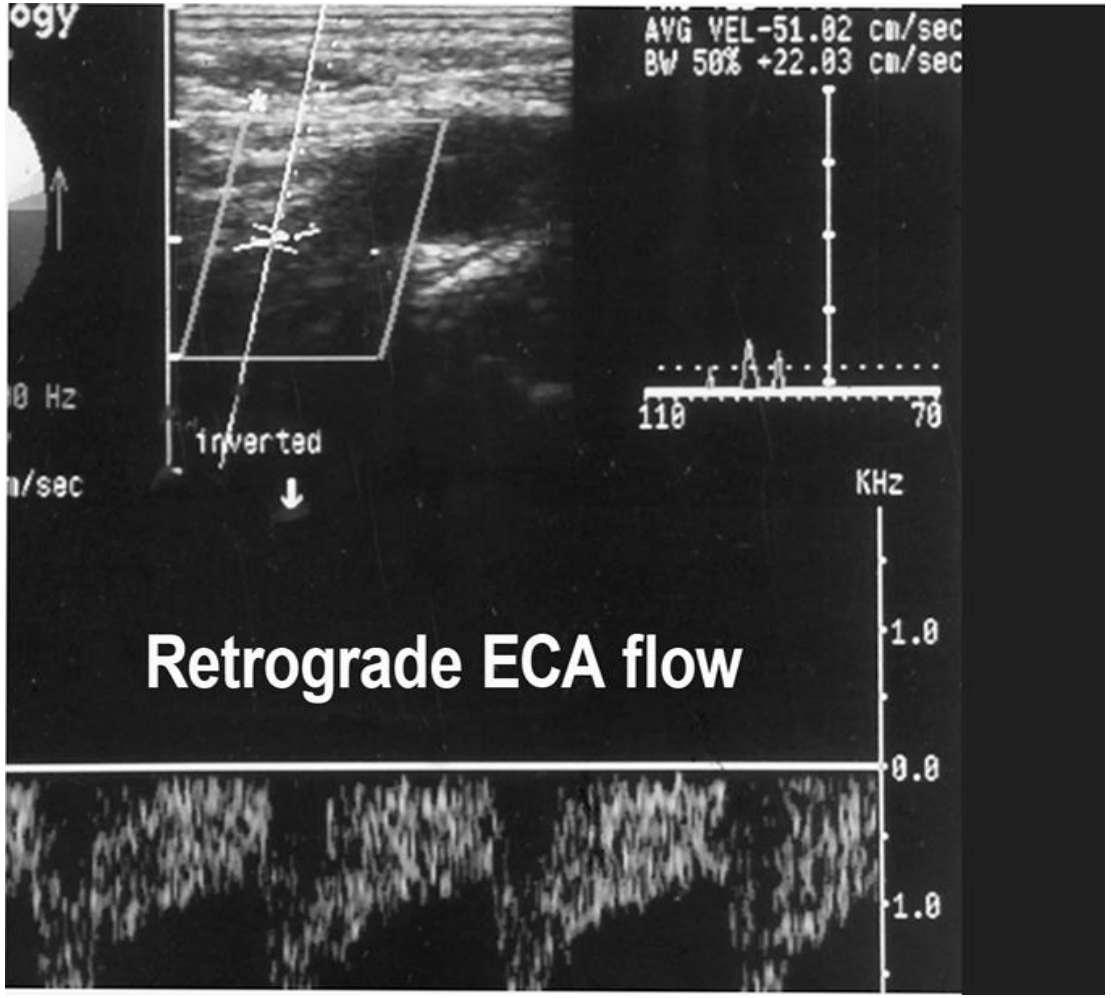
CCA OCCLUSION

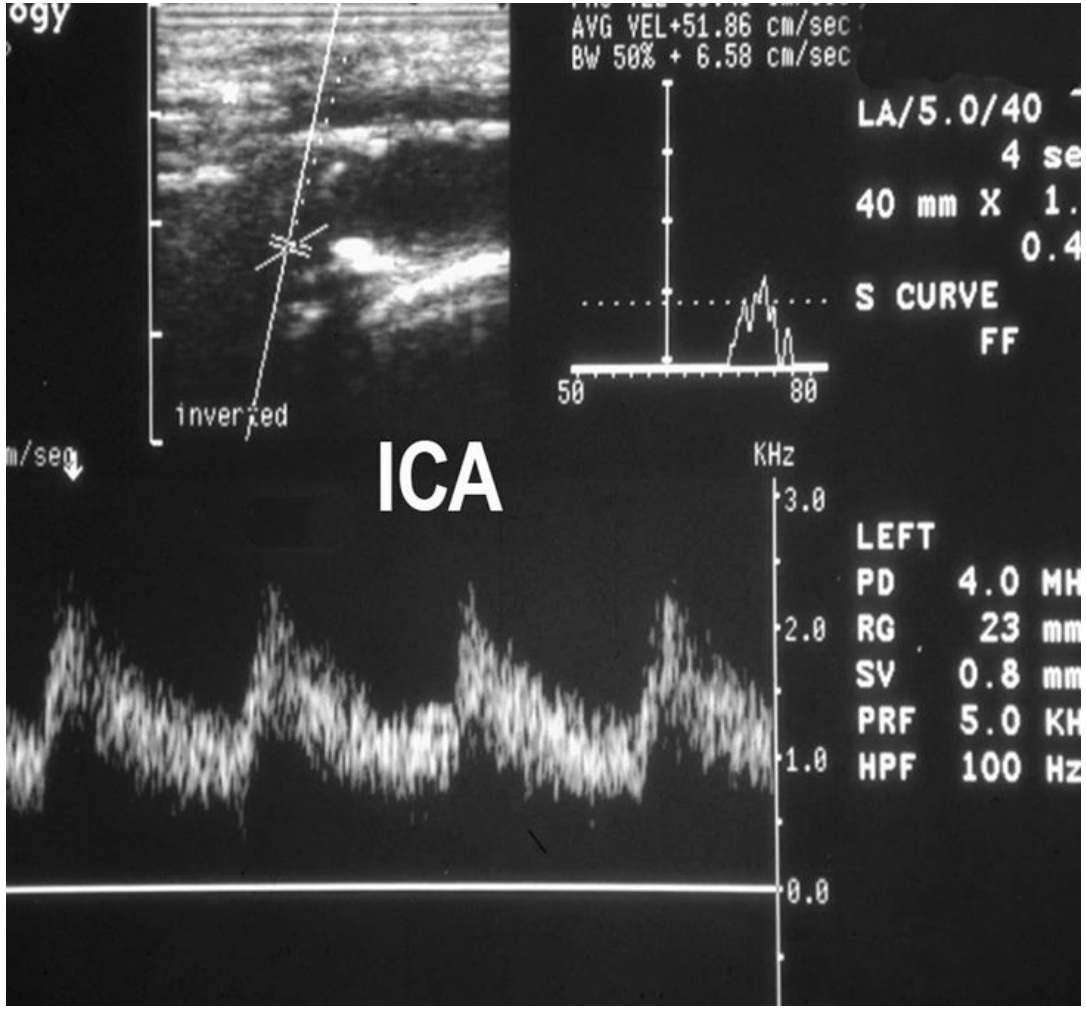
- Verify no flow in CCA
- Evaluate ICA and ECA – note the direction of flow
- ICA will remain open due to collateral (retrograde) flow from ECA
  - ICA will have abnormal spectral doppler





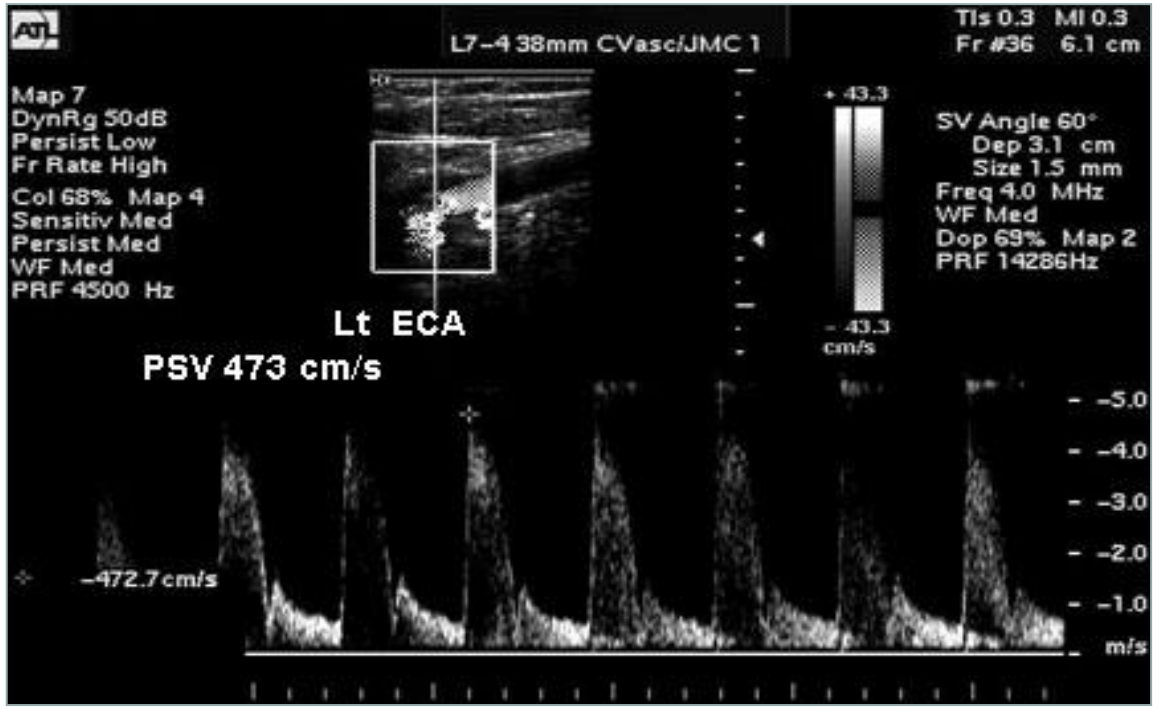
OCCLUDED CCA

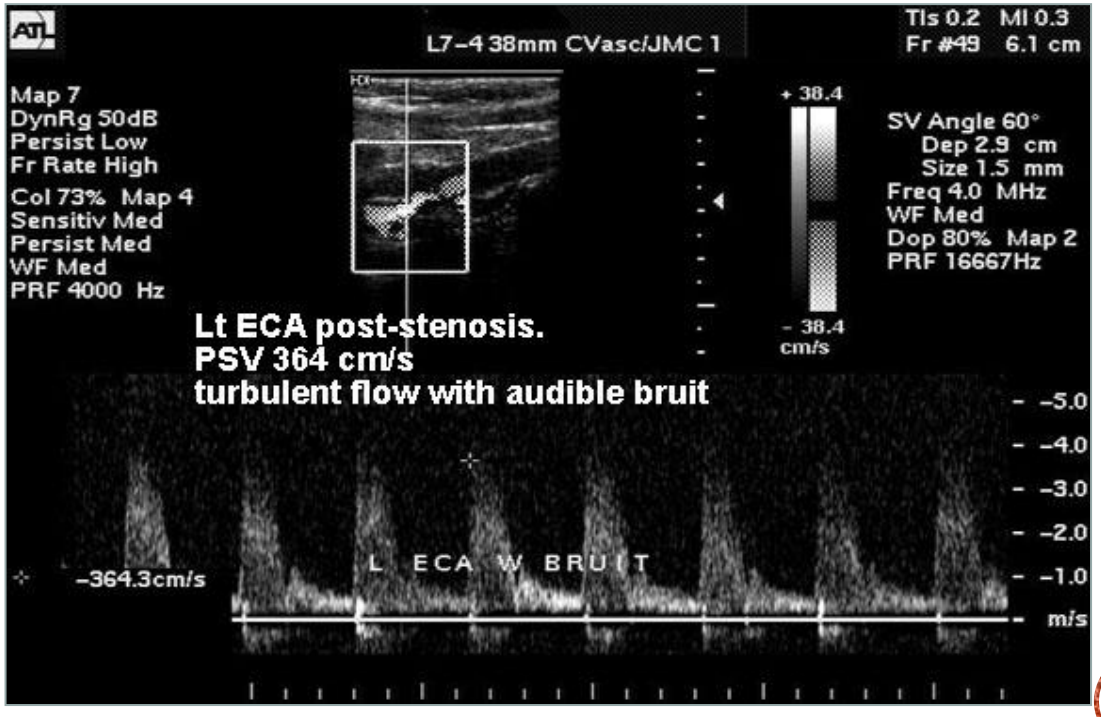




ECA STENOSIS

- No established criteria
- Look for abrupt increase in velocity at the stenosis and post-stenotic turbulence





SURGICAL TREATMENT FOR NEAR OCCLUSIONS OF THE ICA

- Endarterectomy (CEA)
  - Surgical intervention to remove plaque from an artery
  - Usually the intima and media are removed

- Stent Placement
  - Alternative to CEA in high-risk patients; mesh tube acts as a scaffold to keep the narrowed artery from narrowing

- Follow up U/S are required for both treatments to check for complications

ENDARTERECTOMY

CAROTID STENT

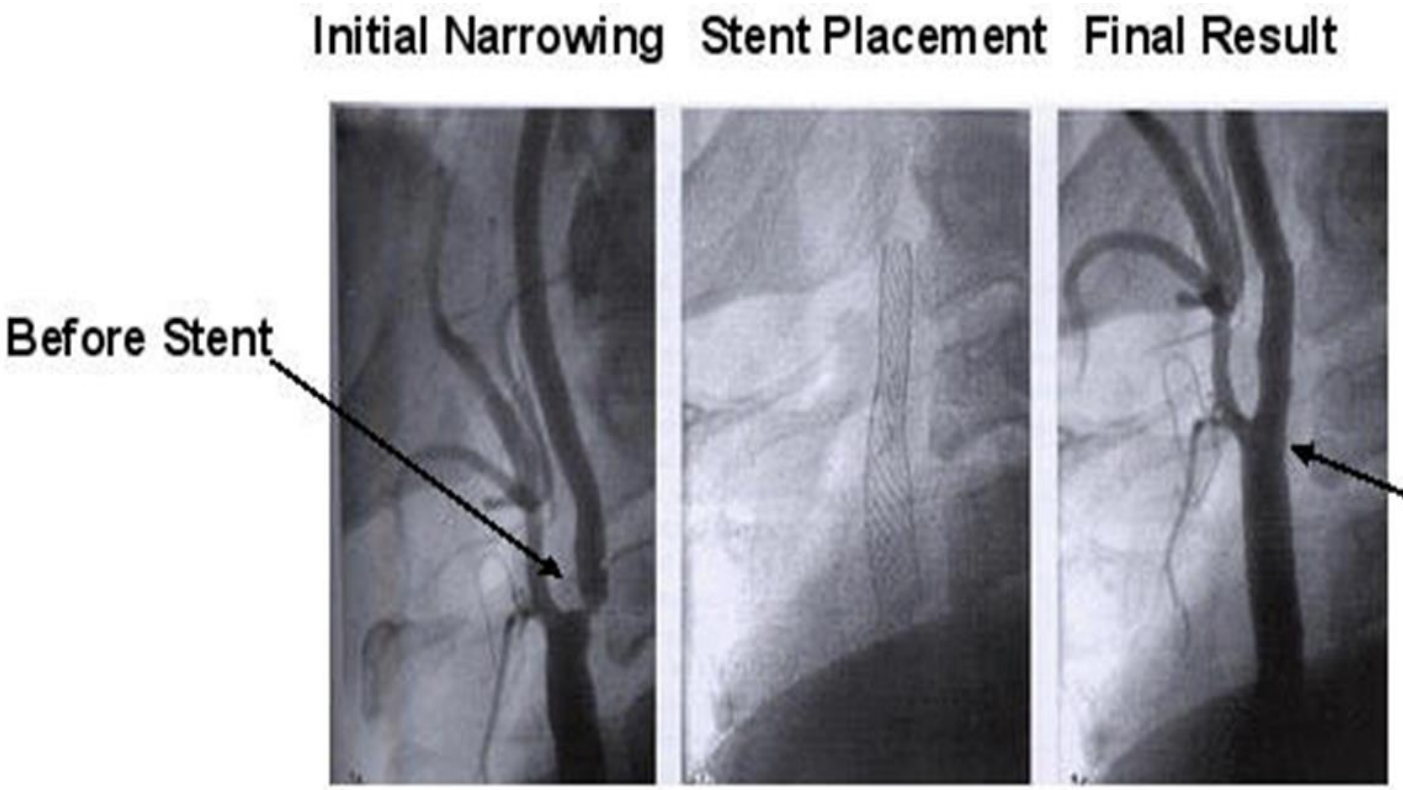
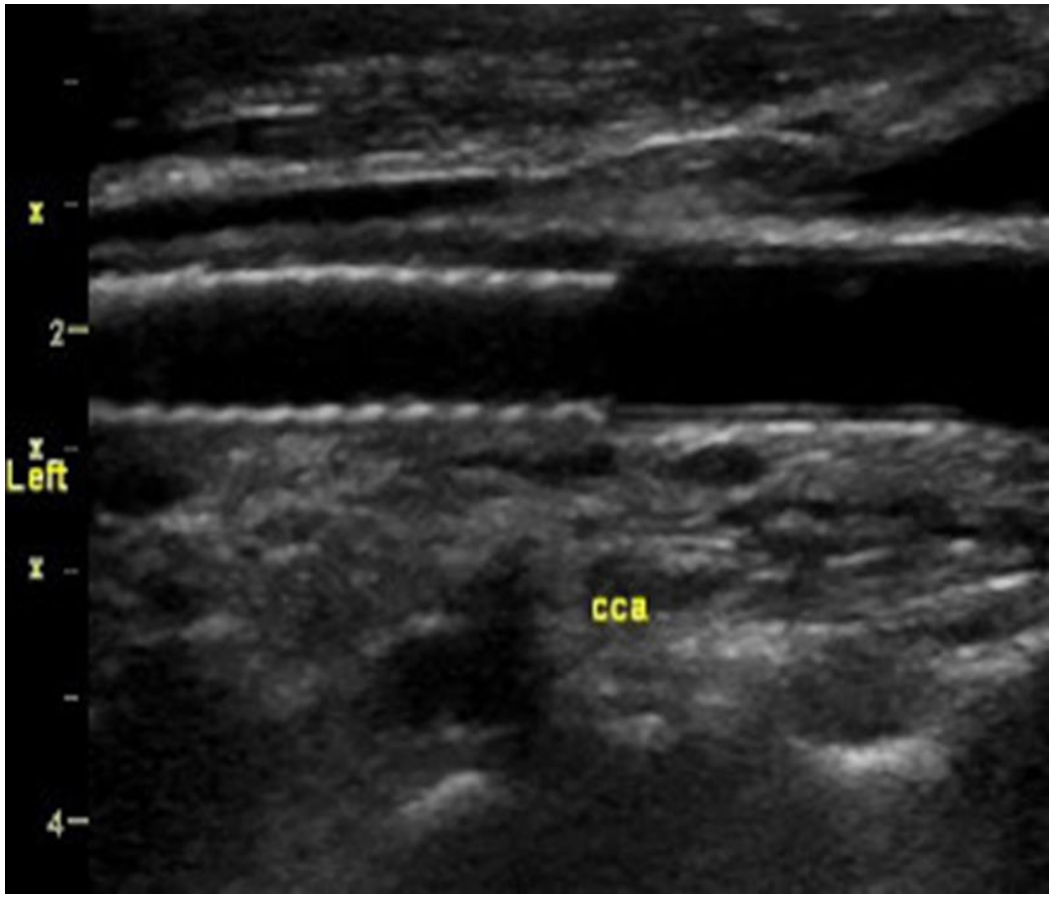


Figure 2 Figure 3 Figure 4



COMPLICATIONS POST-SURGICAL TREATMENTS

- Carotid Endartectomy:
  - Occlusion of the CCA
  - Neointimal hyperplasia
  - Stroke due to embolism during the procedure
- Stent:
  - Poor deployment
  - Stent shift
  - Distal stenosis/re-stenosis of the stent

DOPPLER ARTIFACTS

- Aliasing
  - Seen with low PRF when the velocities exceed the Nyquist limit
  - True velocities are not visible as the waveform is cut off and wraps around the bottom
- Crosstalk
  - Form of mirror imaging
  - Blood flow appears bidirectional in areas of no flow disturbance