Carotid US: More than just a chart on the wall

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DISCLOSURES

- Educational consultant for Philips Healthcare

OBJECTIVES

- Start with the chart
- Always correlate the spectral Doppler findings w/ grayscale and color Doppler appearance PLUS waveform analysis
- Explain any discordance

OBJECTIVES

- Know when the charts don't work
  - High and low output states
  - Tortuous vessels, contralateral stenoses/occlusions
  - Tandem lesions, long segment stenoses, near occlusive lesions
  - Post intervention

SRU 2002 CONSENSUS CONFERENCE
≥ 70% to near occlusive STENOSIS

- PSV > 230 cm/s
- PSVR > 4.0
- EDV > 100 cm/s

Grant, Radiology: 2003

SRU 2002 CONSENSUS CONFERENCE
< 50% STENOSIS

- PSV < 125 cm/s
- PSVR < 2.0
- EDV < 40 cm/s

Grant, Radiology: 2003

SRU 2002 CONSENSUS CONFERENCE
50 - 69% STENOSIS

- PSV 125 - 230 cm/s
- PSVR 2.0 - 4.0

Grant, Radiology: 2003

SYMPTOMATIC PATIENTS
≥ 70% ICA STENOSIS

PSV cm/s	Sens	Spec	Acc
100	100.0	82.8	85.0
125	100.0	87.6	89.2
150	96.1	90.5	91.2
175	96.1	92.5	93.0
200	92.2	95.1	94.7
225	86.3	95.7	94.5
250	70.6	96.8	93.5
275	66.7	97.1	93.2
300	60.8	97.4	92.7
350	41.2	98.6	91.2
400	33.3	99.4	91.0

Grant, Radiology: 1999

SYMPTOMATIC PATIENTS
≥ 70% ICA STENOSIS

PSVR	Sens	Spec	Acc
1.50	100.0	83.9	86.0
2.00	100.0	88.5	90.0
2.50	100.0	91.7	92.7
2.75	92.2	93.4	93.2
3.00	90.2	94.5	94.0
3.25	86.3	94.8	93.7
3.50	84.3	94.8	93.5
3.75	76.5	95.7	93.2
4.00	76.5	95.7	93.2
4.50	62.7	96.8	92.5
5.00	54.9	97.7	92.2

Grant, Radiology: 1999

DOPPLER CRITERIA

- Validated only for ICA
- Range of absolute numbers and ratios for any given % stenosis
  - laboratory dependent
- Can not accurately differentiate carotid stenoses @ 10% increments
- Tend to overestimate carotid stenoses

Sabeti, Radiology: 2004

DOPPLER CRITERIA

- More accurate for detecting high grade stenoses (70-99%)
- Less accurate for low grade stenoses (< 50%)

Sabeti, Radiology: 2004

DOPPLER CRITERIA

- If you plan to use US as a screening test
  - criteria should emphasize high sensitivity
  - lower discriminatory numbers
- As a diagnostic test, i.e., instead of angiogram
  - criteria should emphasize high specificity
  - higher discriminatory numbers

DOPPLER CRITERIA

- In high risk pt, perhaps criteria should emphasize high sensitivity
  - lower discriminatory numbers
  - avoid false negatives (F-)
- For low risk pt, criteria should emphasize high specificity
  - higher discriminatory numbers
  - avoid false positives (F+)

DOPPLER CRITERIA

- SRU consensus criteria focused on maximizing **ACCURACY**
- What about outcome analysis?
- The consequences of a missing a stenosis (F-) may be more or less favorable than the consequences of performing unnecessary intervention (F+), depending upon the clinical situation

Heijenbrok-Kal, Radiology: 2005

- Premise #1: referring a pt for CEA with a non-significant ICA stenosis < 50% is more harmful than missing a 50-69% stenosis
  - F+ more harmful than F-
  - therefore, criteria should be more specific in this category
  - higher discriminatory numbers

Heijenbrok-Kal, Radiology: 2005

- Premise #2: missing a ≥ 70% ICA stenosis is more harmful (assoc with higher monetary and life expectancy cost) than operating on a 50-69% ICA stenosis
  - F- more harmful than F+
  - therefore, criteria in this category should be more sensitive
  - lower discriminatory numbers

Heijenbrok-Kal, Radiology: 2005

- ≥ 70% stenosis, use PSV > 220 cm/s
- 50-69% stenosis, use PSV > 180 cm/s
- However, with changes in pt management, these assumptions are undergoing revision

2017: TIMES ARE CHANGING

- Crest Trial
  - pts w/ moderate stenoses do better with medical management
- Stent reimbursement
  - only if >70% stenosis or enrolled in trial
- May want more specificity for >70% stenosis
  - higher threshold numbers

DOPPLER CRITERIA

- Whatever criteria you choose,
  - the closer you are to the discriminatory value, the more likely you are to be wrong
  - the farther away you are from the discriminatory value, the more likely you are to be right
  - dependent on SD of measurement
  - ***F+ vs F-*** dependent on sens vs. spec of the cut off value
- Consider correlative imaging if close to discriminatory thresholds

WHICH CRITERIA IS BEST?

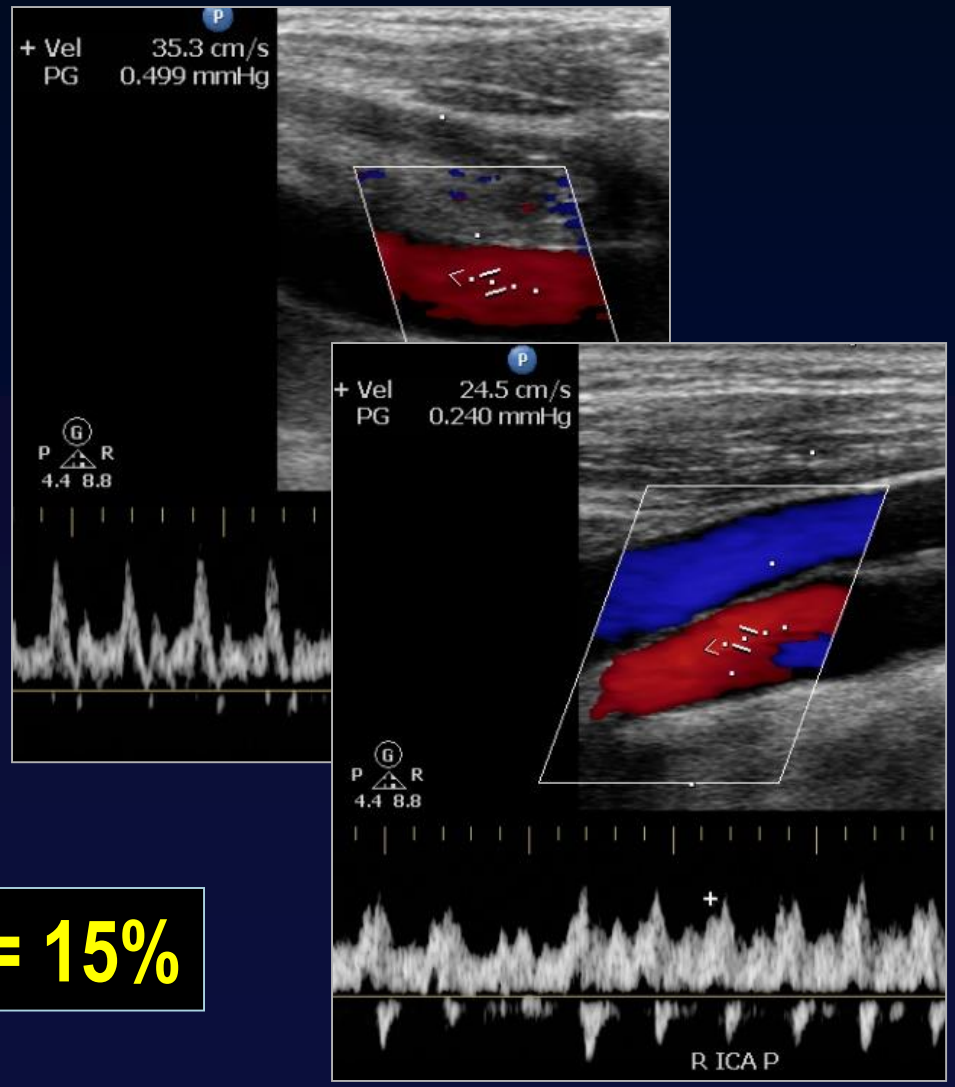
- PSV = primary Doppler criteria, BUT…..
- If PSV in CCA is > 100 cm/s or < 60 cm/s
  - PSV likely not as accurate
  - emphasize PSVR, grayscale and color Doppler imaging

PSV < 60 cm/s

- Low output states
  - ↓ ejection fraction
    - cardiomyopathies, LV dysfunction, LV aneurysm, AS
  - hypotension
  - thoracic aortic aneurysm

PSV < 60 cm/s: Low Cardiac Output

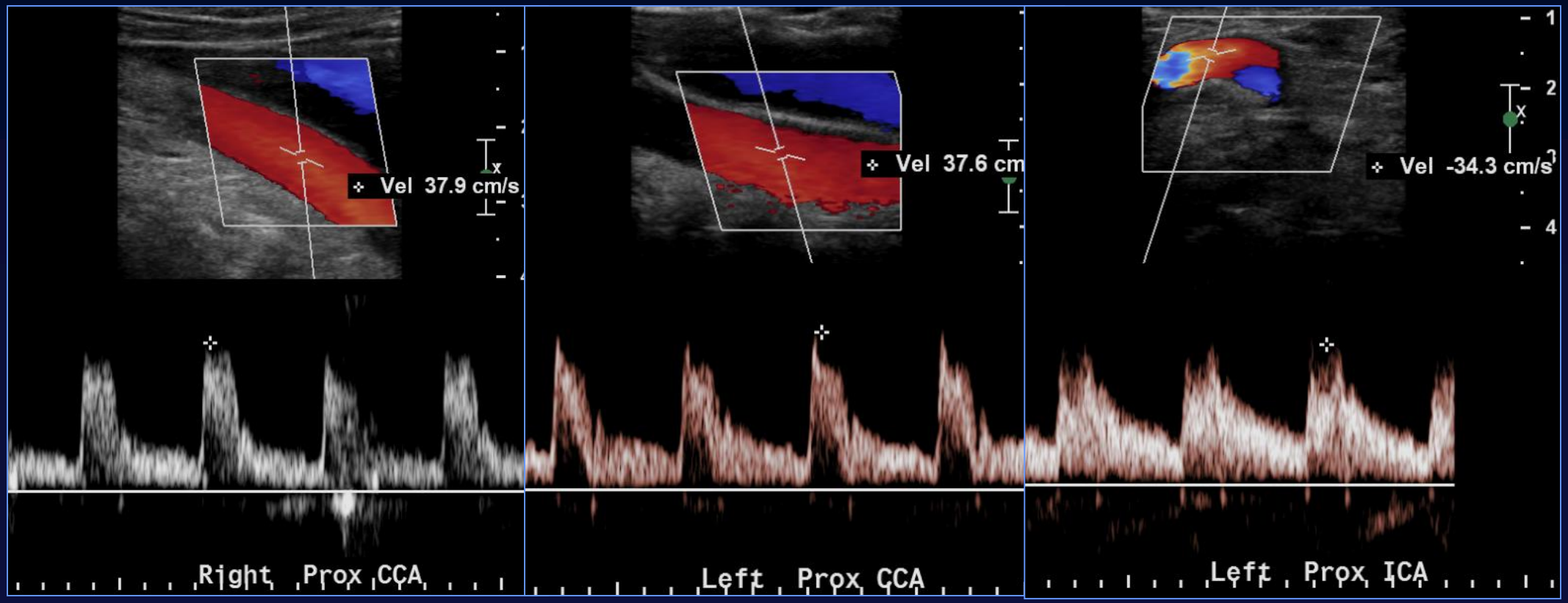
- PSV in CCA = 35 cm/s
- When ICA PSV reaches 230 cm/s, PSVR will be > 6.5
- Relying on PSV will result in underestimation of ICA stenosis



EF = 15%

DECREASED PSV

- Pre-op for ascending thoracic aortic aneurysm



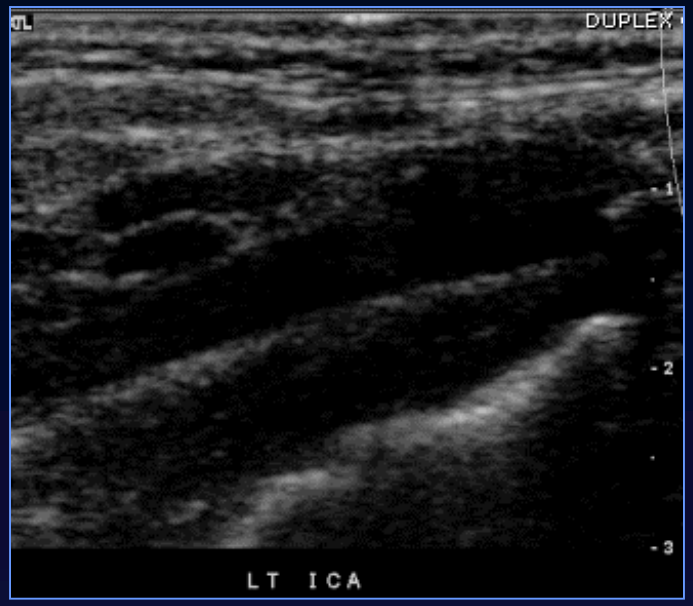
PSV > 100 cm/s

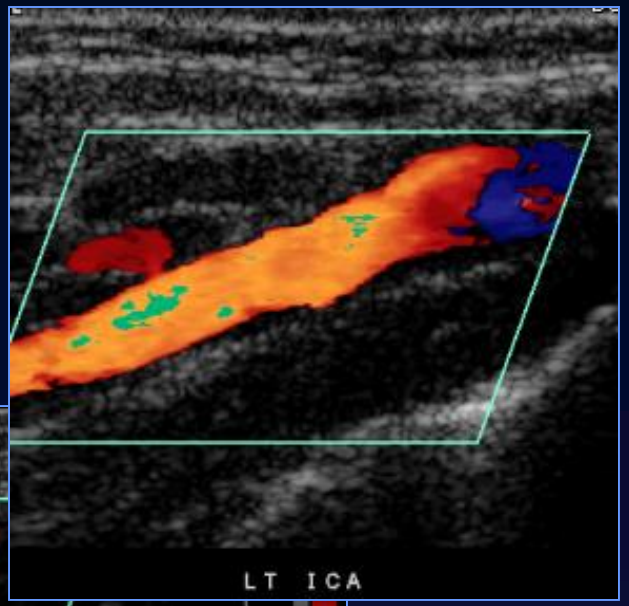
- High output states
  - hypertension
  - hyperdynamic state
  - aortic regurgitation
  - thyrotoxicosis

PSV > 100 cm/s: High Cardiac Output

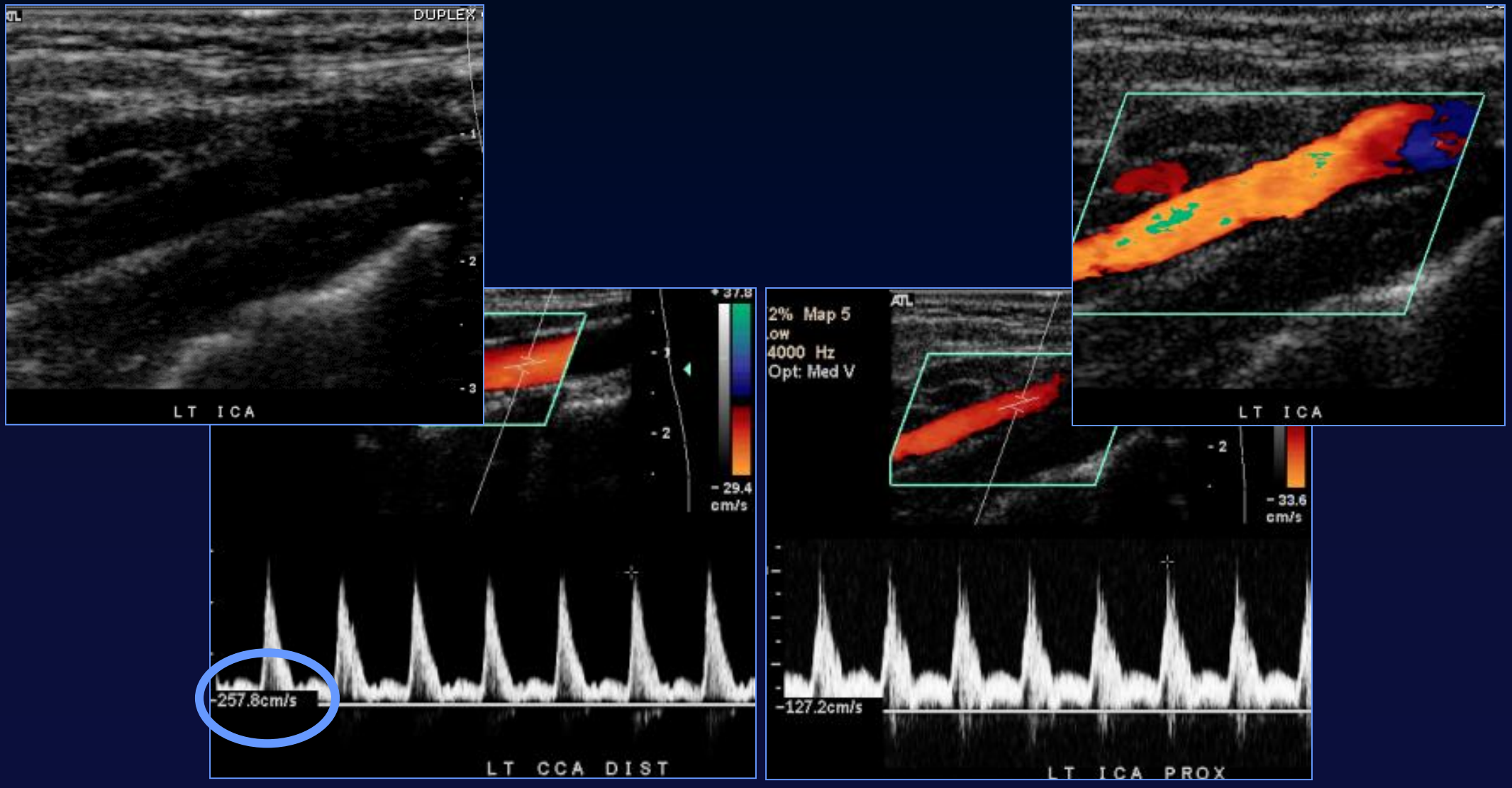
- PSV will overestimate % stenosis

Is this a 50% Stenosis?



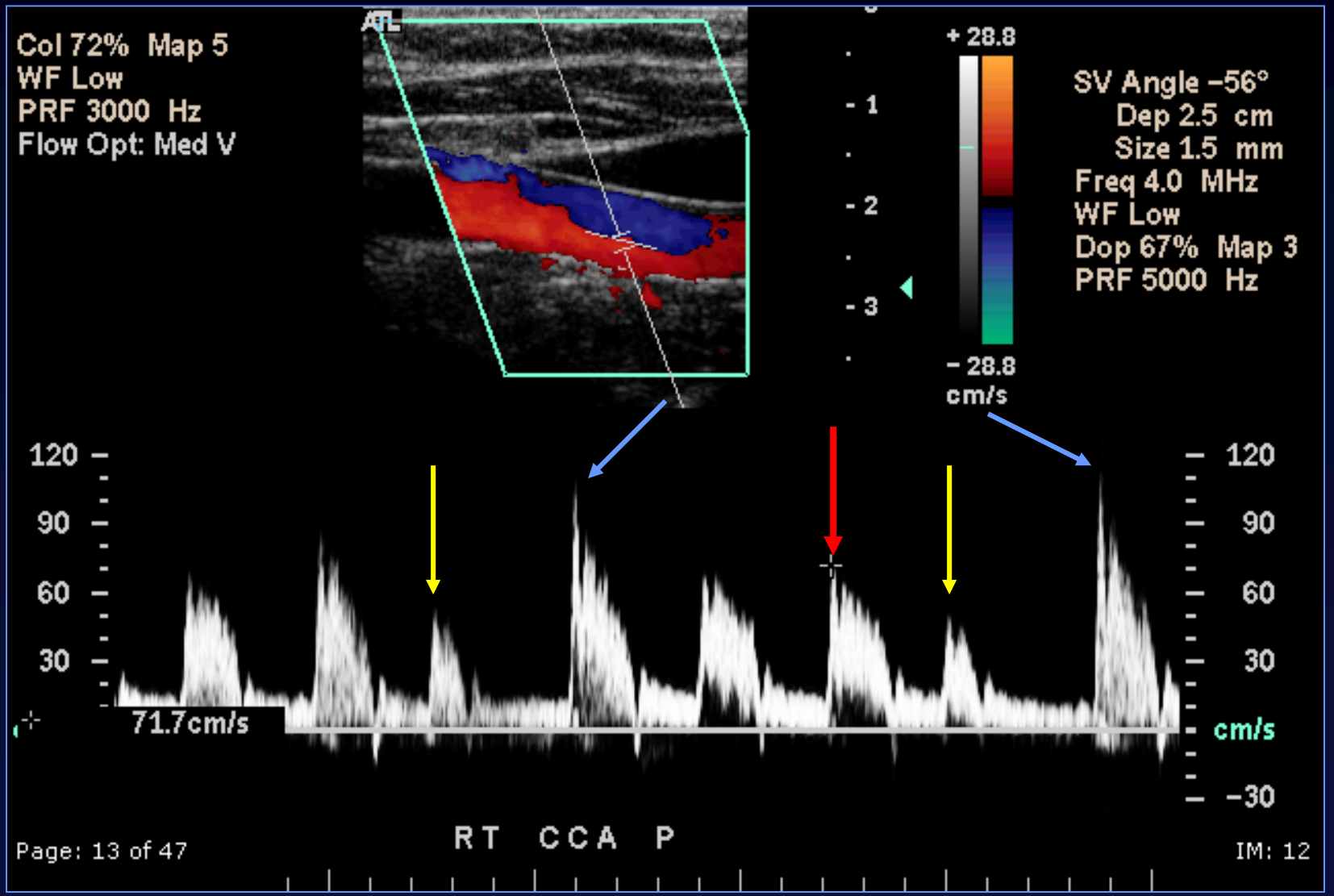


PSVR = 1:2, NO STENOSIS!



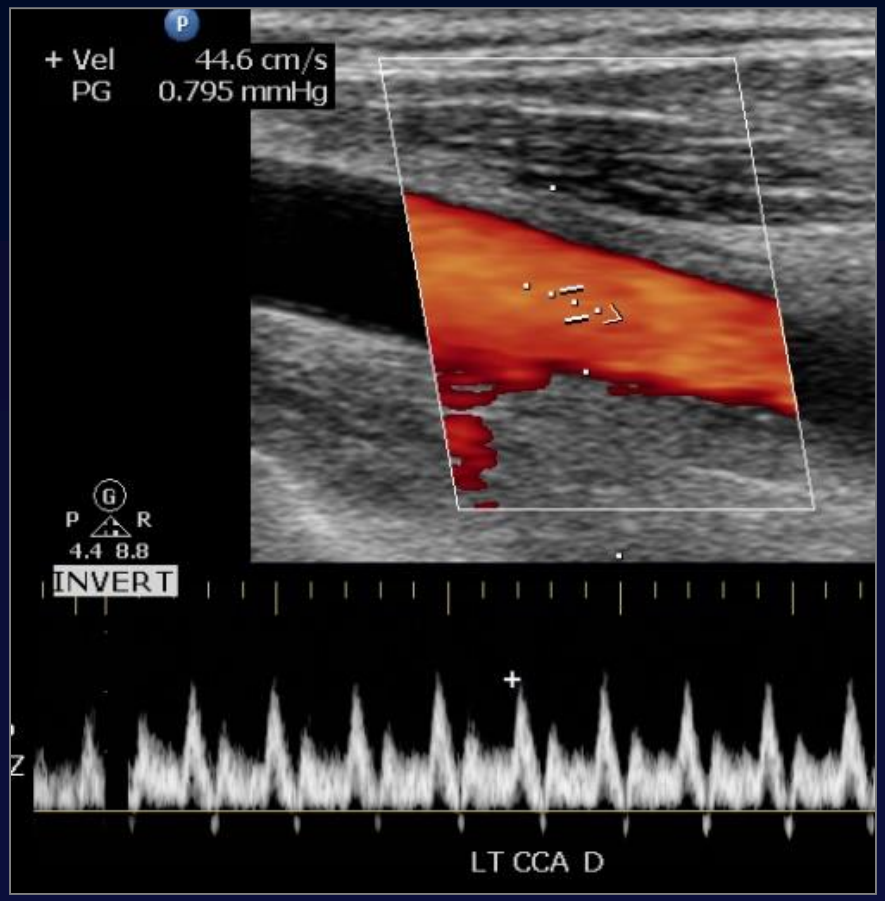
PITFALLS: Cardiac Arrhythmia

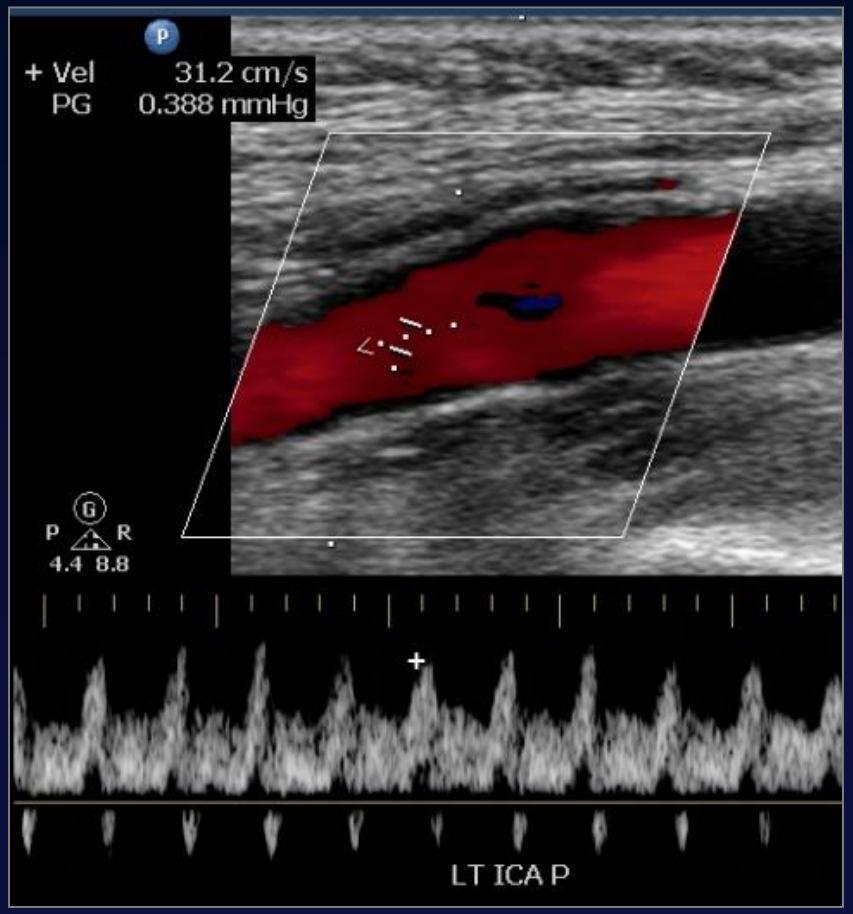
- ↑ HR results in ↓ PSV, ↑ EDV
- ↓ HR results in ↑ PSV, ↓ EDV


Col 72% Map 5
WF Low
PRF 3000 Hz
Flow Opt: Med V
ATL
+ 28.8
- 28.8
cm/s
SV Angle -56°
Dep 2.5 cm
Size 1.5 mm
Freq 4.0 MHz
WF Low
Dop 67% Map 3
PRF 5000 Hz
120
90
60
30
71.7cm/s
cm/s
-30
RT CCA P
Page: 13 of 47
IM: 12

PITFALLS: Tachycardia

- Underestimates PSV



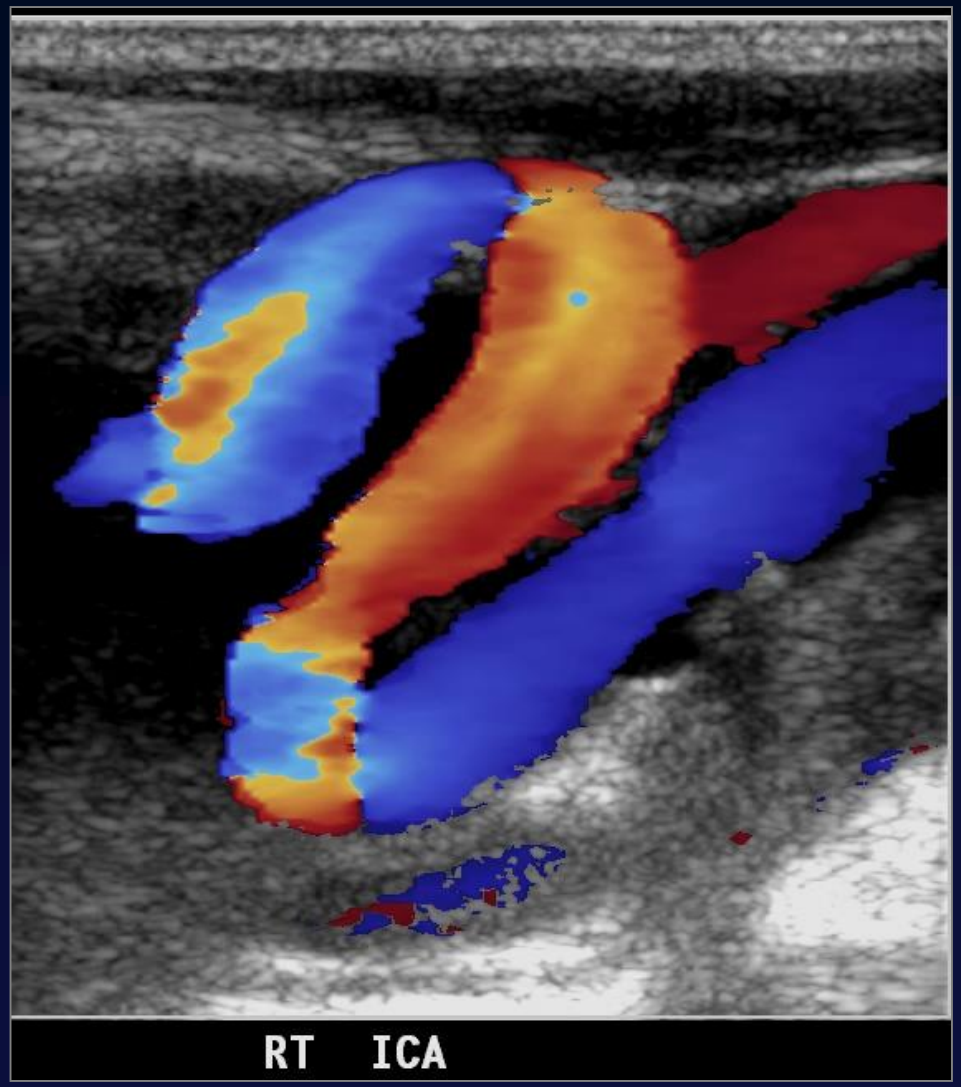


DISCORDANCE BETWEEN GRAYSCALE AND DOPPLER FINDINGS

- PSV elevated
- Unilateral
- But no plaque!
  - tortuous vessel
  - contralateral occlusion/stenosis

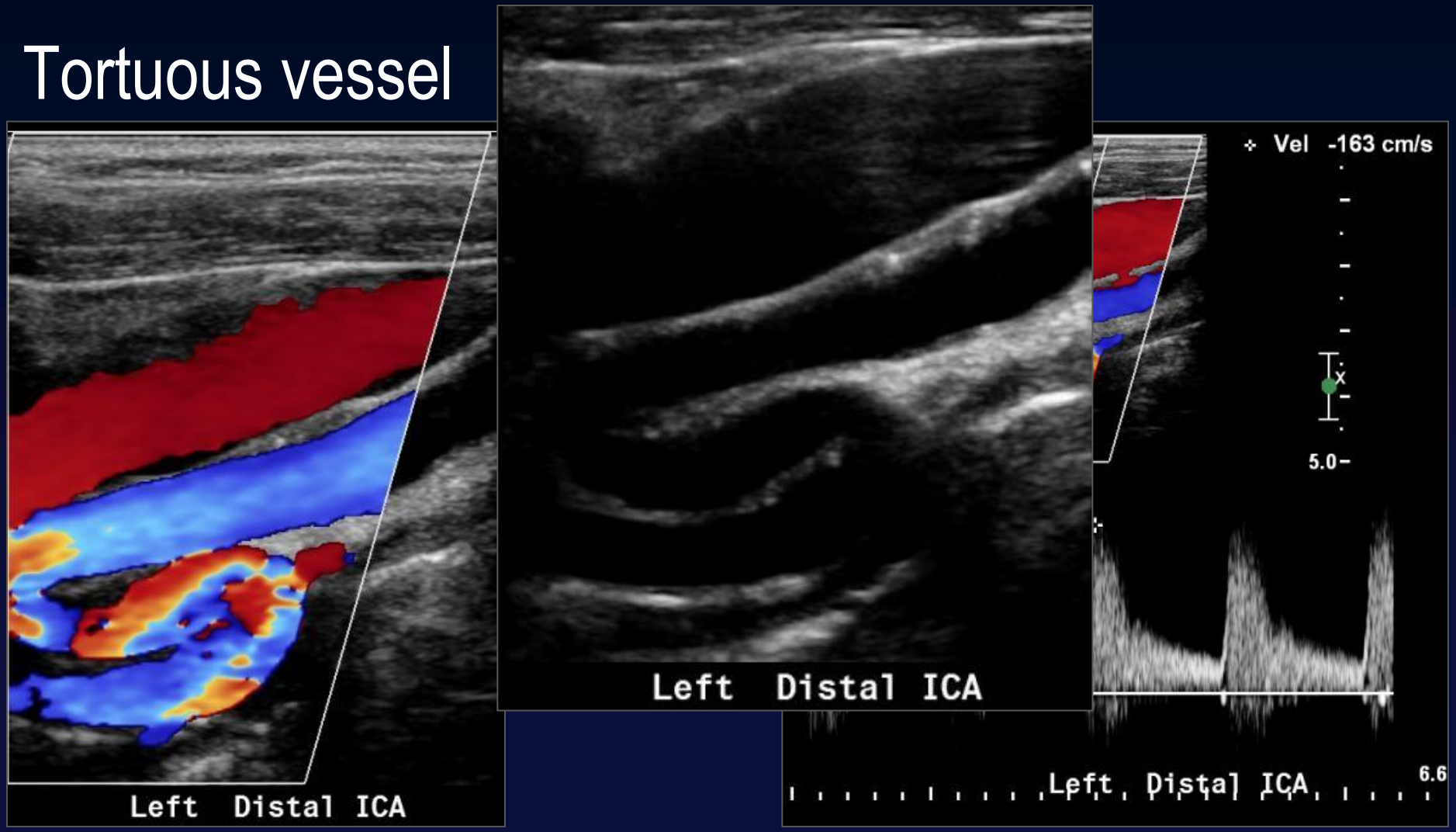
TORTUOUS VESSELS

- Velocity increases around a curve
- Difficult to assign correct Doppler angle as direction of blood flow changes rapidly

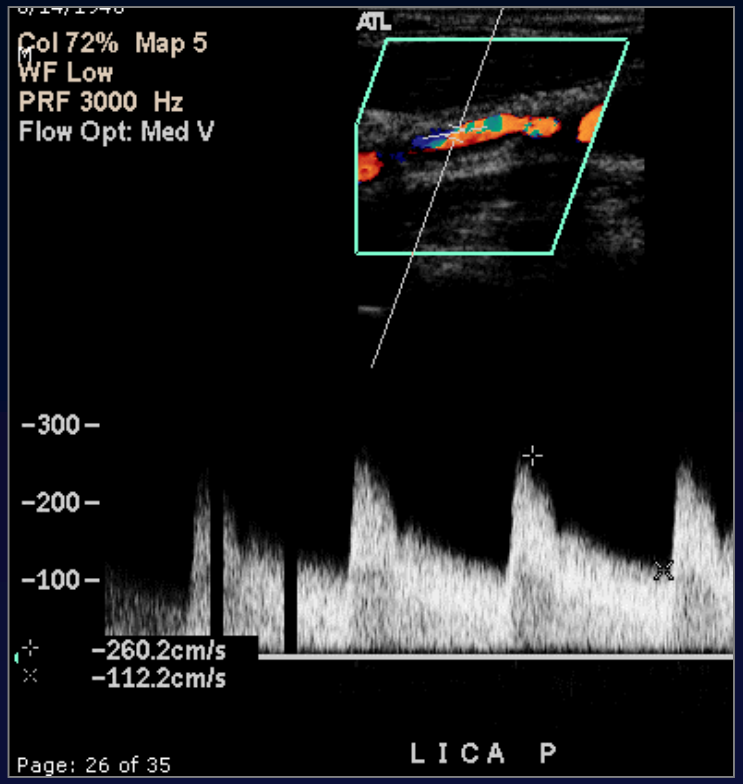


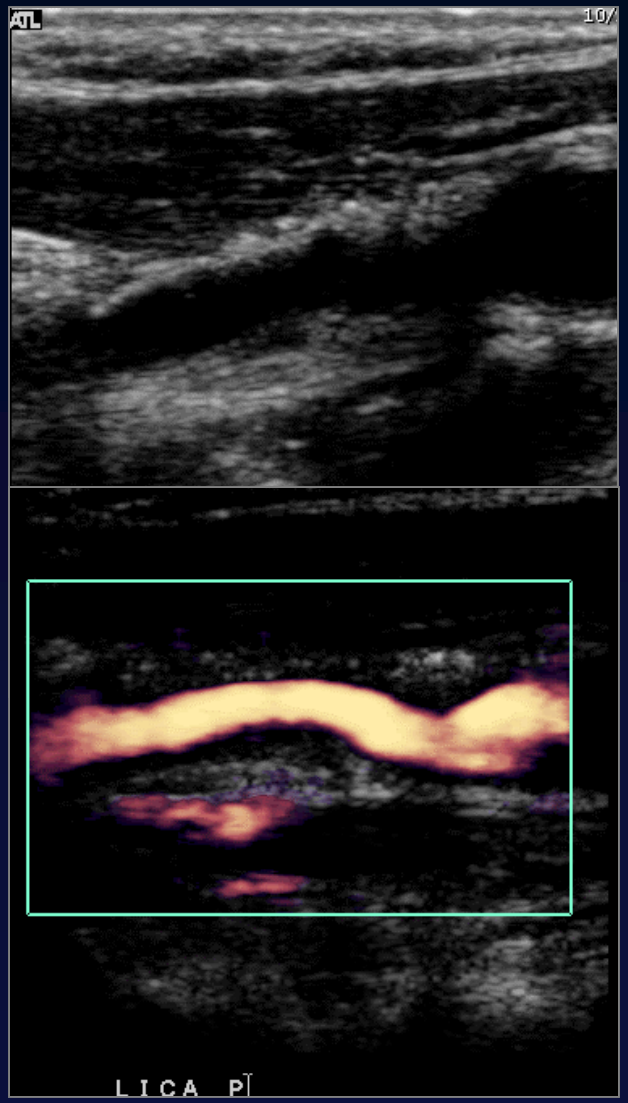
INCREASED PSV & NO PLAQUE

- Tortuous vessel



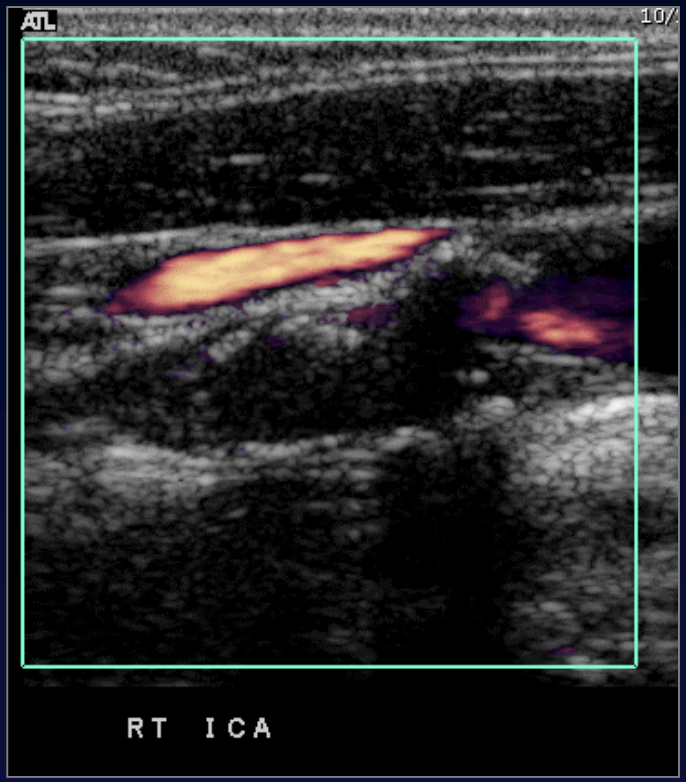
INCREASED PSV & NO PLAQUE

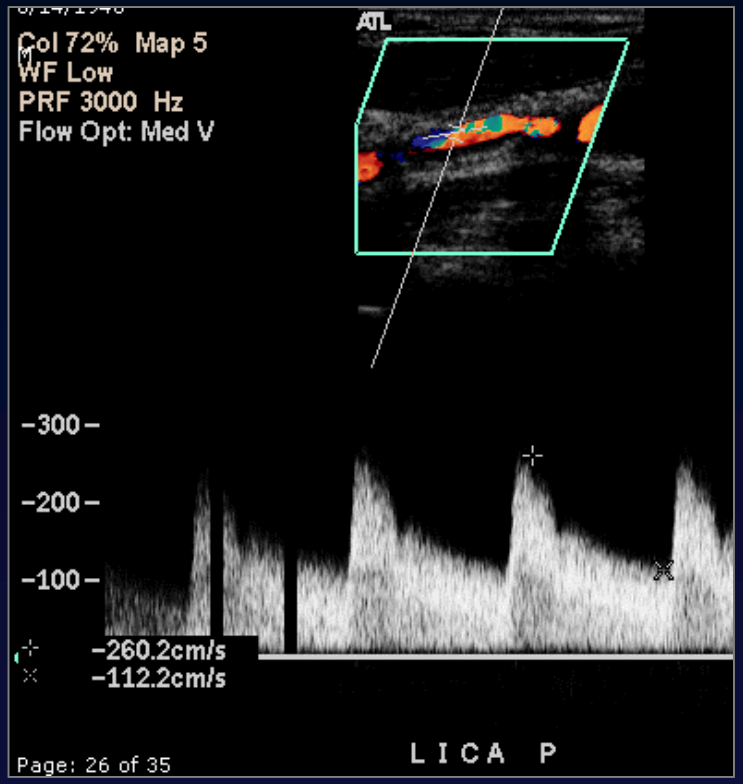


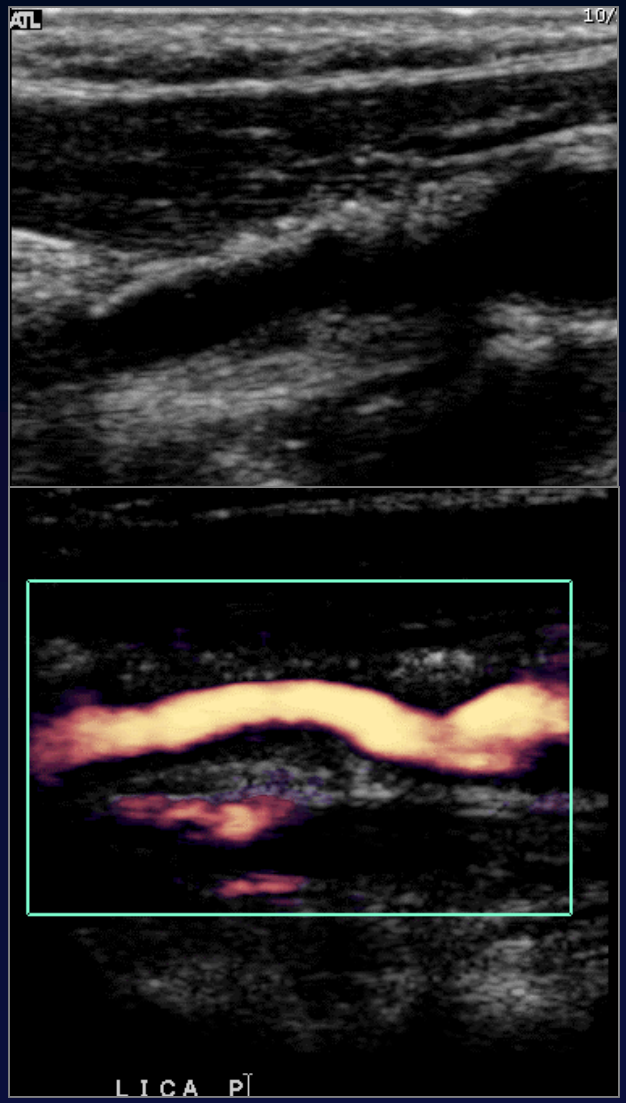


PSV = 260 cm/s
? 70-95% stenosis

CONTRALATERAL HI-GRADE STENOSIS/OCCLUSION







PSV = 260 cm/s
50% stenosis at most

CONTRALATERAL HI-GRADE STENOSIS/OCCLUSION

- ↑ PSV in CCA and ICA, esp at a stenosis
- Variable, unpredictable
- Use of PSVR may not compensate, but probably better than using PSV alone

Beckett, AJNR: 1990

AbuRahma, J Vasc Surg: 1995

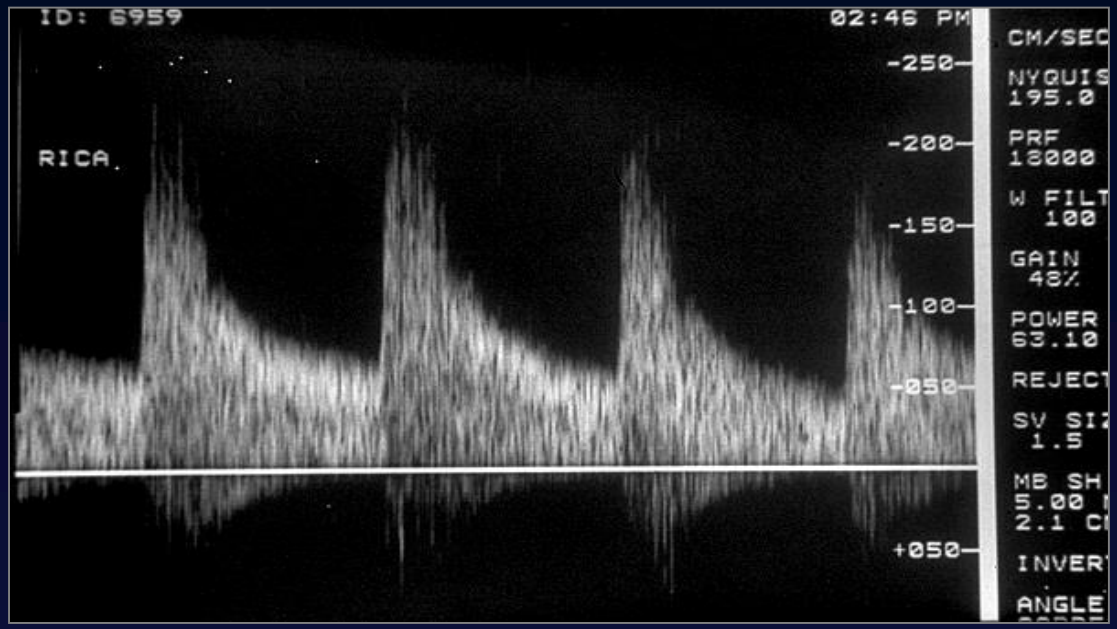
Busuttil, Am J Surg: 1996

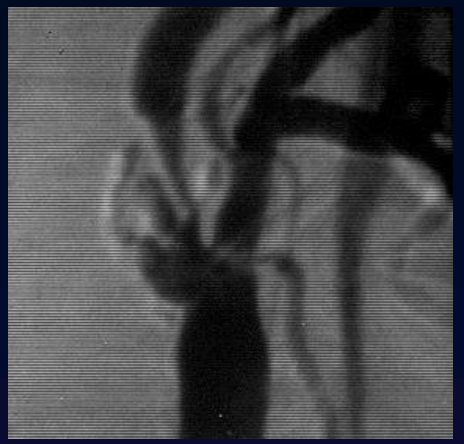
Grajo & Barr, US Quarterly: 2007

DISCORDANCE BETWEEN GRAYSCALE AND DOPPLER FINDINGS

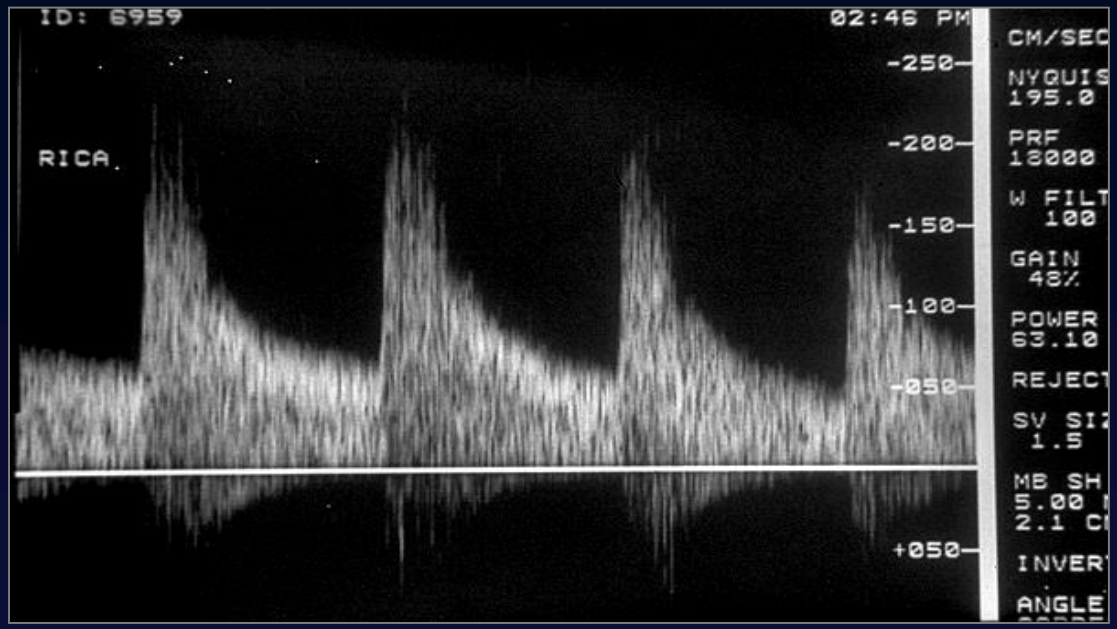
- Plaque – LOTS!
- But velocity not as elevated as one would expect
  - tandem lesions
  - long segment stenosis
  - > 95% stenosis

LOTS OF PLAQUE; PSV NOT SO ELEVATED



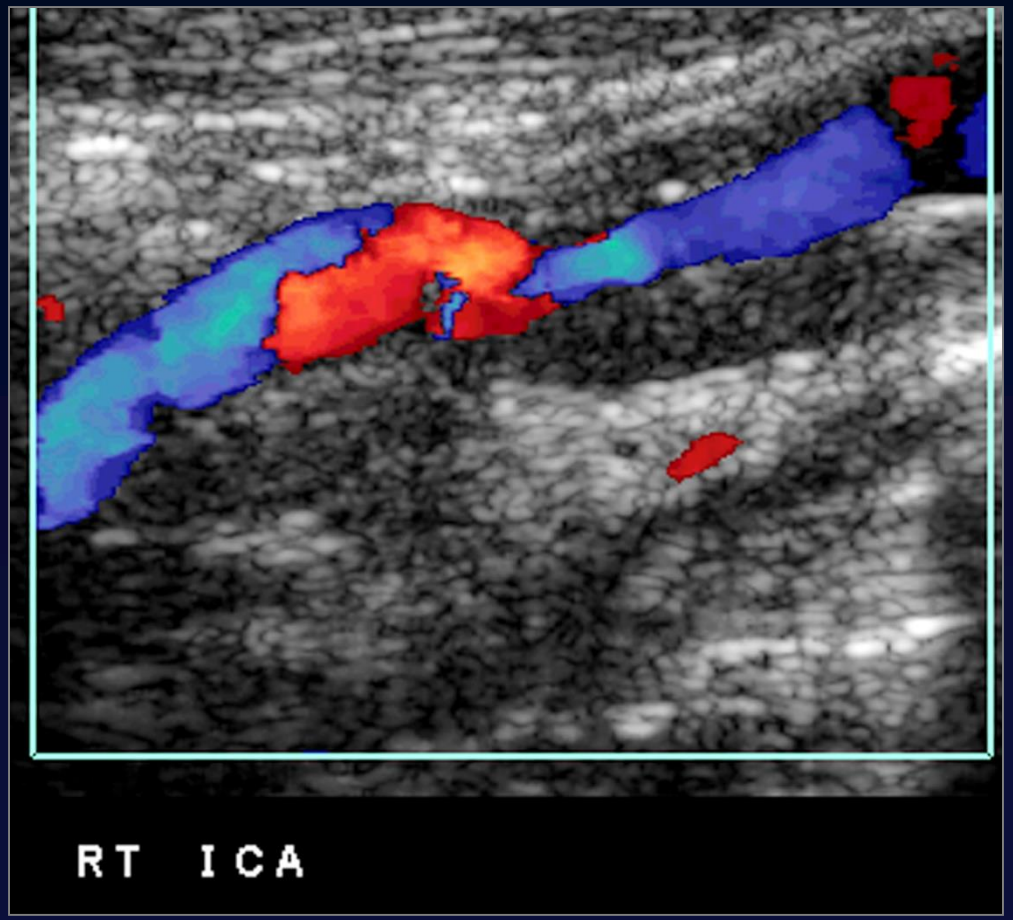


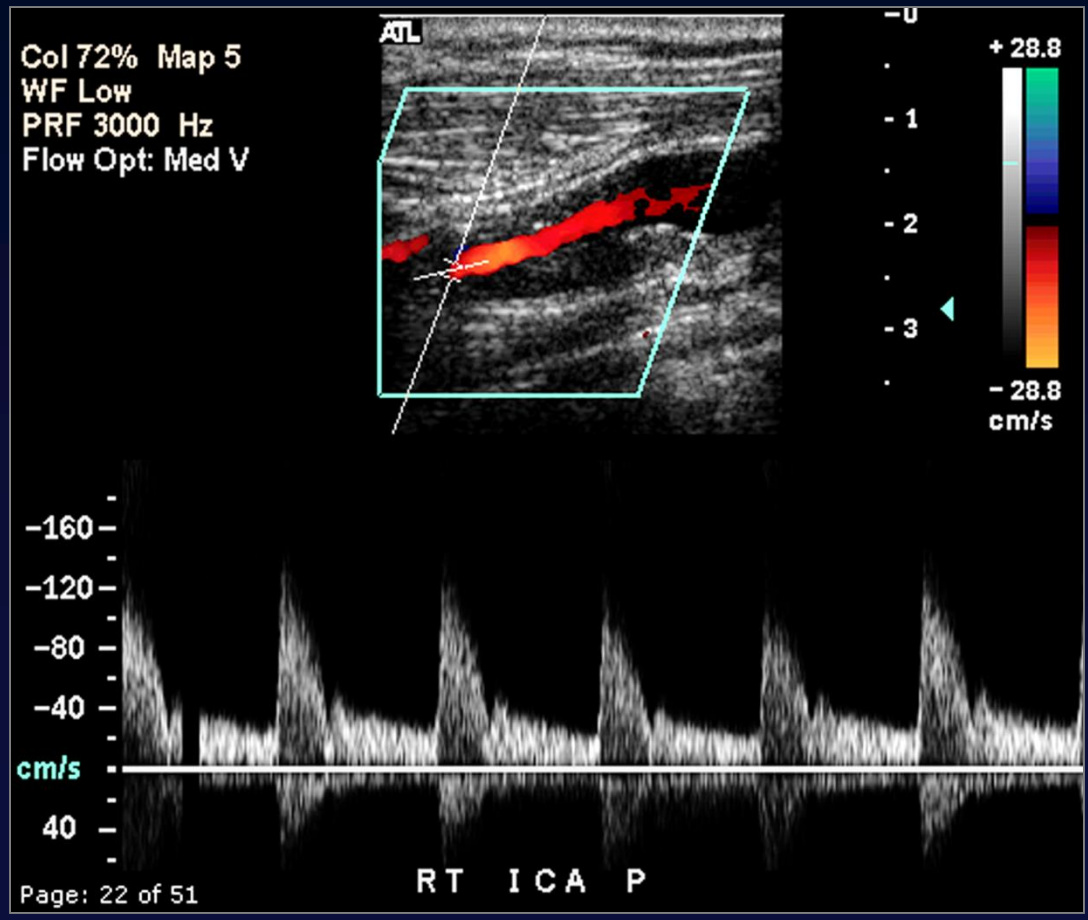
TANDEM LESIONS



- PSV < expected for a given % stenosis

LOTS OF PLAQUE; PSV NOT SO ELEVATED



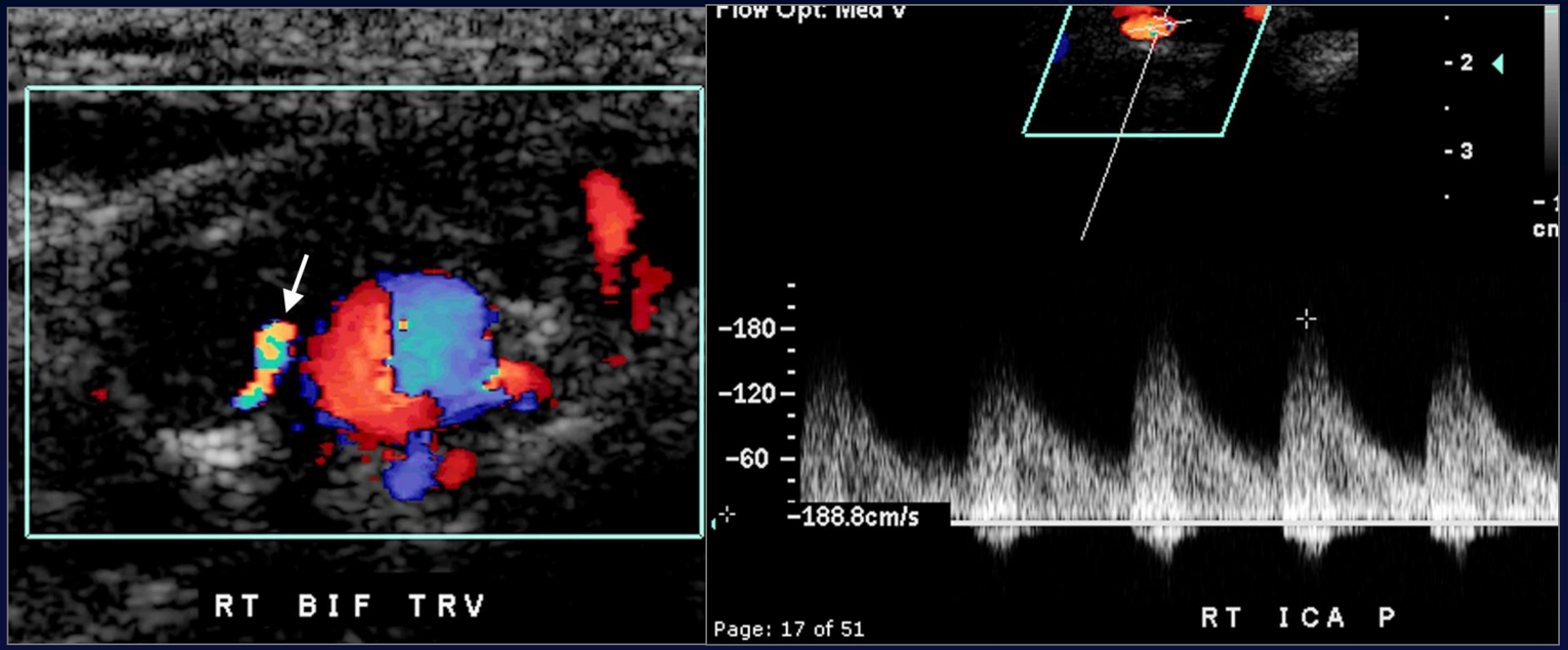


LONG SEGMENT STENOSIS

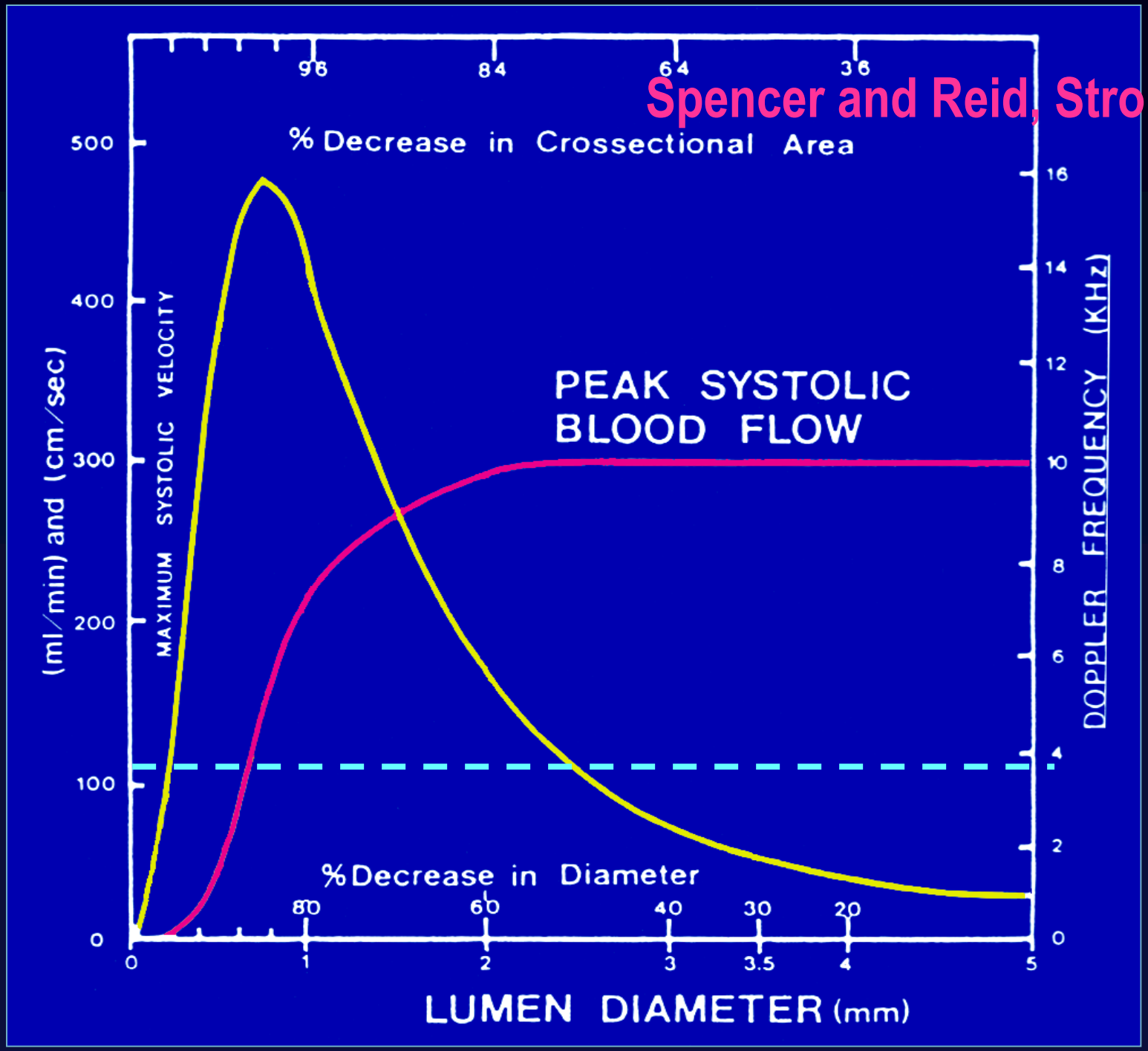
- Most atherosclerotic plaques ~ 1 cm in length
- Doppler parameters derived from pts with short segment plaque
- If plaque extends over more than 2 cm
  - PSV will ↓
  - diastolic velocity usu remains high
- Likely due to increased in-flow resistance
  - resistance is proportional to length of stenosis

LOTS OF PLAQUE; PSV NOT SO ELEVATED

- Tight (> 95%) stenosis



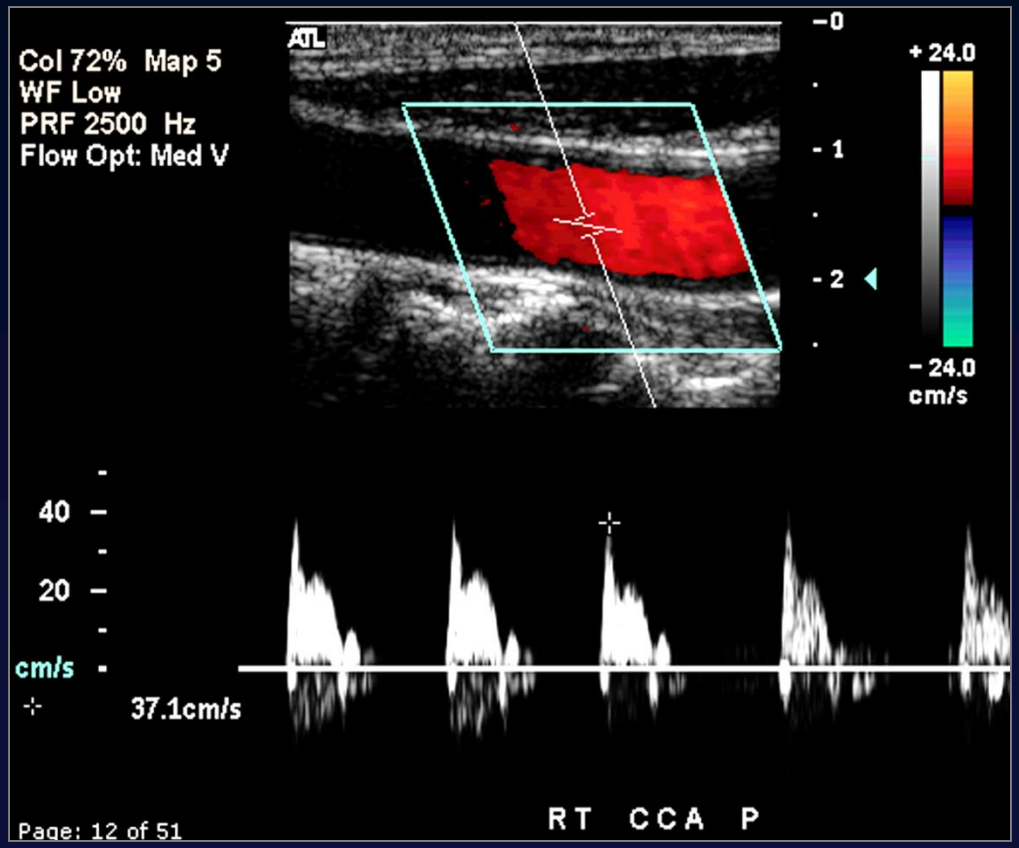
Spencer and Reid, Stroke: 1979



CLUES TO A TIGHT STENOSIS

- ↓ diameter of lumen on grayscale and/or color images
- "Knocking" or "Staccato" waveform proximally
  - ↓ PSV
  - reversed, absent or decrease diastolic flow
  - high resistance waveform
- Tardus parvus waveform distally
  - you should always sample as distally as possible in the ICA

TIGHT STENOSIS

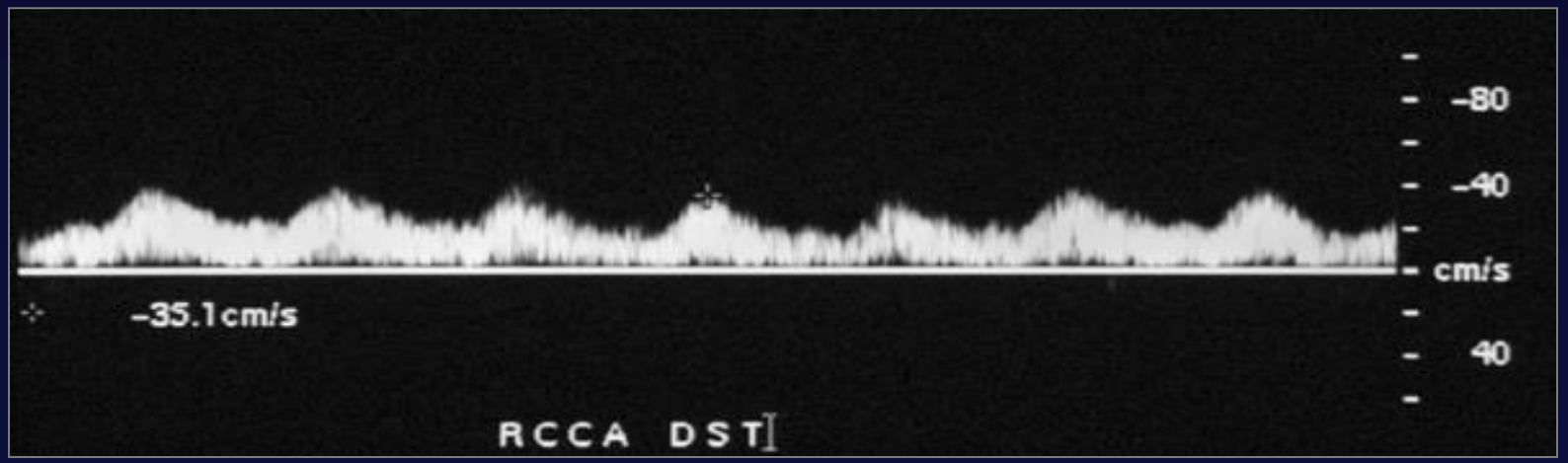


Proximal CCA

Distal ICA

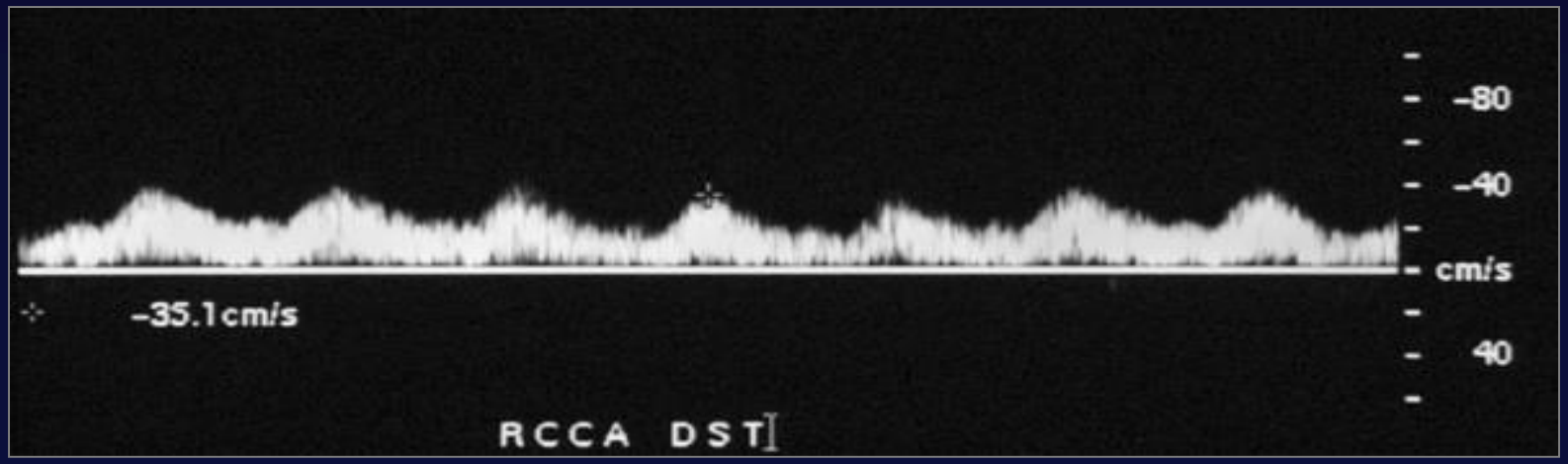
TARDUS PARVUS WAVEFORM

- Delayed systolic upstroke
- Decreased PSV
- Rounded systolic peak



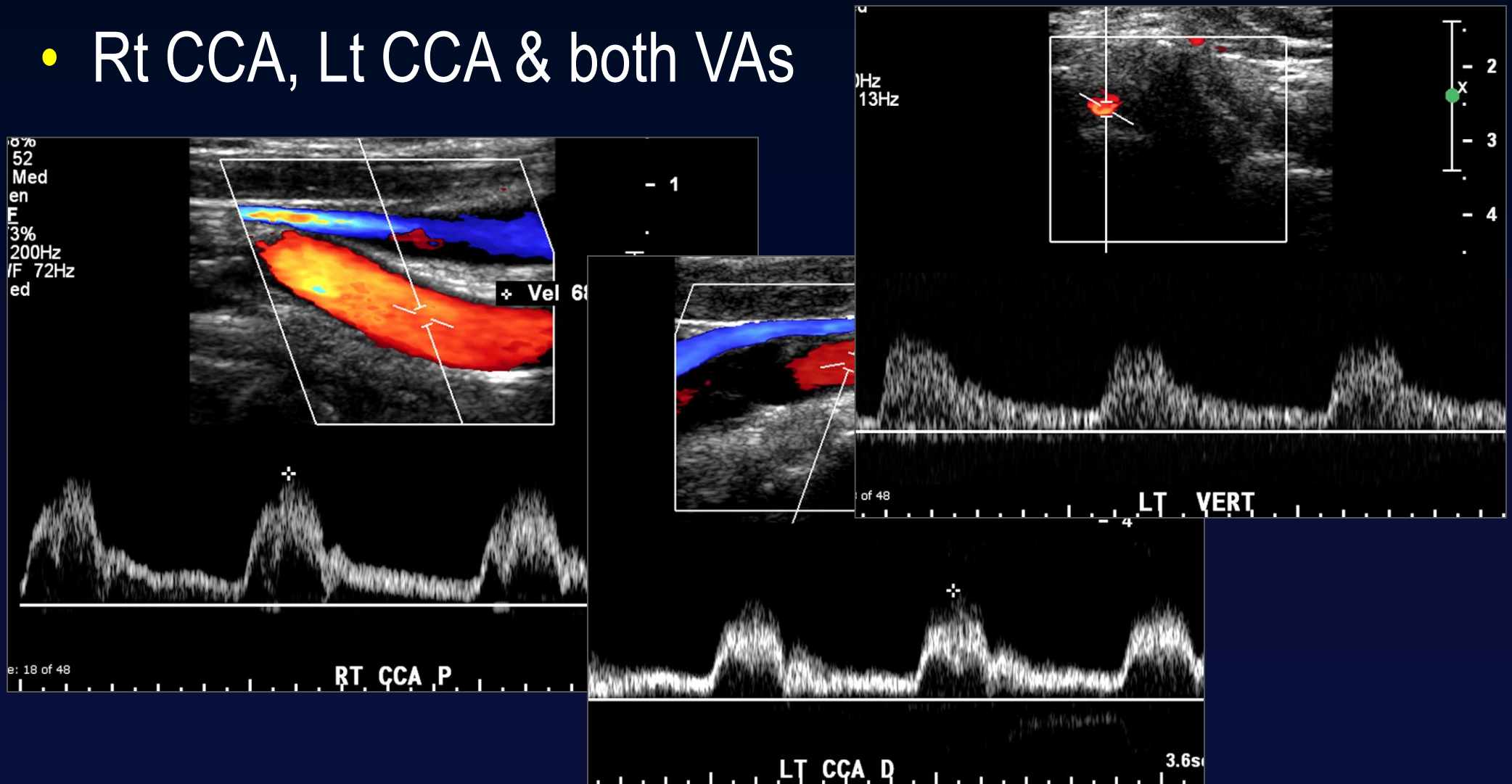
TARDUS PARVUS WAVEFORM

- Occurs distal to a high grade stenosis
- The more distal to the stenosis, the more pronounced
- Pattern of distribution can help localize stenosis



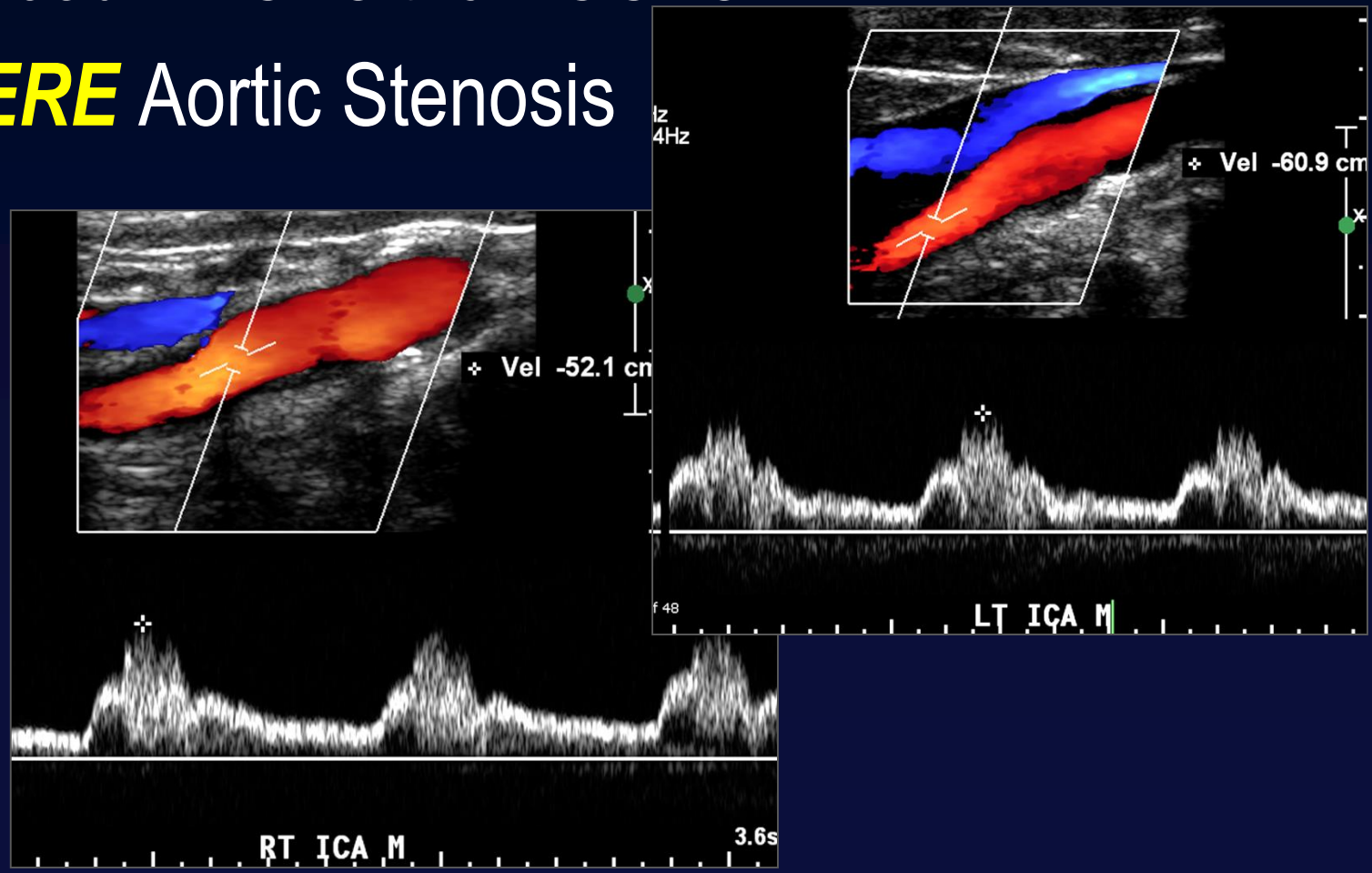
TARDUS PARVUS WAVEFORM

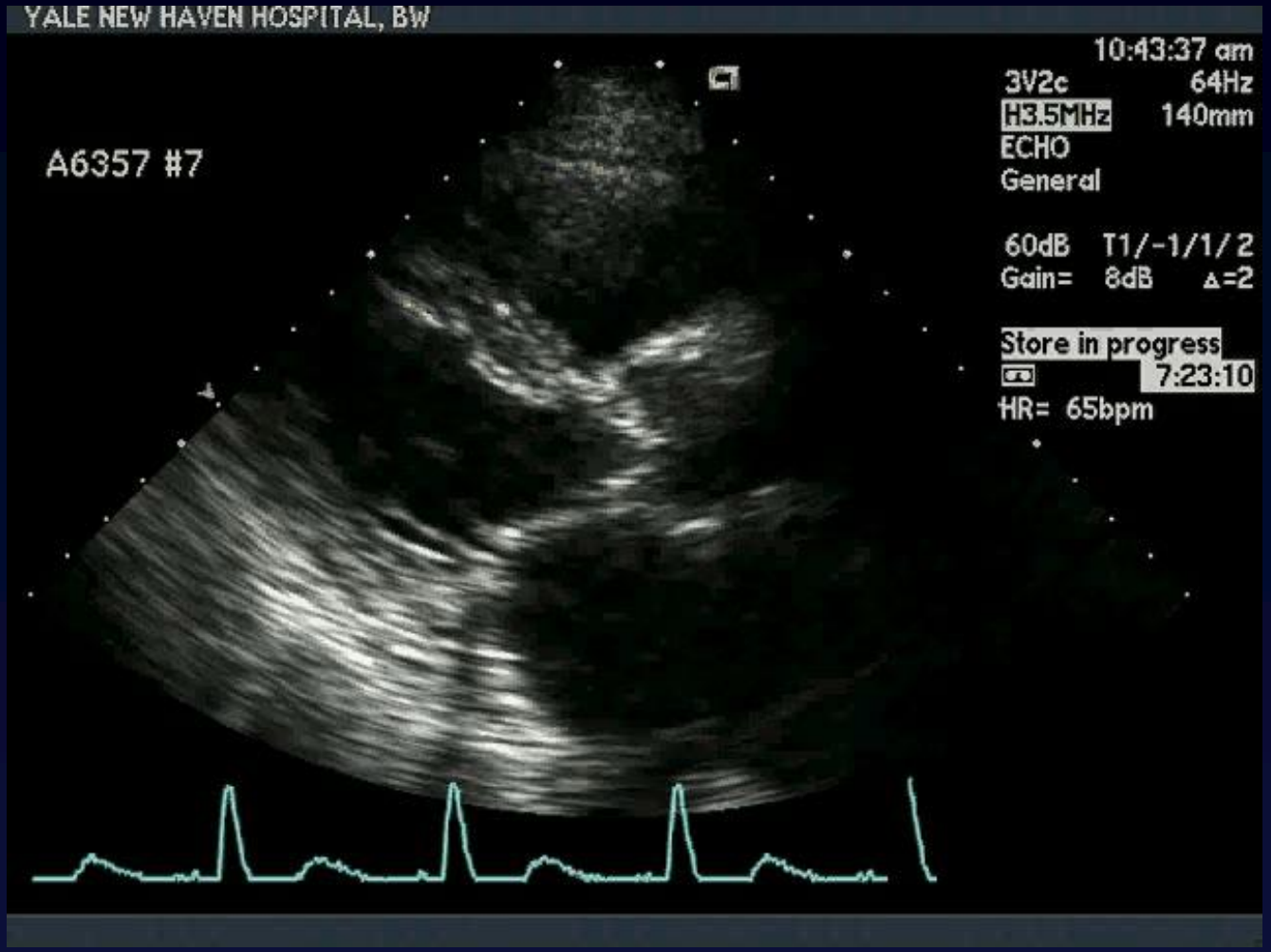
- Rt CCA, Lt CCA & both VAs



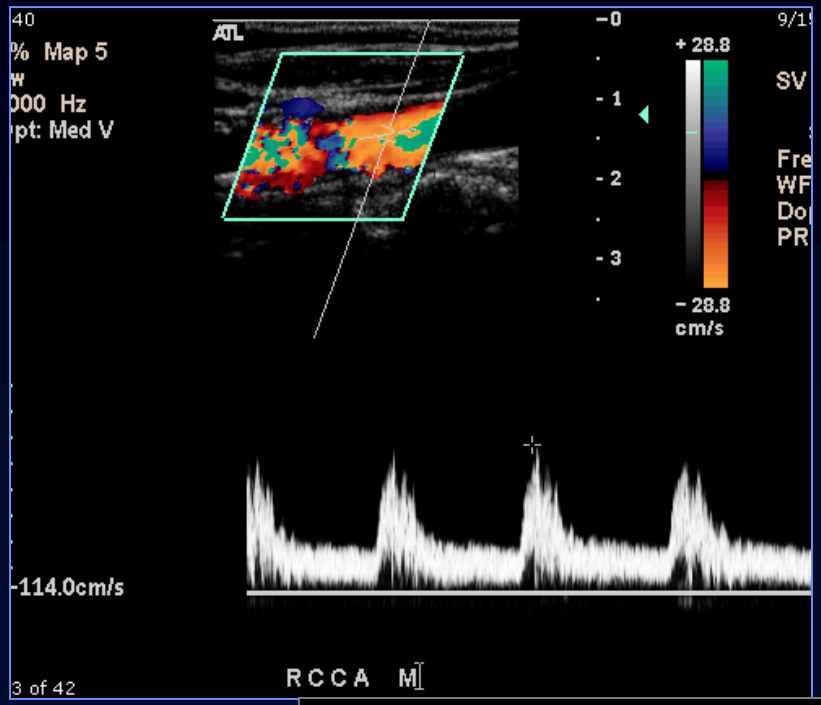
TARDUS PARVUS WAVEFORM

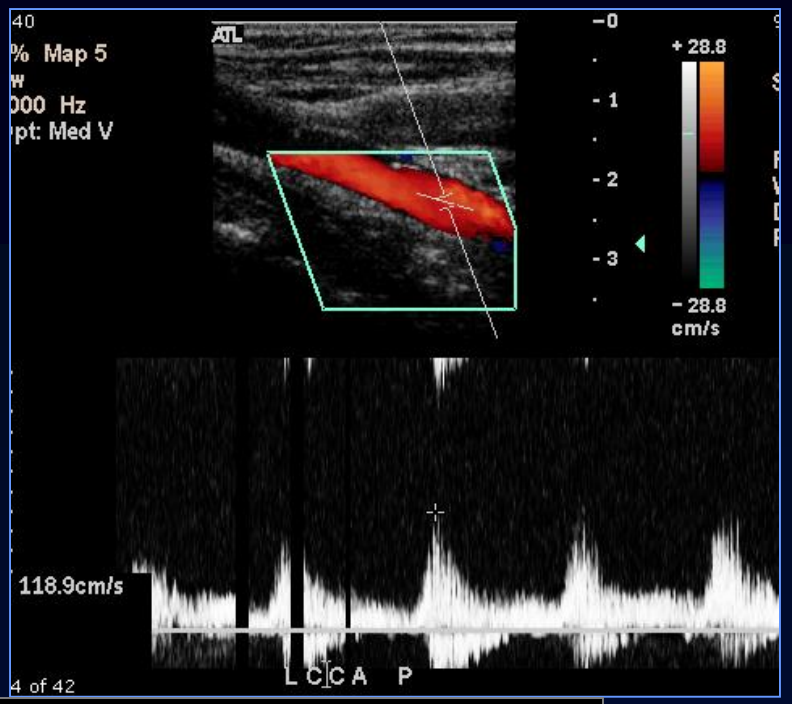
- More pronounced in ICAs than CCAs
- Seen in ***SEVERE*** Aortic Stenosis
- Note: ↓ PSV



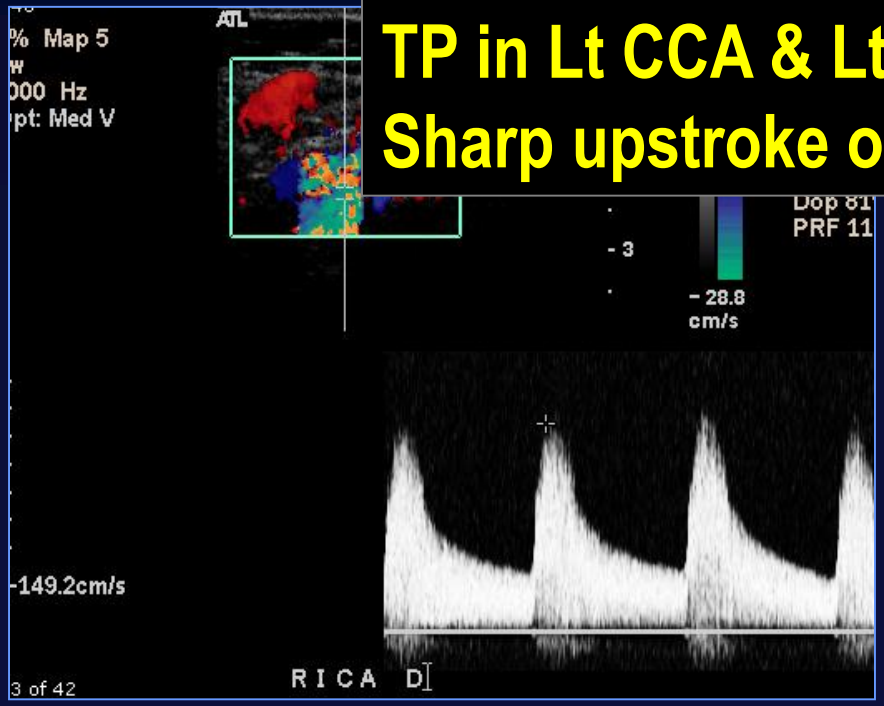


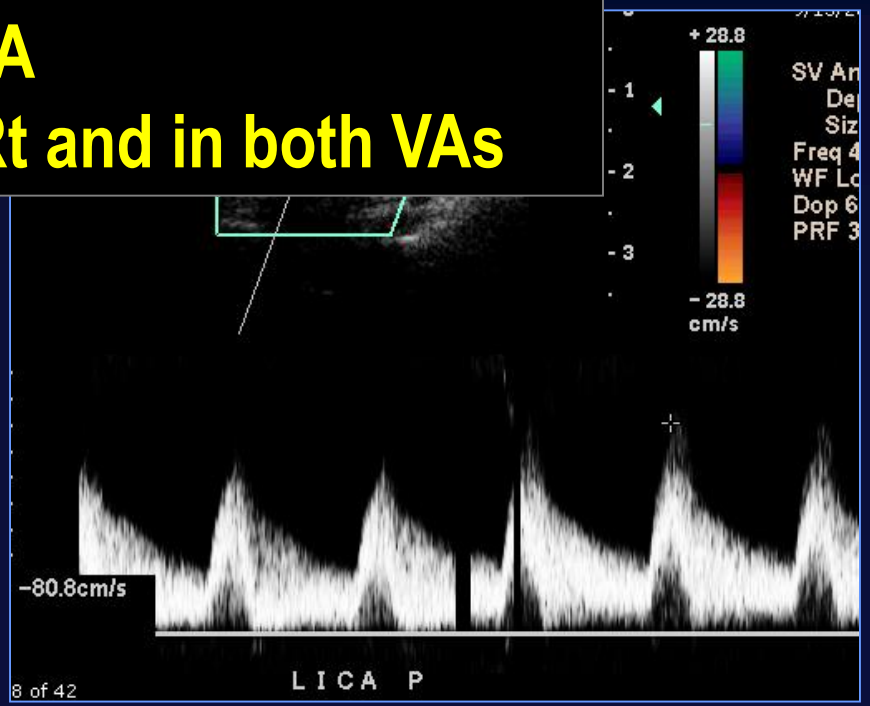
Severe Aortic Stenosis

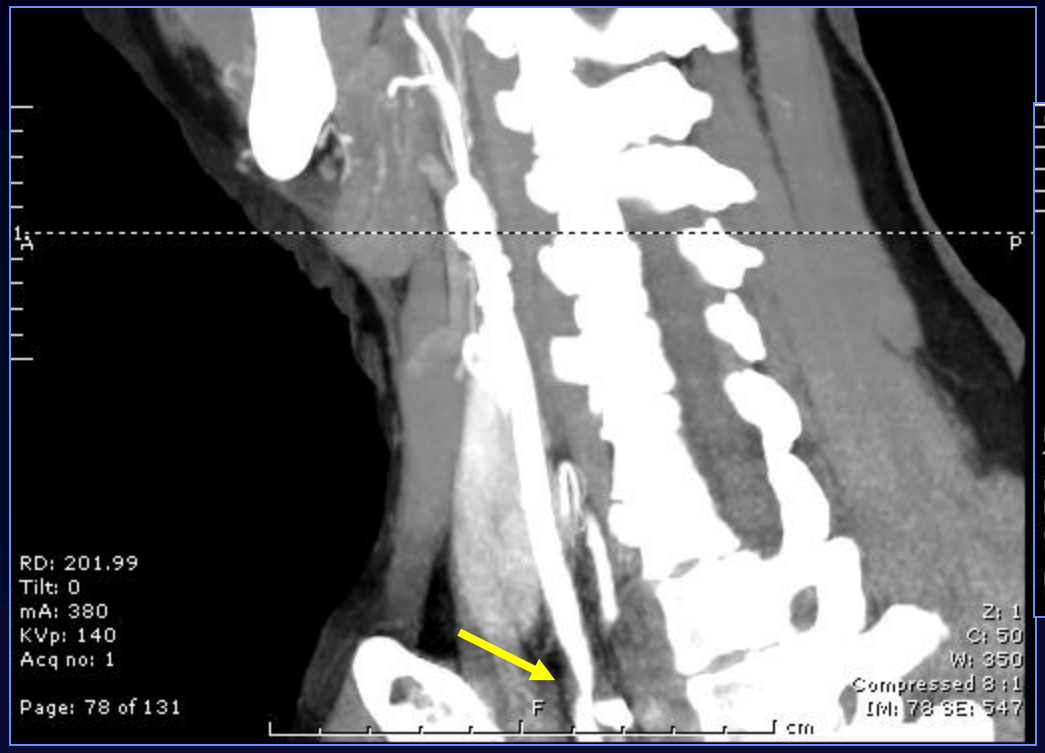


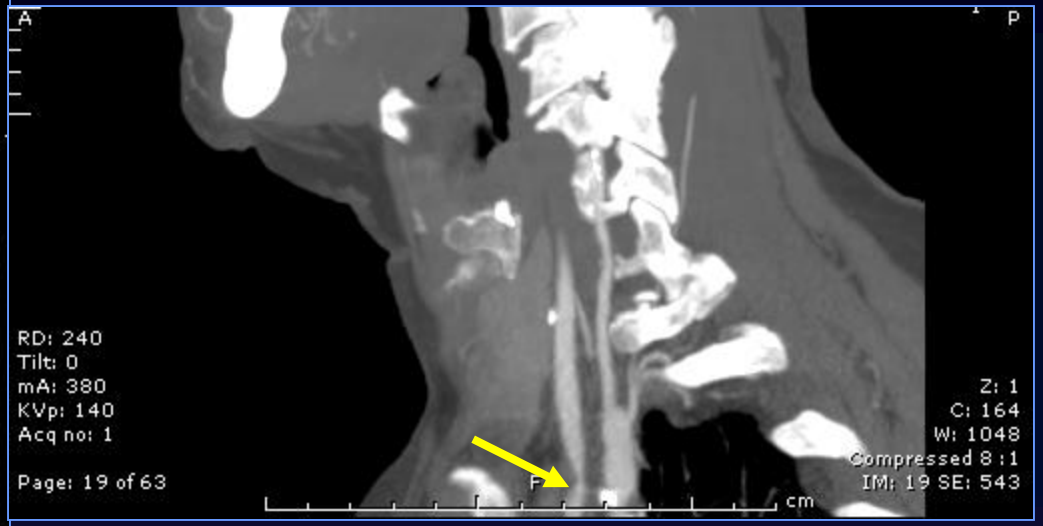


TP in Lt CCA & Lt ICA
Sharp upstroke on Rt and in both VAs





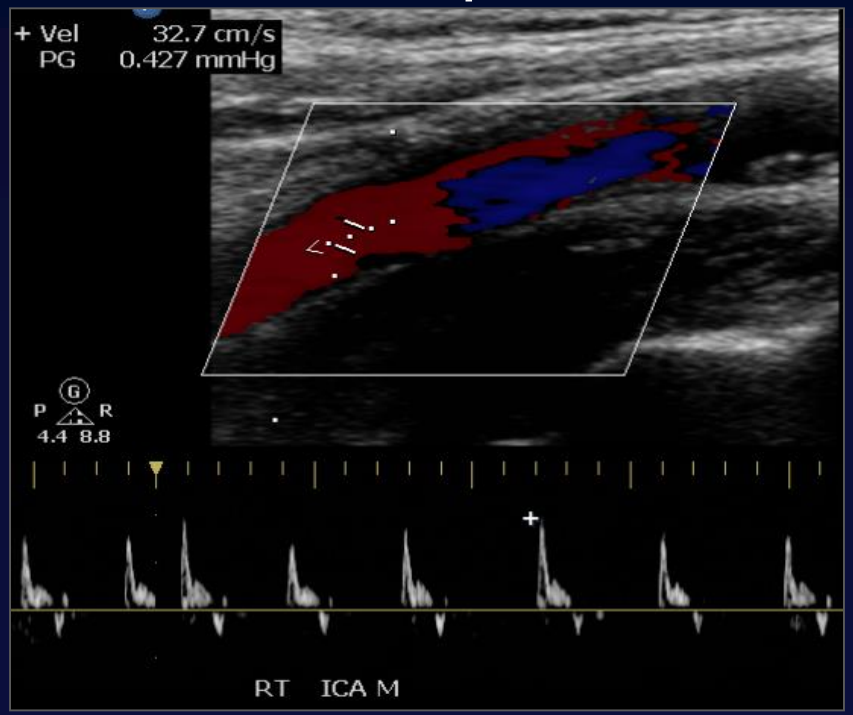




Stenosis at Origin of Lt CCA

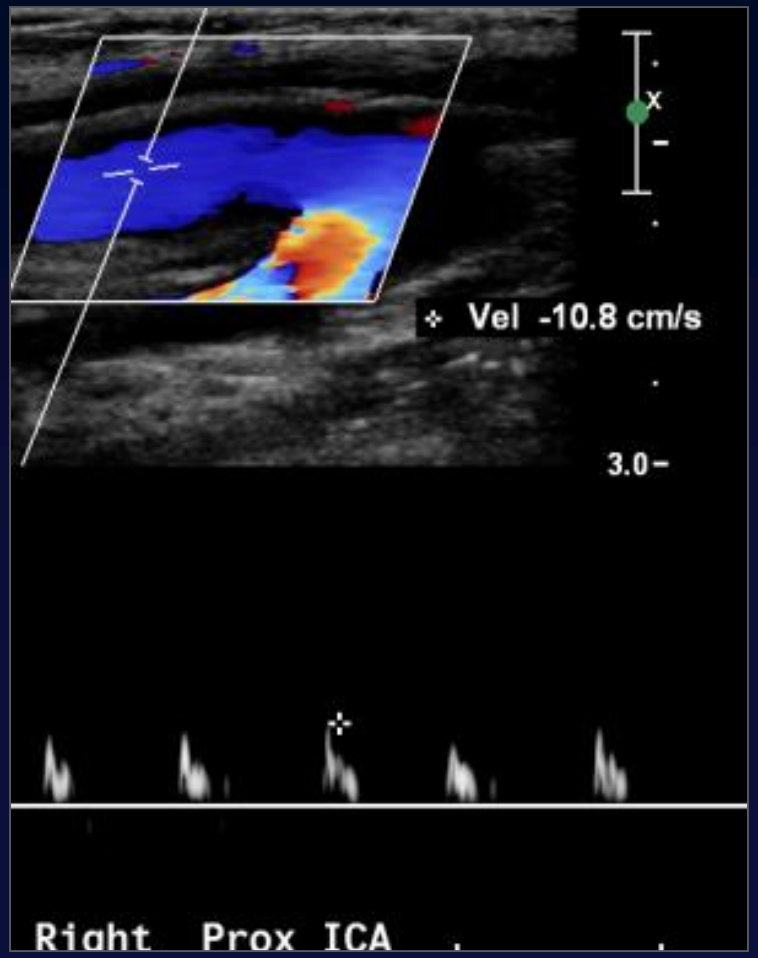
“KNOCKING” WAVEFORM

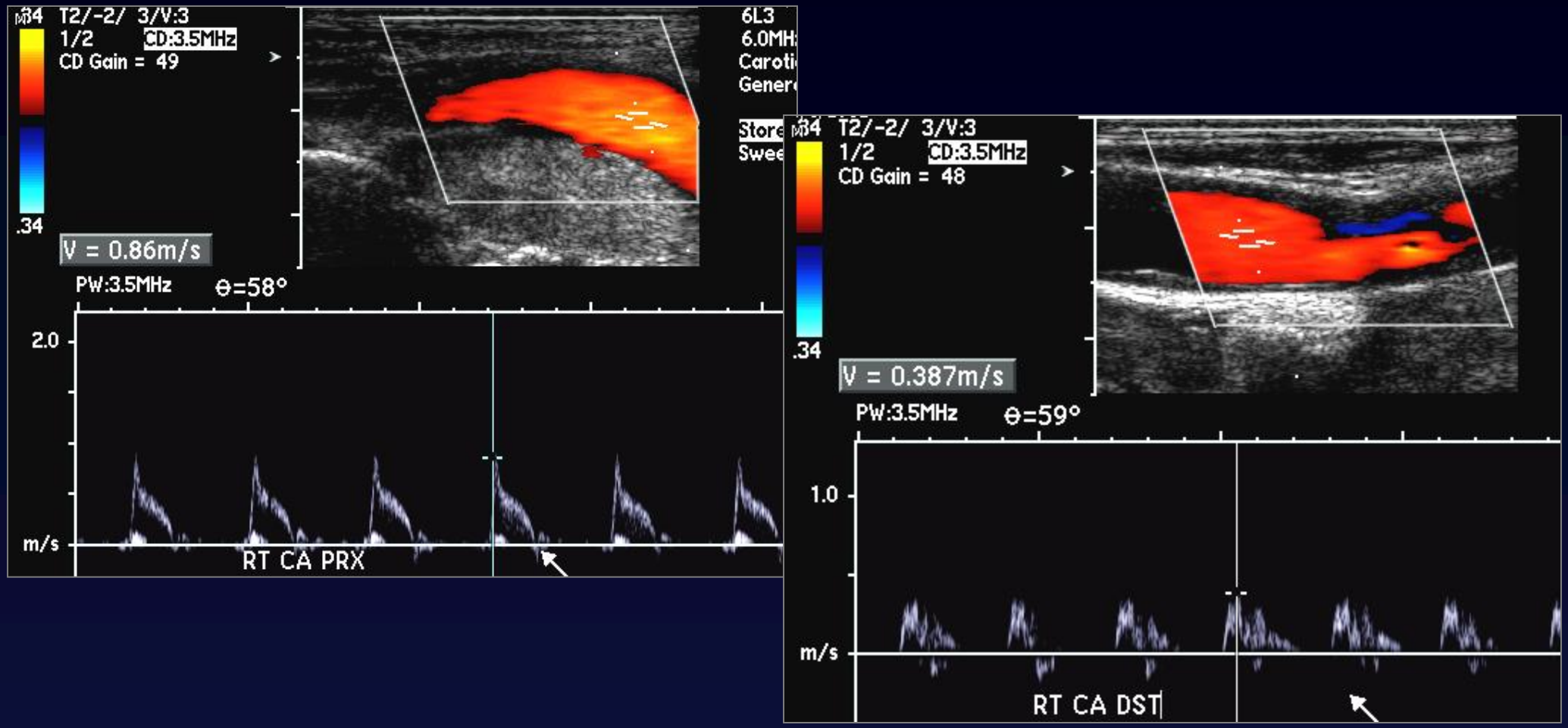
- Low PSV
- Decreased, absent or reversed diastolic flow
- High resistance waveform pattern



"KNOCKING" WAVEFORM

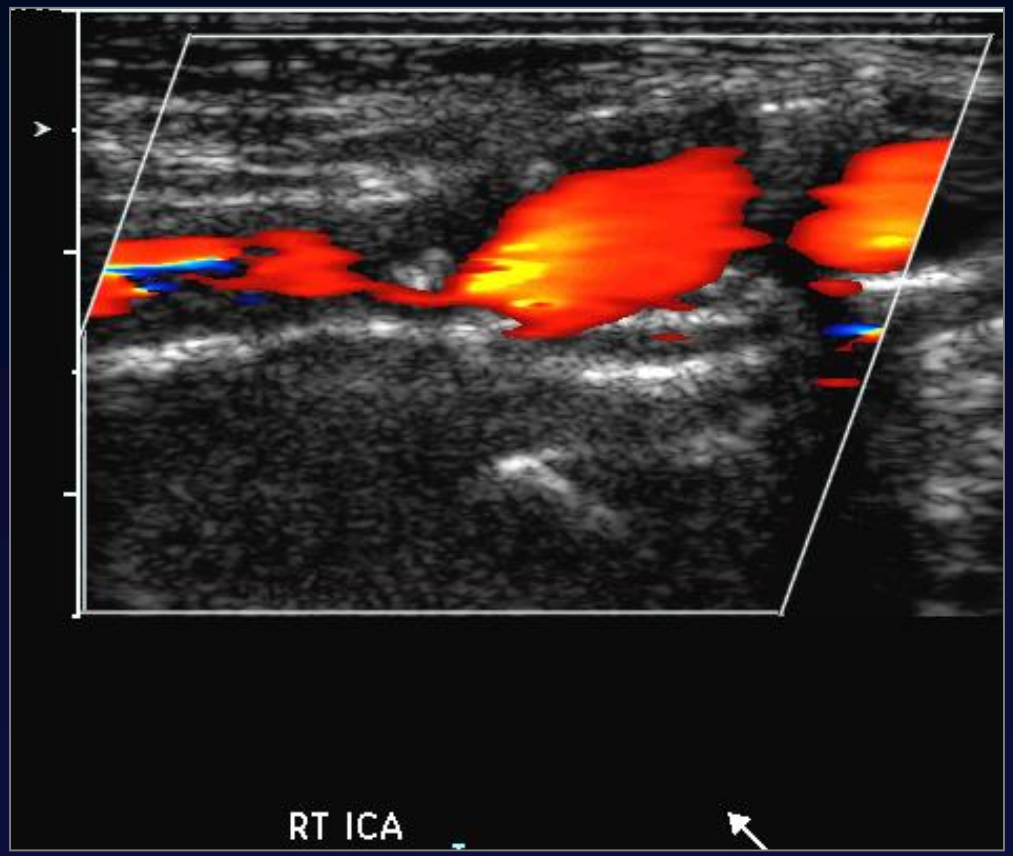
- Occurs proximal to an occlusion or high grade stenosis
  - atherosclerosis
  - dissection
  - vasospasm
  - increased ICP

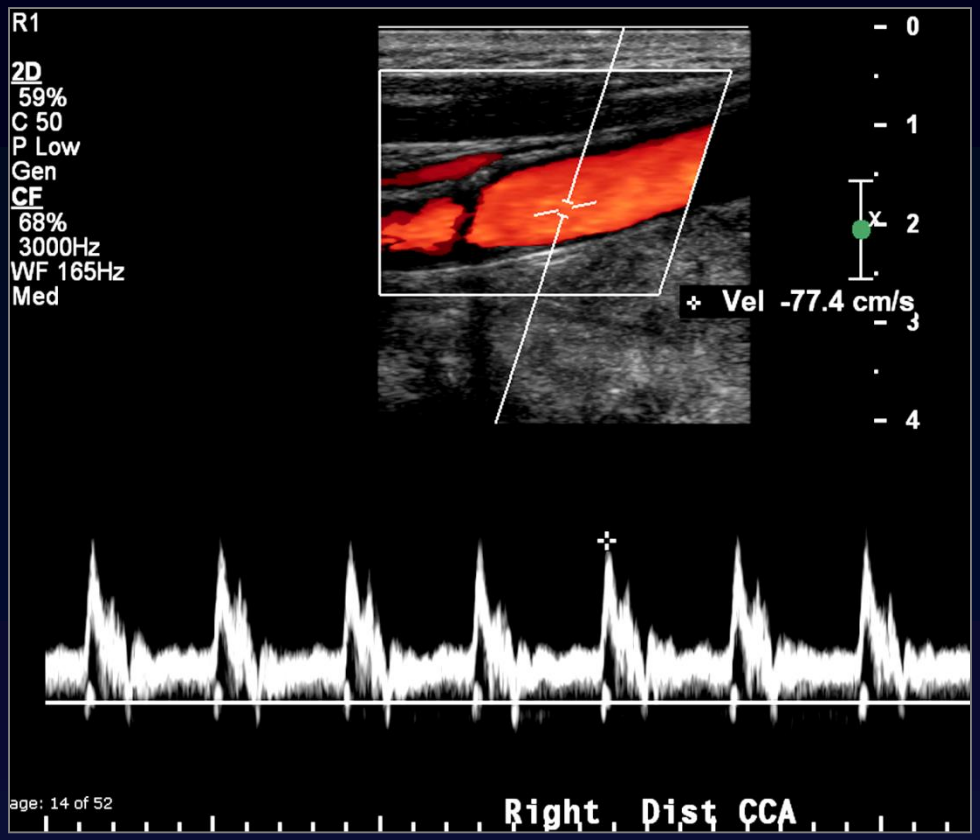


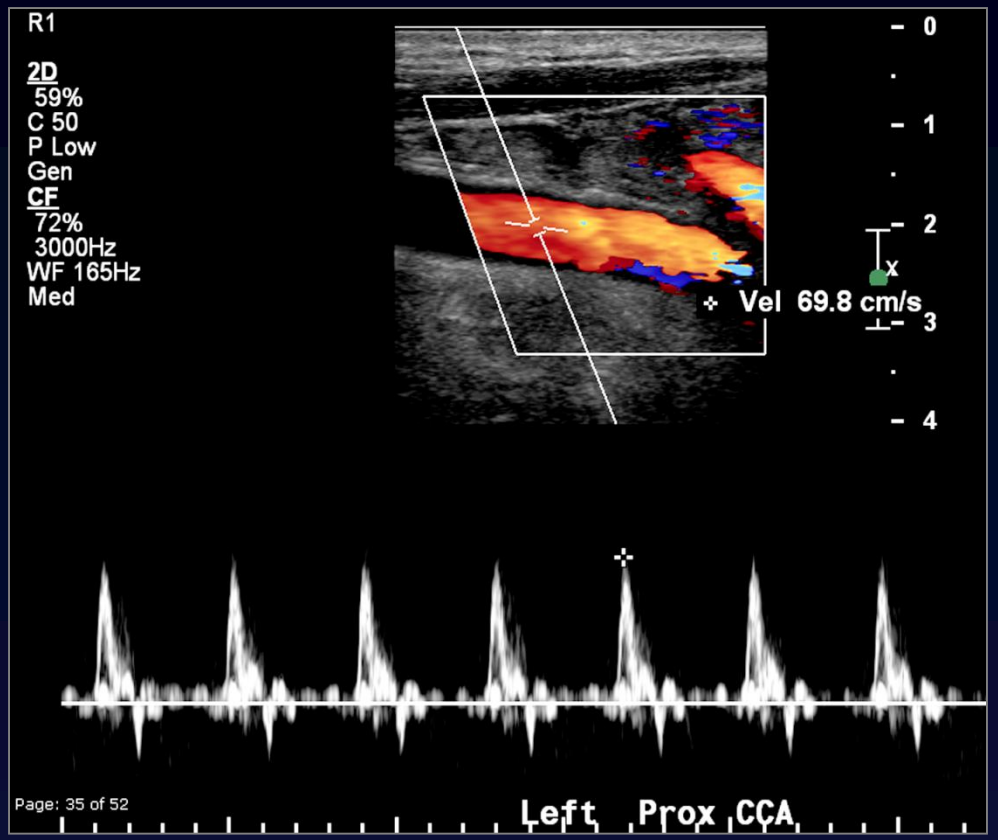


- More pronounced the closer one samples to the obstructing lesion

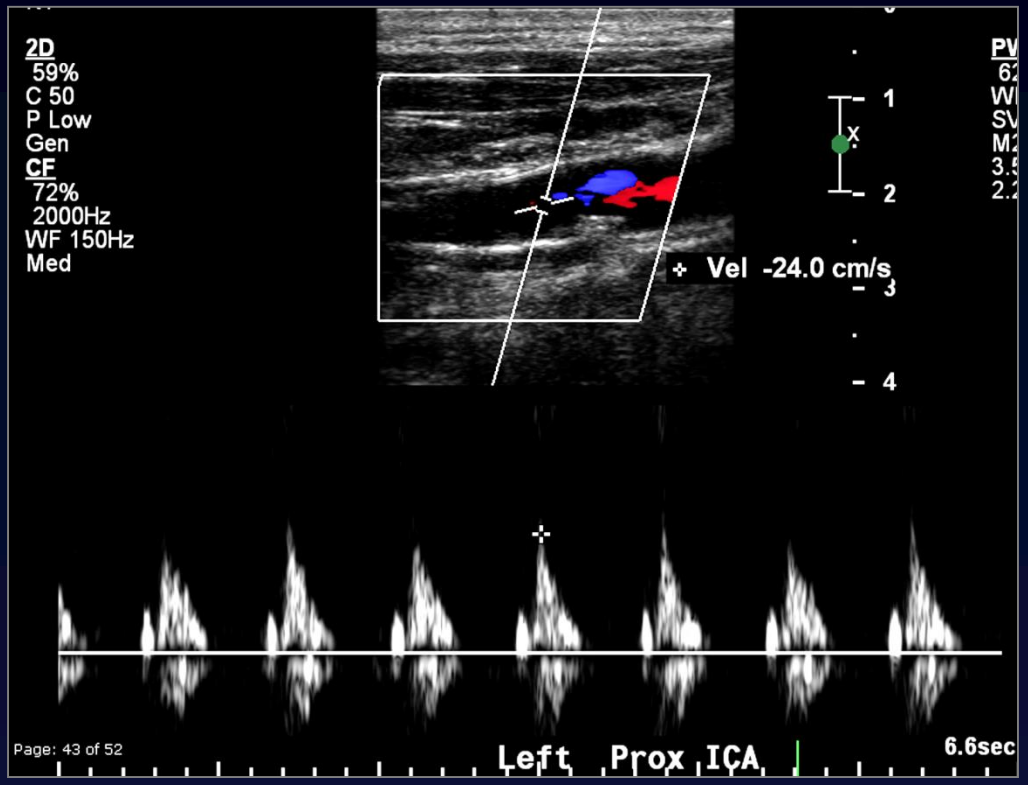
RICA "STRING SIGN"



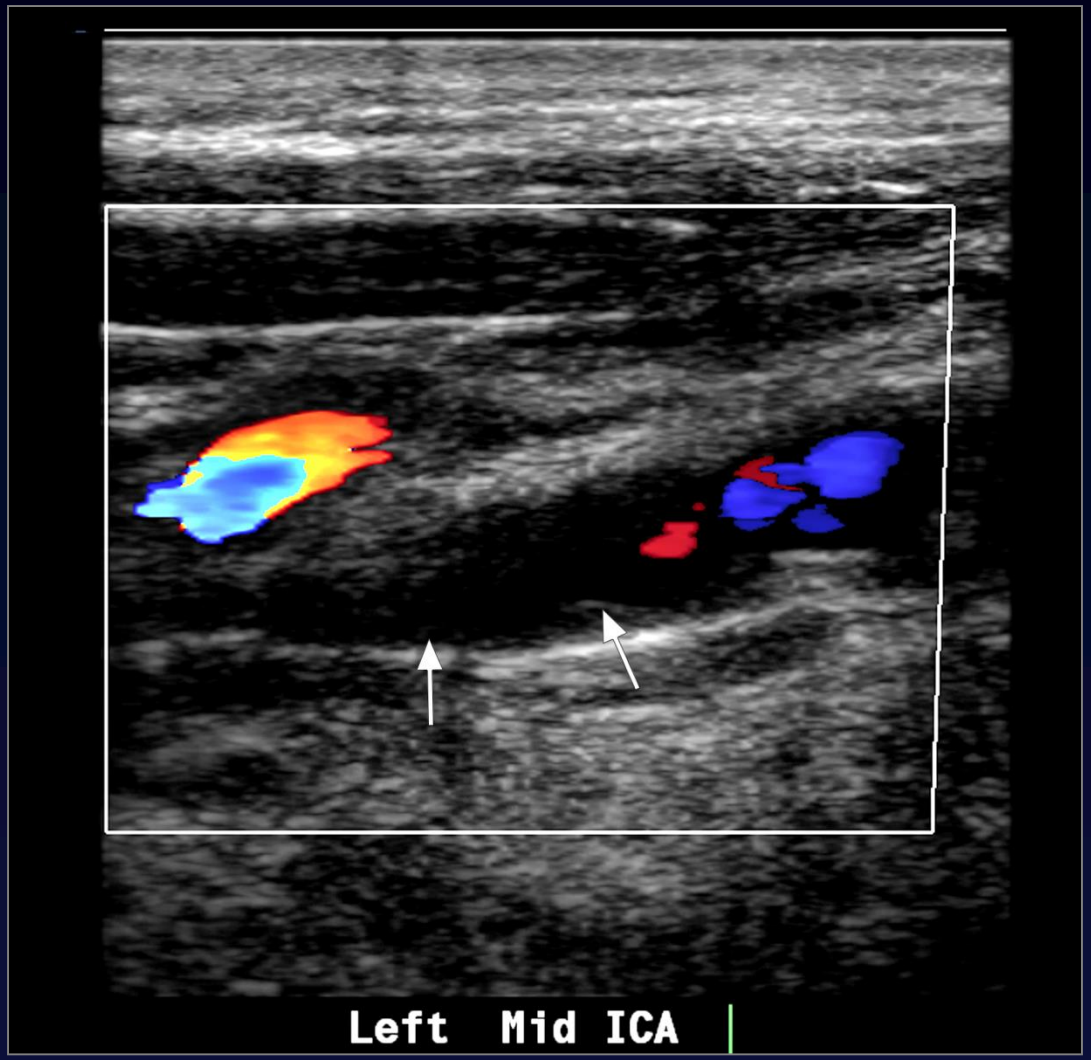




- Asymmetry of Rt & Lt CCA waveforms
- ↓ diastolic flow in Lt CCA

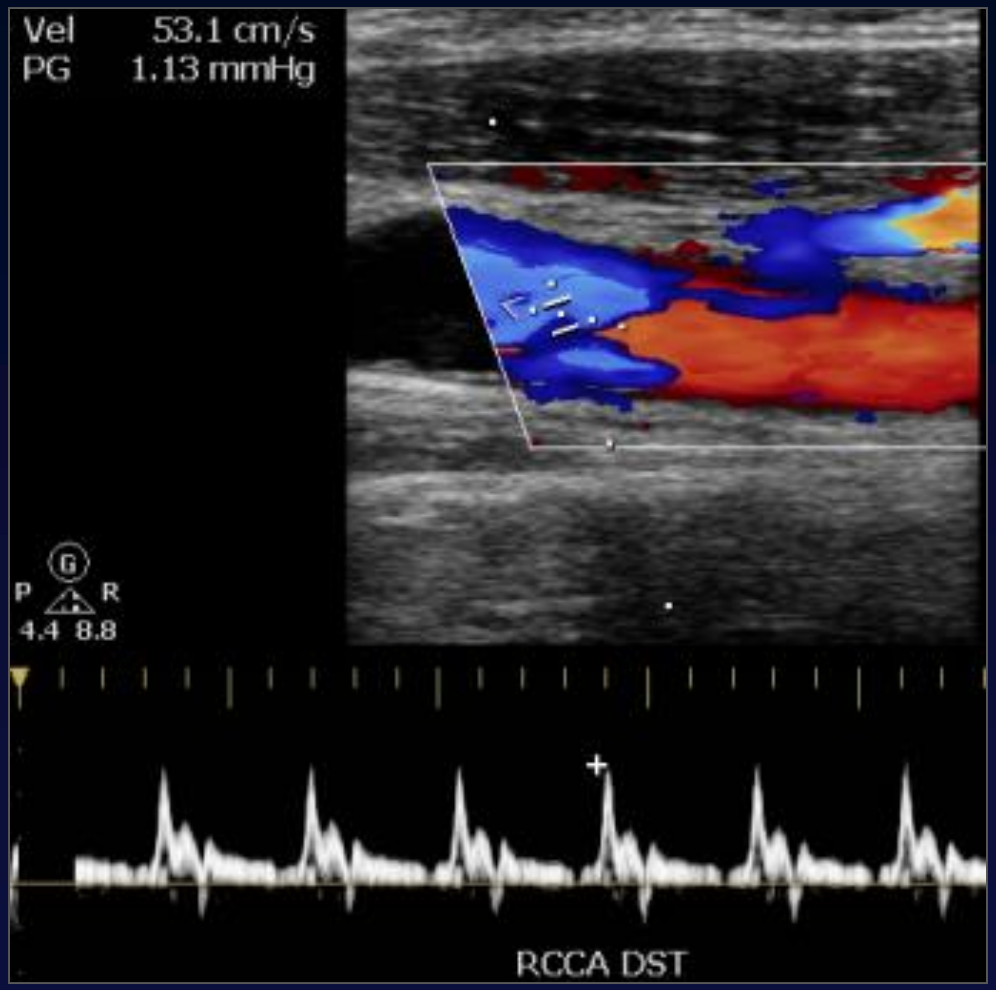


- More pronounced in Lt ICA

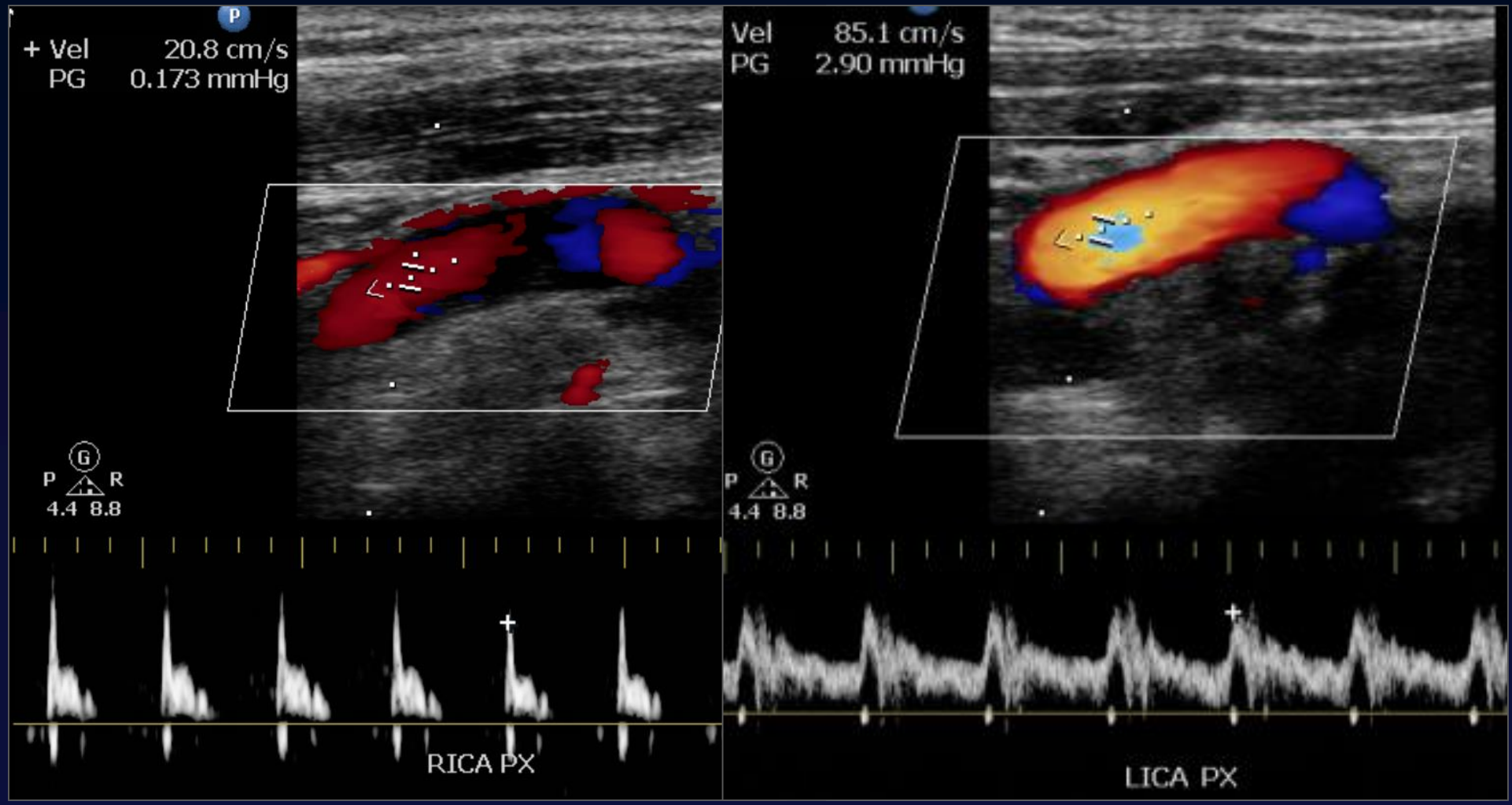


Distal Lt ICA Occlusion

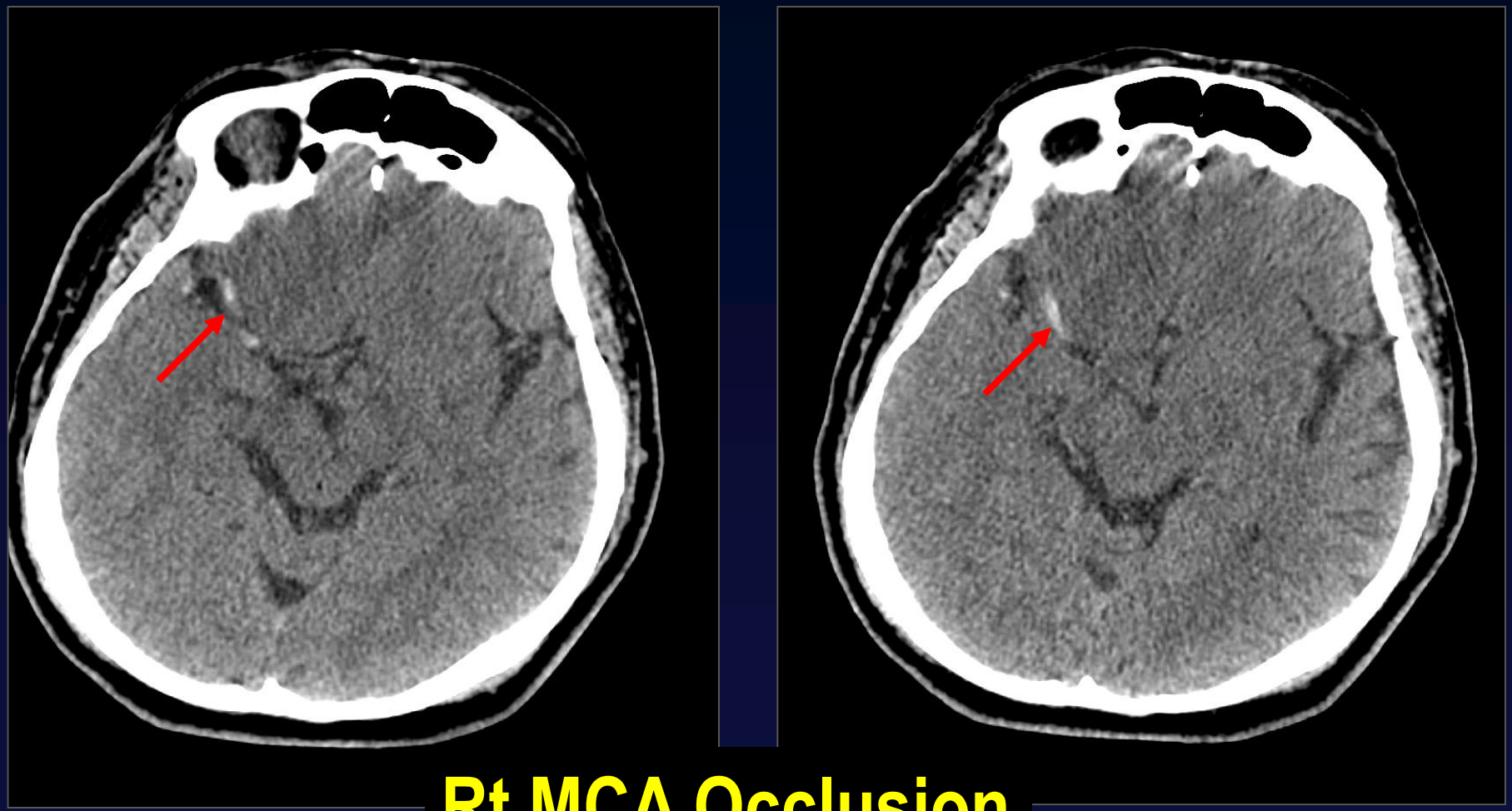
↓ PSV & EDV: RT CCA



↓ PSV & EDV: RT ICA

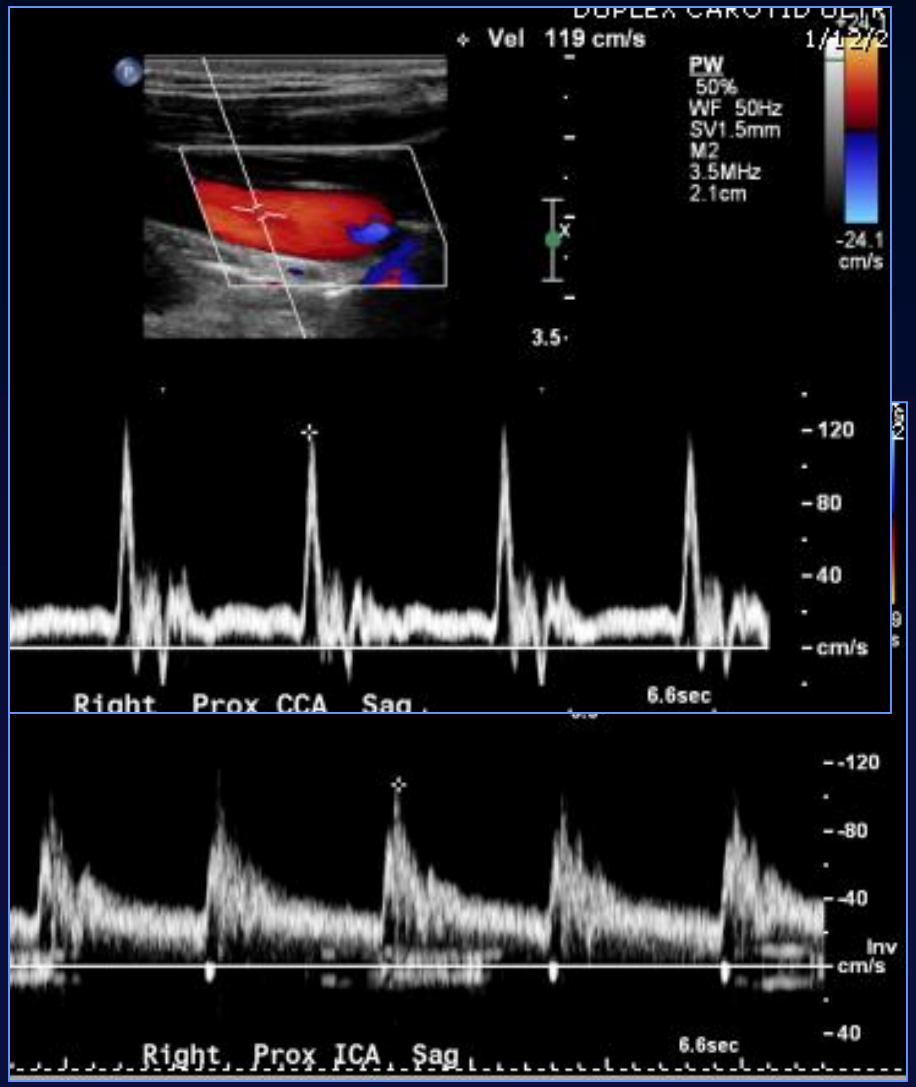


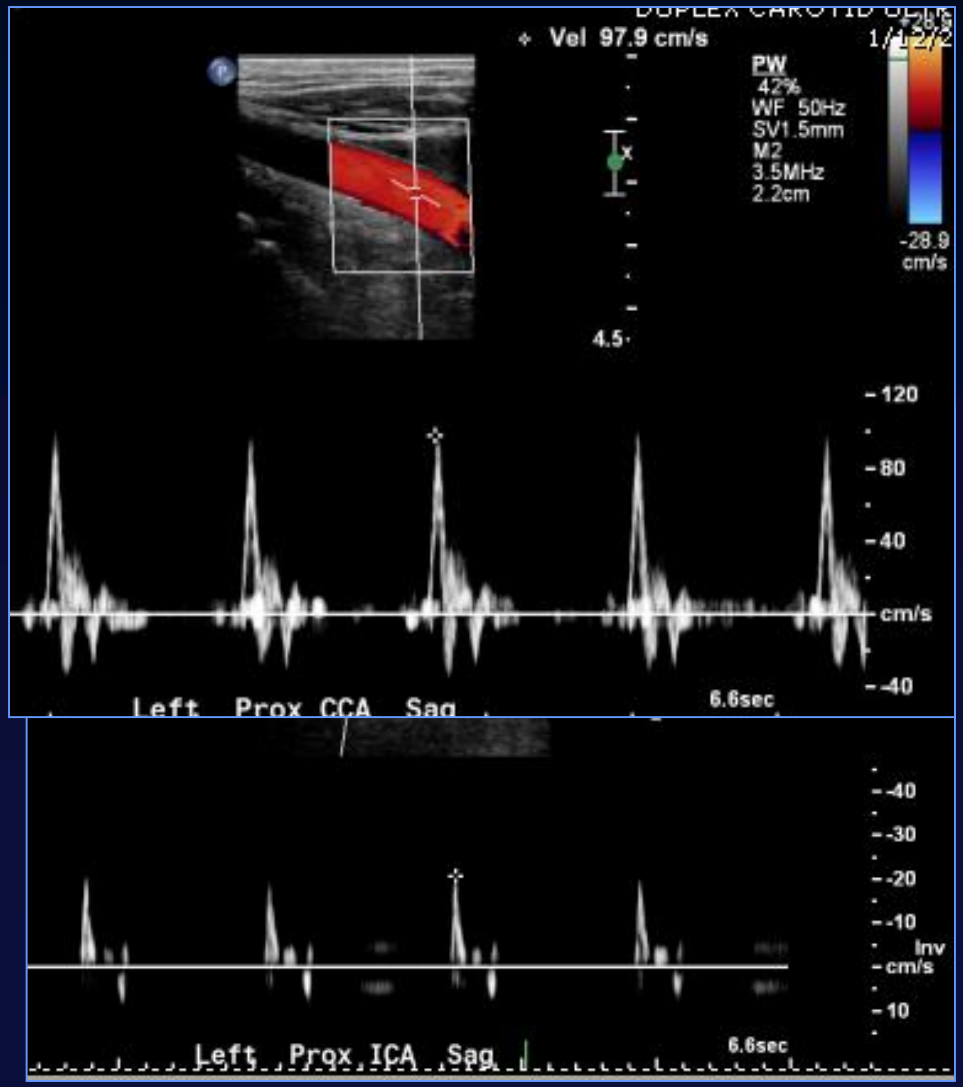
↓ PSV & EDV: RT CCA & ICA



Rt MCA Occlusion

24 yo Female w/ Headache





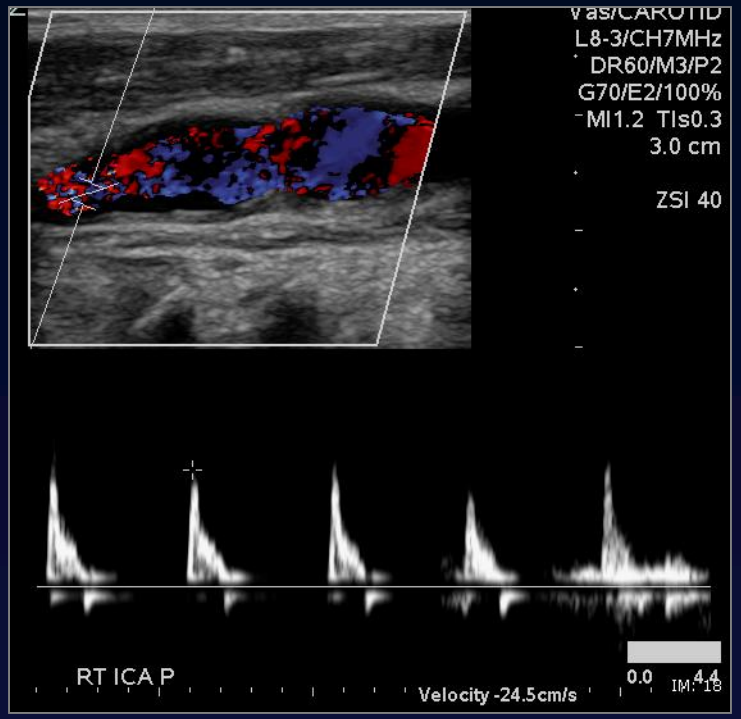
ICA DISSECTION @ SKULL BASE

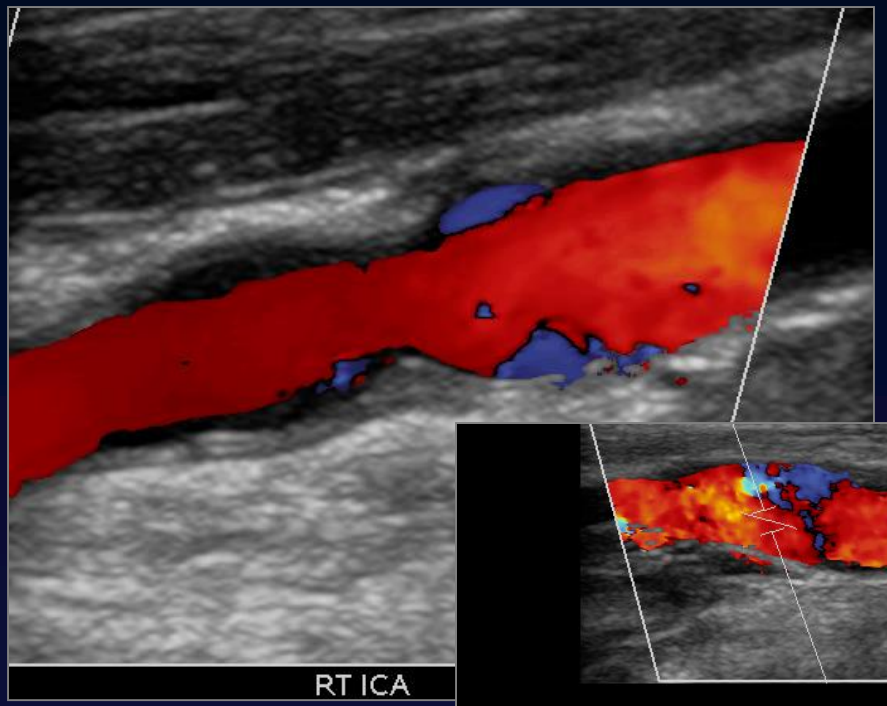
RT

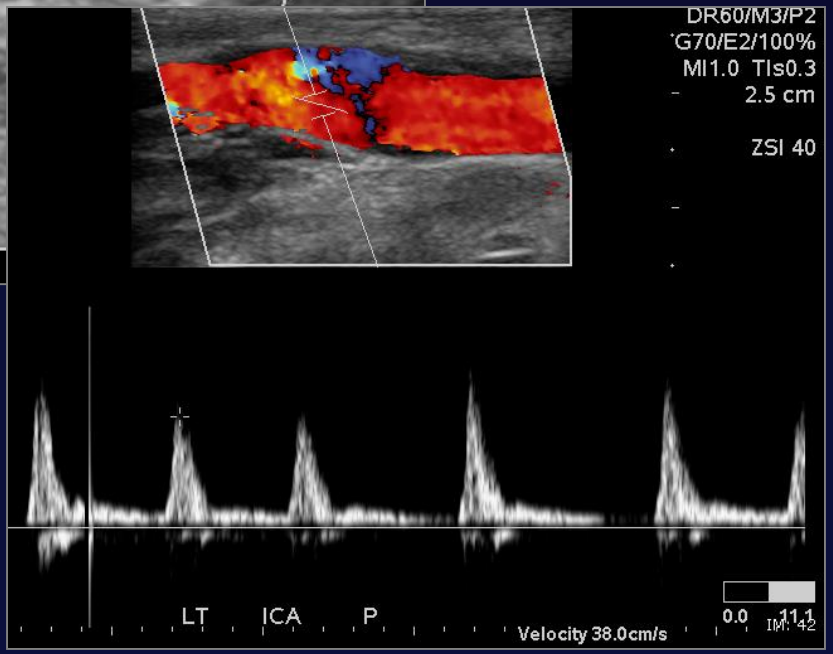
LT

ICA DISSECTION @ LT SKULL BASE

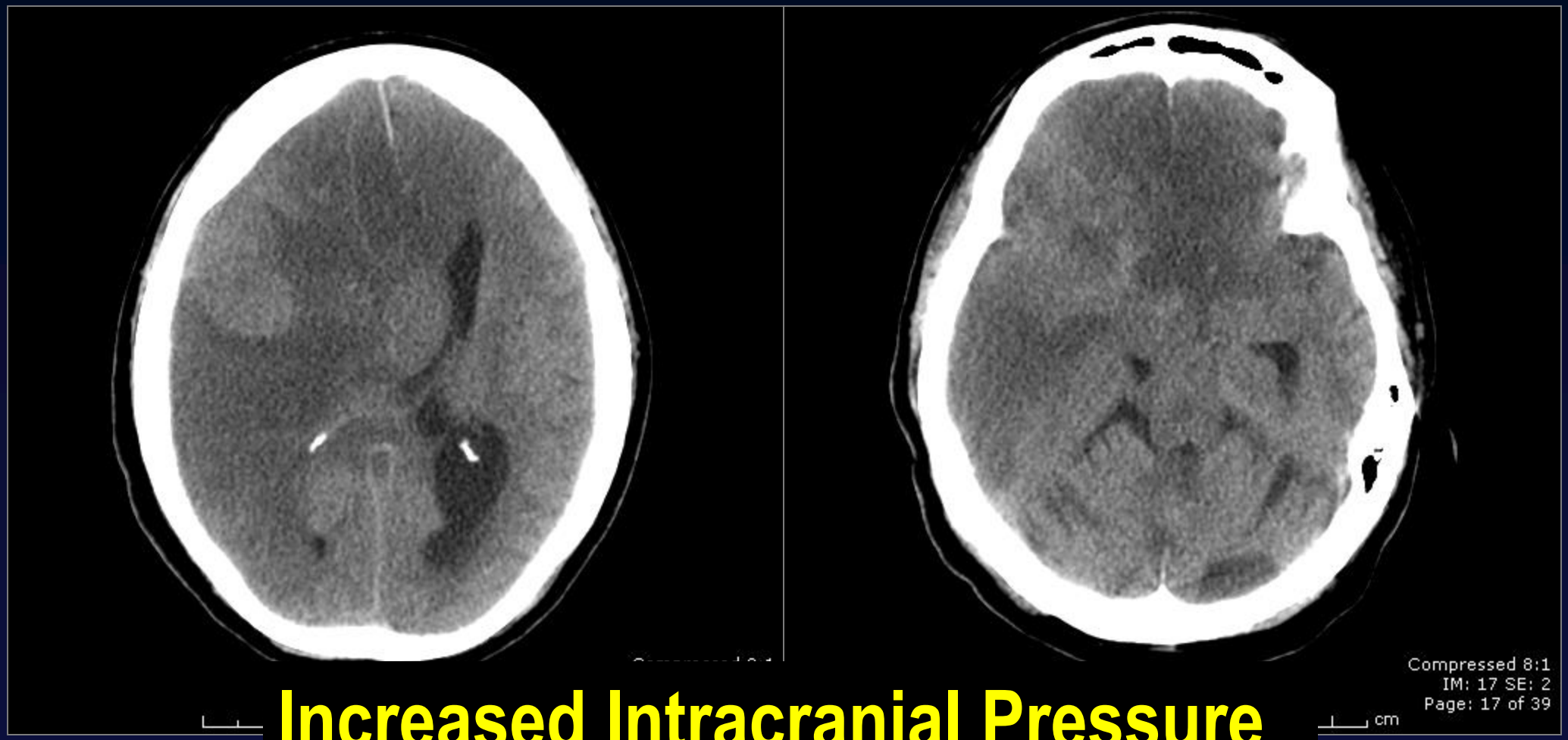
BILATERAL ↓ PSV & EDV in ICAs





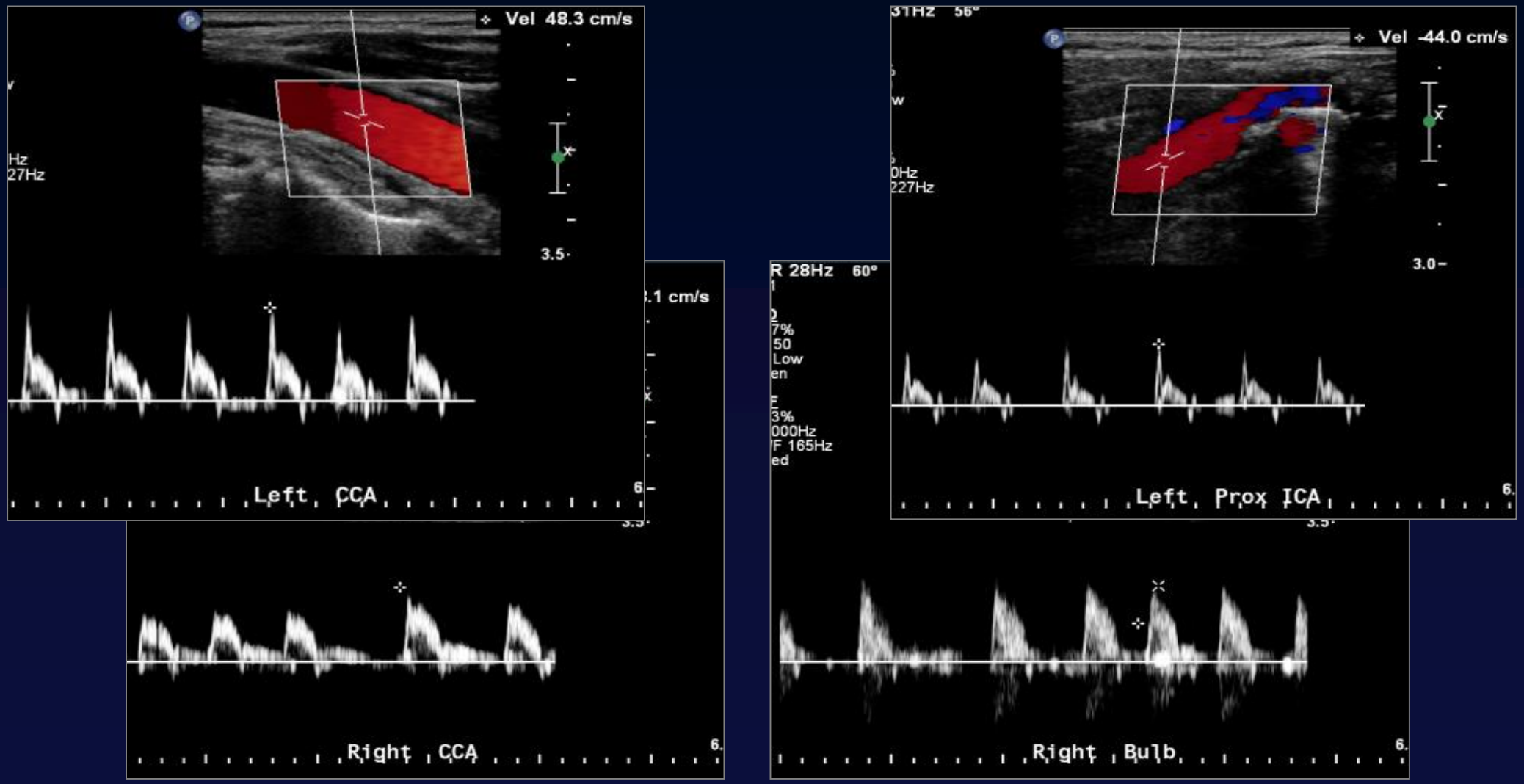


BILATERAL ↓ PSV & EDV in ICAs

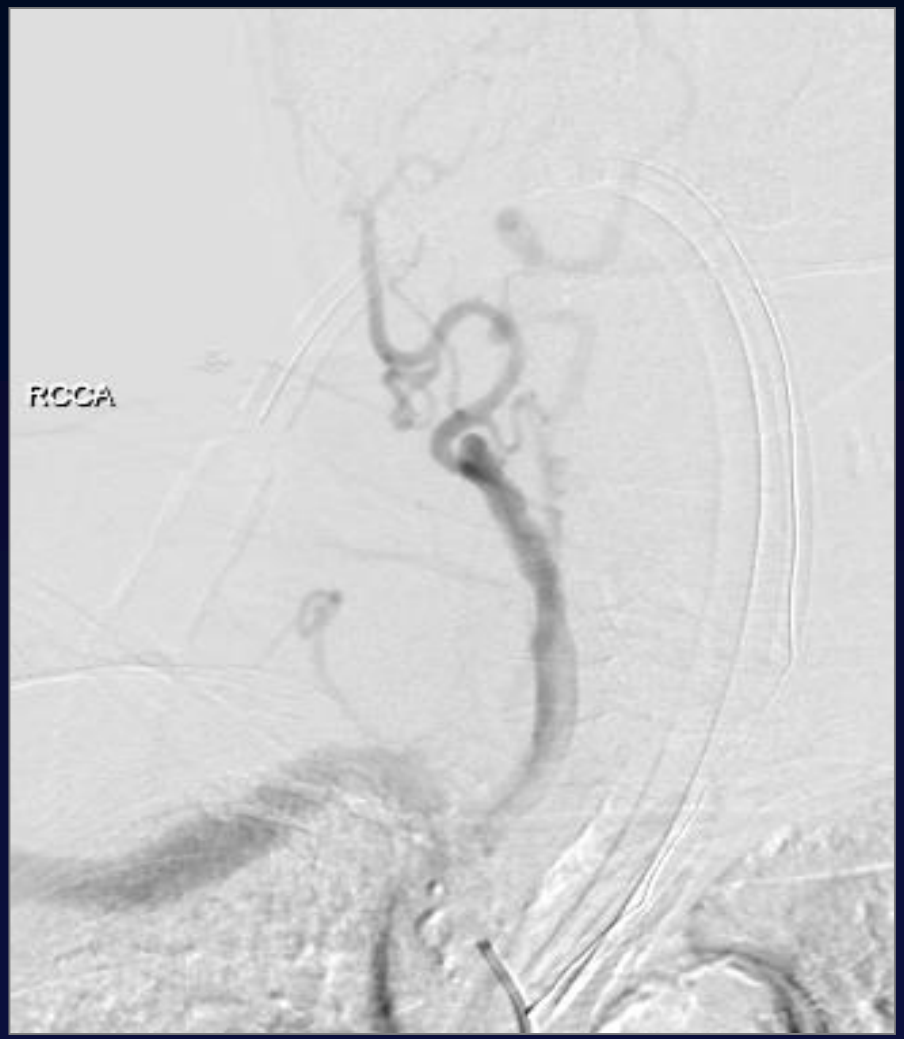


Increased Intracranial Pressure

74 yo Female w/ Stroke

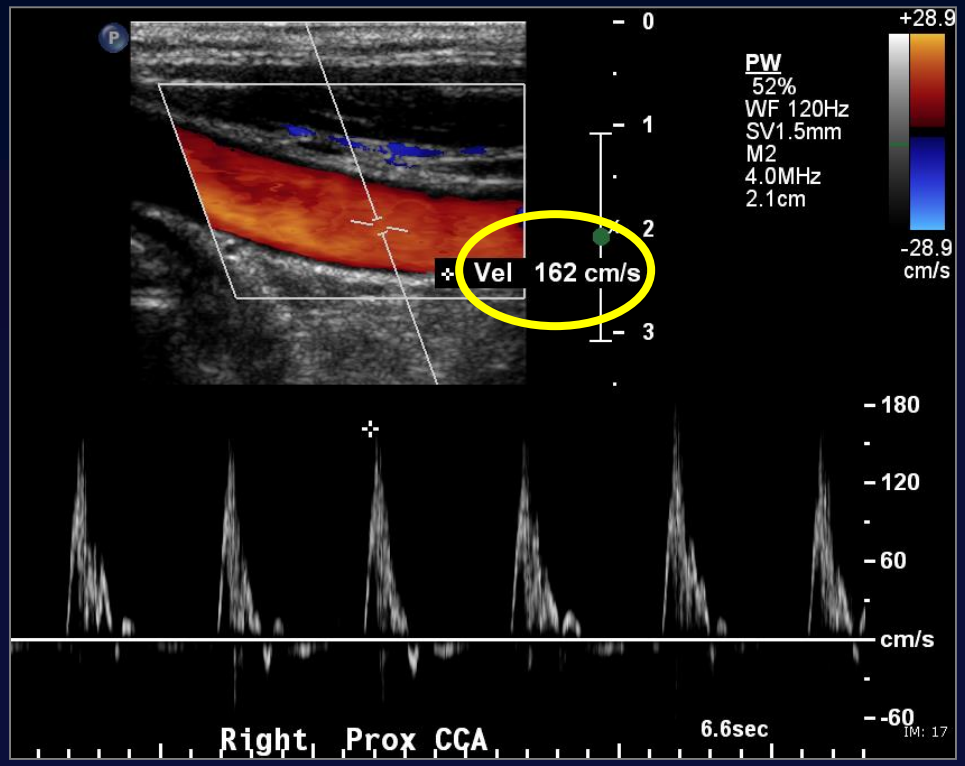


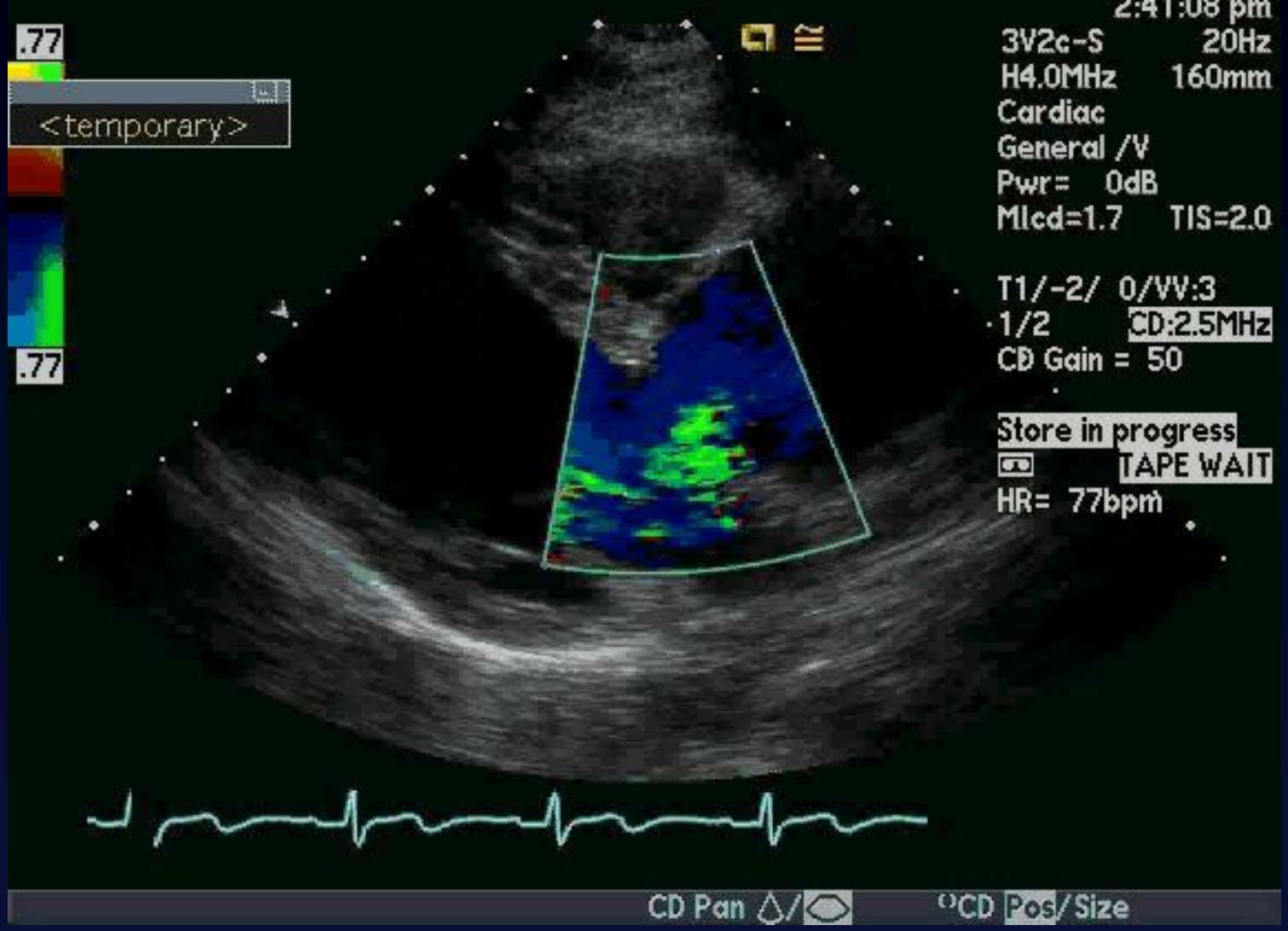
Bilateral Distal ICA Occlusions



BILATERAL ↓ EDV in CCAs

- ↑ PSV





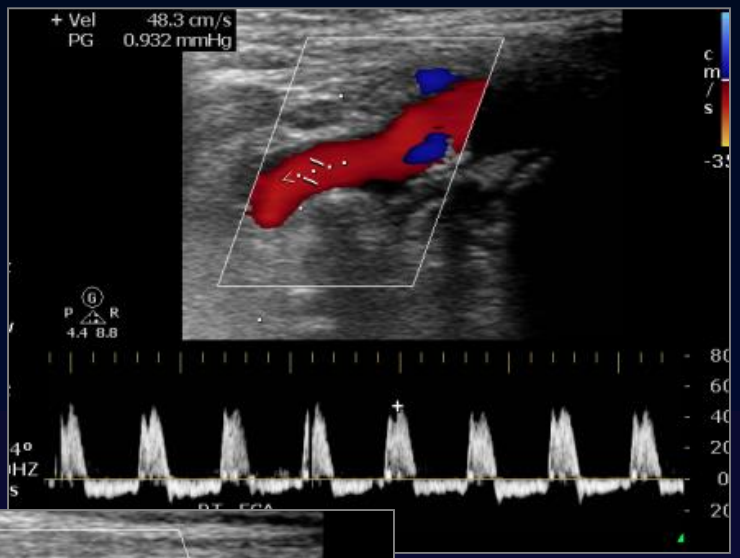
Aortic Regurgitation

WATER HAMMER PULSE

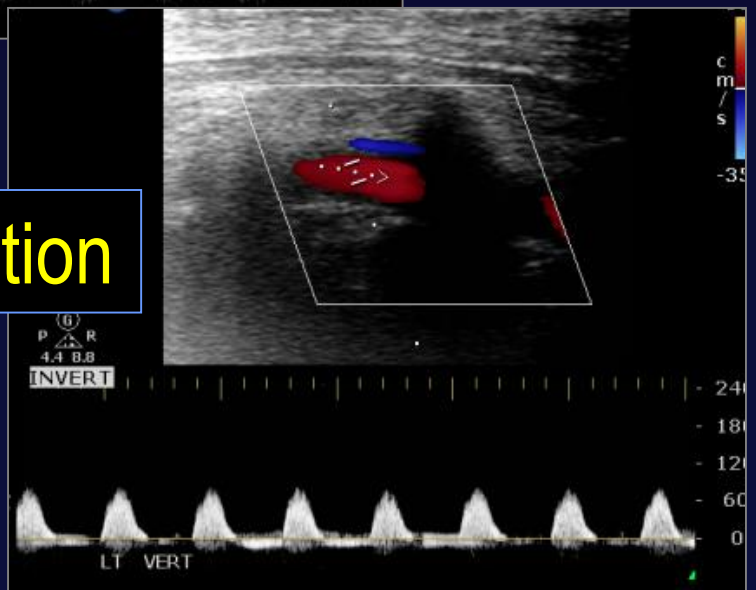
- Severe aortic regurgitation
  - sharp systolic upstroke
  - normal to ↑ PSV
  - reversed diastolic flow
  - bilateral
  - waveform normalizes distally

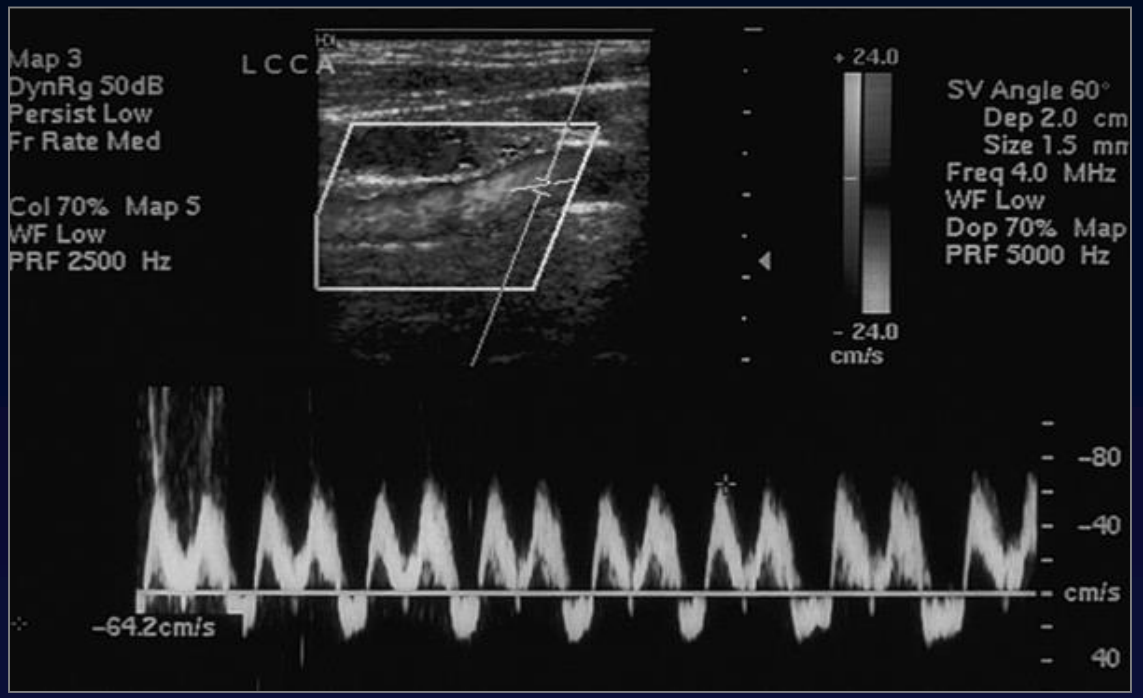
BILATERAL REVERSED DIASTOLIC FLOW

BILATERAL REVERSED DIASTOLIC FLOW

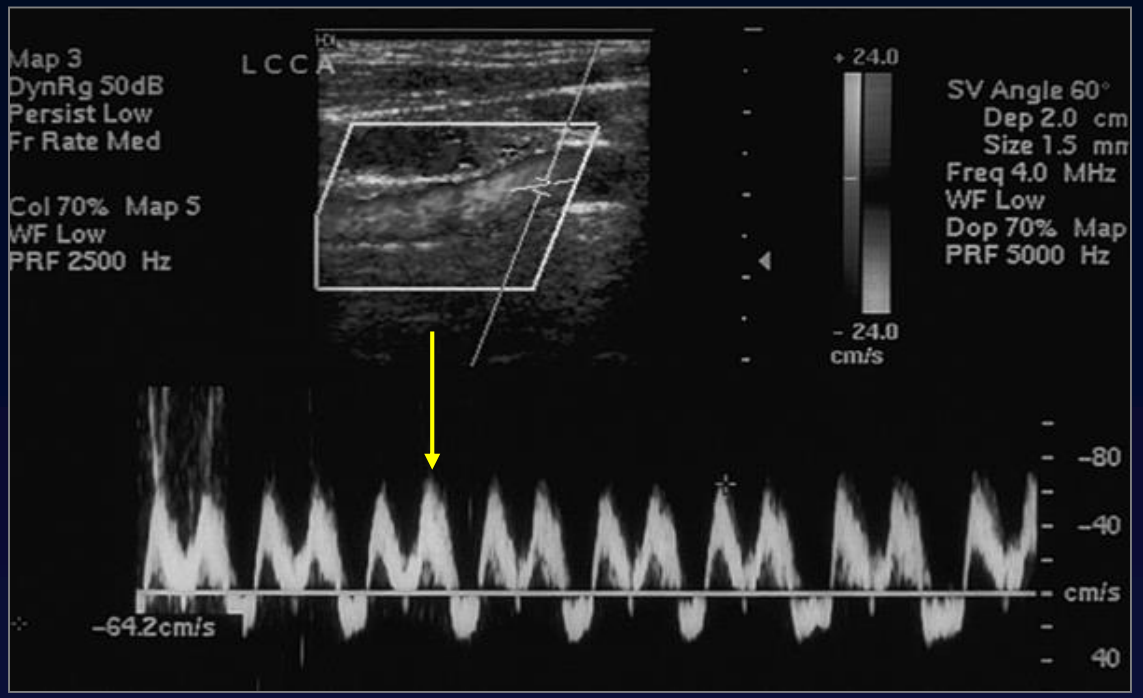


Severe Aortic Regurgitation



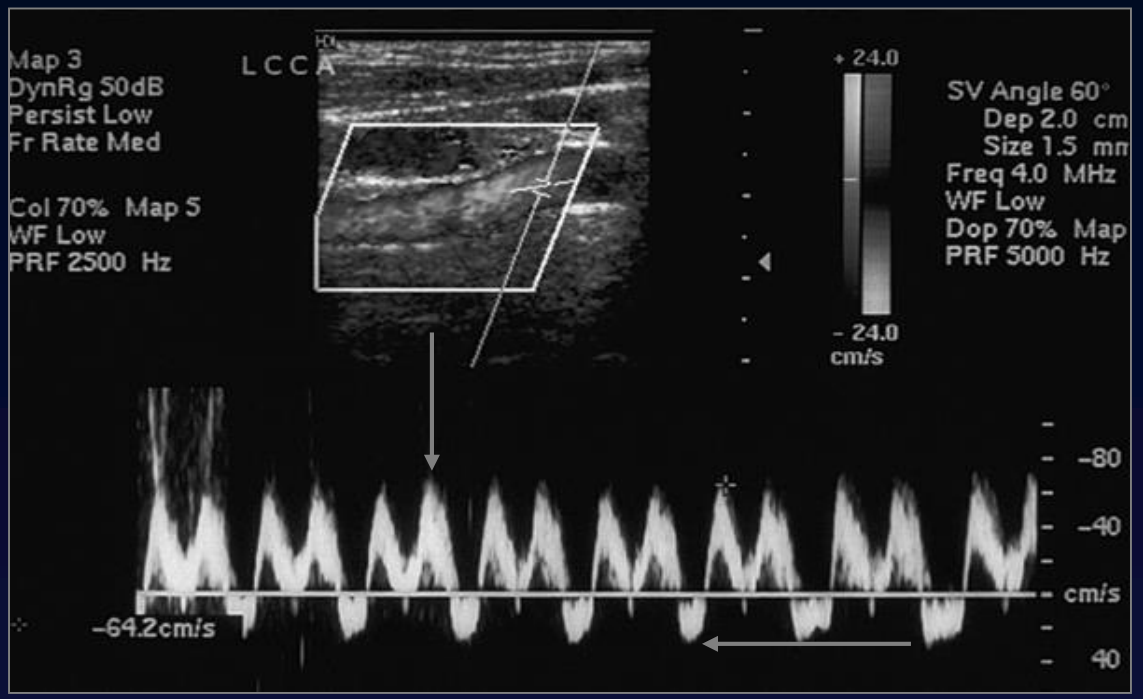

Map 3
DynRg 50dB
Persist Low
Fr Rate Med
Col 70% Map 5
WF Low
PRF 2500 Hz
L C C A
+ 24.0
- 24.0
cm/s
SV Angle 60°
Dep 2.0 cm
Size 1.5 mm
Freq 4.0 MHz
WF Low
Dop 70% Map
PRF 5000 Hz
-80
-40
cm/s
40
-64.2cm/s

INTRA-AORTIC BALLOON PUMP



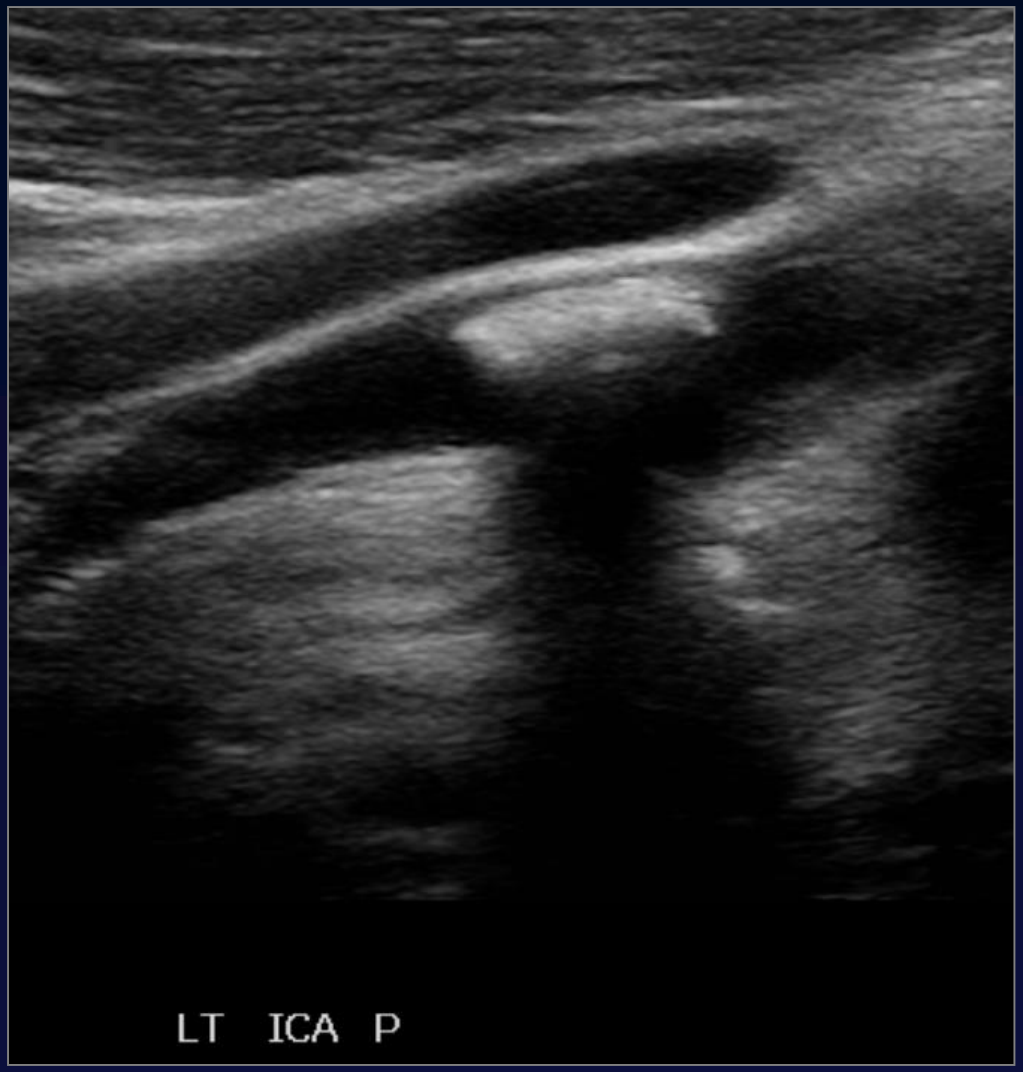
- Inflation of balloon causes 2nd peak of forward flow during early diastole

INTRA-AORTIC BALLOON PUMP



- Inflation of balloon causes 2nd peak of forward flow during early diastole
- Flow reversal at end of diastole corresponds to deflation of balloon

INTRA-AORTIC BALLOON PUMP



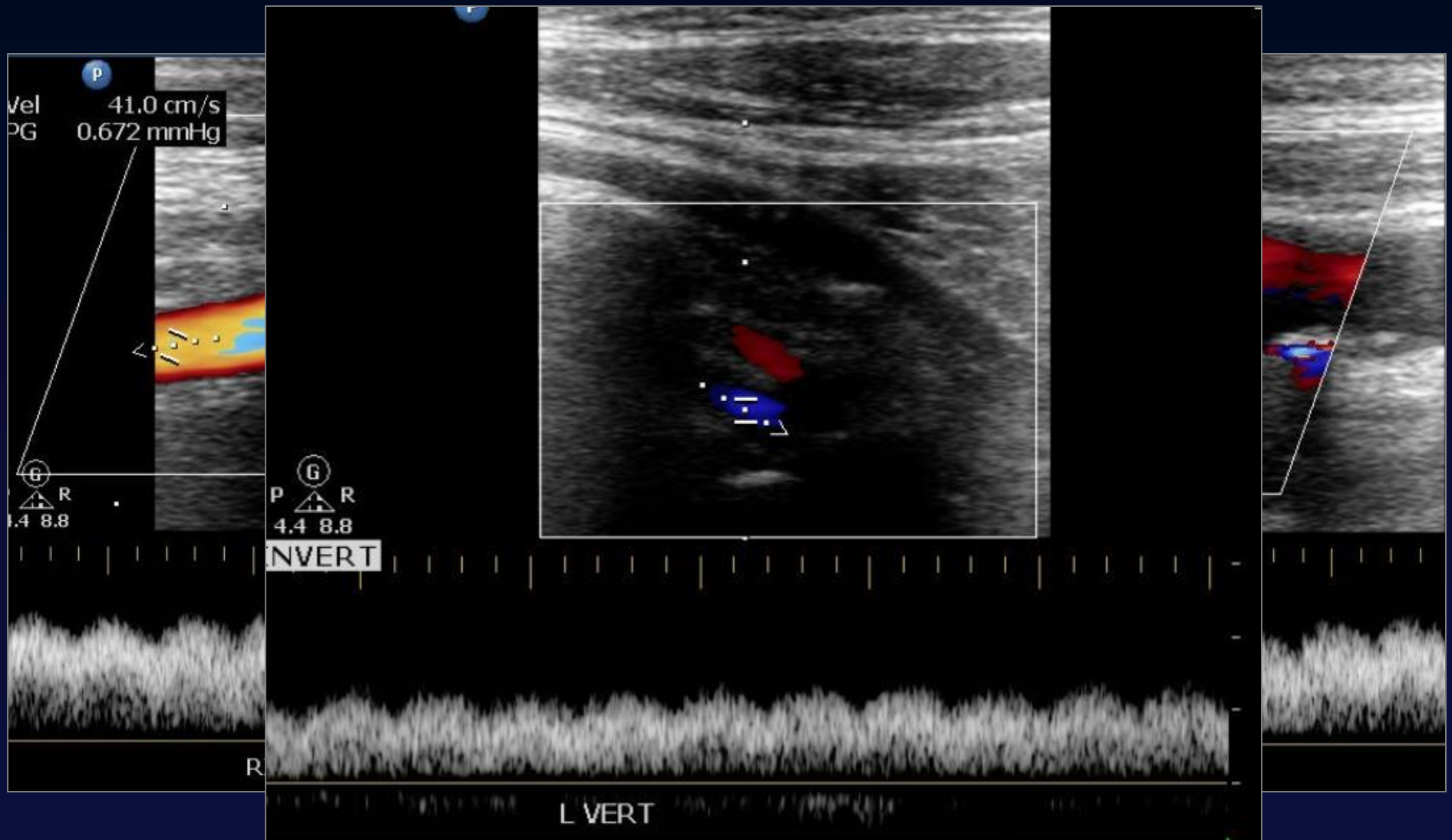
INTRA-AORTIC BALLOON PUMP

- PSV Lt ICA = 222 cm/sec, but PSVR only 2.2
- What % stenosis?

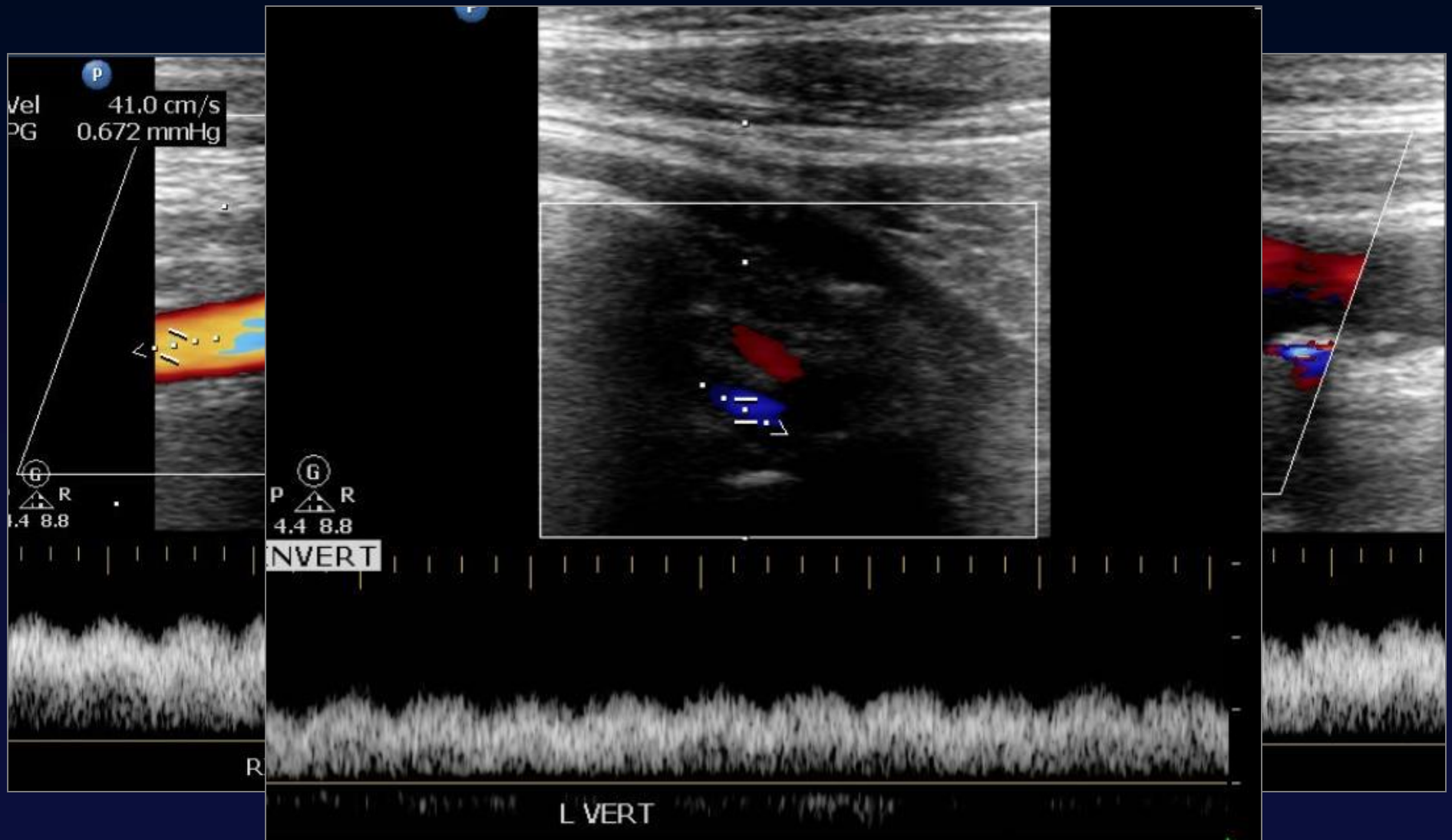
INTRA-AORTIC BALLOON PUMP

- Choose 1st OR 2nd peak to measure PSV and be consistent
- PSVR may be a better Doppler criterion
- Look at grayscale and color Doppler
- May have to turn balloon off or decrease firing ratio

What Kind of Waveform is This?



LEFT VENTRICULAR ASSIST DEVICE



LVAD: US Findings

- Marked tardus parvus waveforms in all vessels
- ↓ PSV
  - average = 32 cm/sec
- Monophasic flow – no flow below the baseline
  - rarely, nonpulsatile monophasic waveform w/o perceptible systolic peak
- Similar waveforms in subclavian, mesenteric, femoral arteries

Cervini, US Quarterly: 2010

CAS vs CEA

- Most recommend CEA for….
  - older patients
  - heavily calcified plaque
  - tortuous vessels

} Increased risk of CAS

Brott, JACC: 2010
Chaktoura, J Vasc Surg: 2001

CAS vs CEA

- Most agree w/ use of stent if….
  - high medical co-morbidity, i.e. ↑ surgical risk
    - advanced cardiopulmonary dxs
  - restenosis s/p CEA > 70%
  - hostile neck – s/p XRT, laryngectomy, lymph node dissection, tracheostomy
    - fibrosis makes dissection difficult and increases risk of cranial nerve damage

Brott, JACC: 2010
Chaktoura, J Vasc Surg: 2001

CAS vs CEA

- Most clinicians agree w/ use of stent if….
  - unfavorable neck anatomy
    - inaccessible lesion above C2

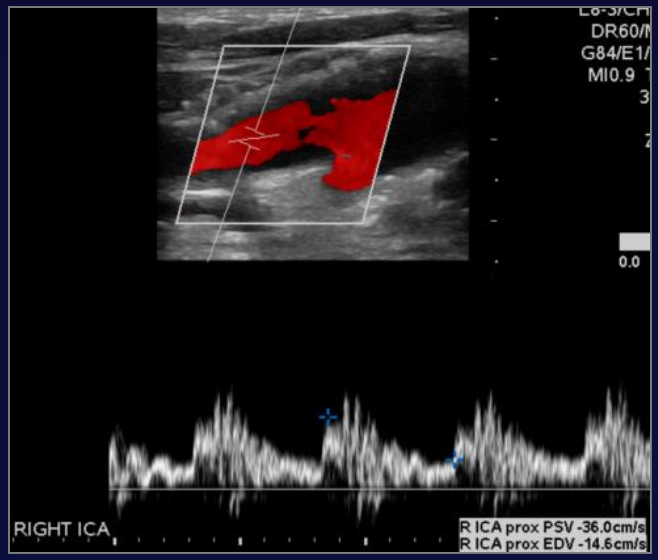
Chaktoura, J Vasc Surg: 2001
Brott, JACC: 2010

CAROTID ENDARTERECTOMY: Restenosis

- Incidence ~ 5-15%
- Risk factors:
  - fibrous, inflammatory plaque
  - DM
  - age
  - females
  - smoking history
- Pts s/p CEA typically followed at yearly intervals w/ US

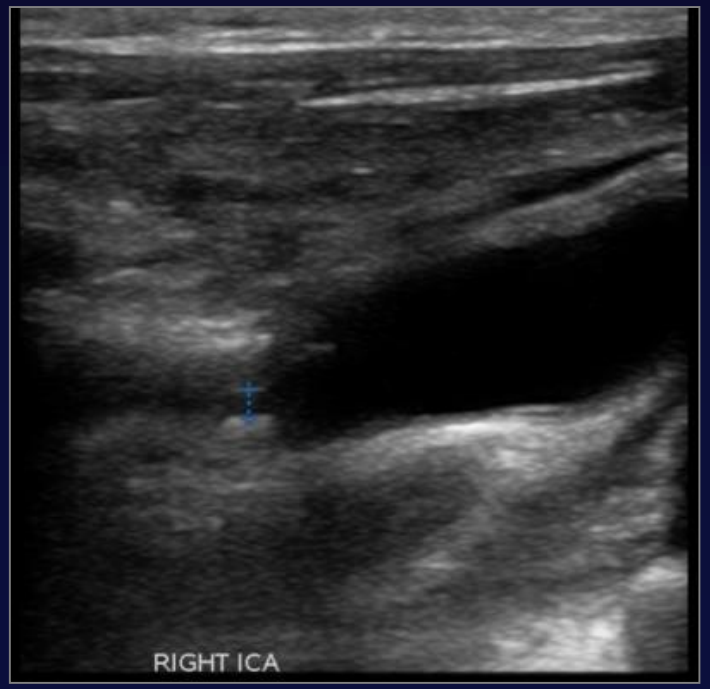
CEA: Restenosis

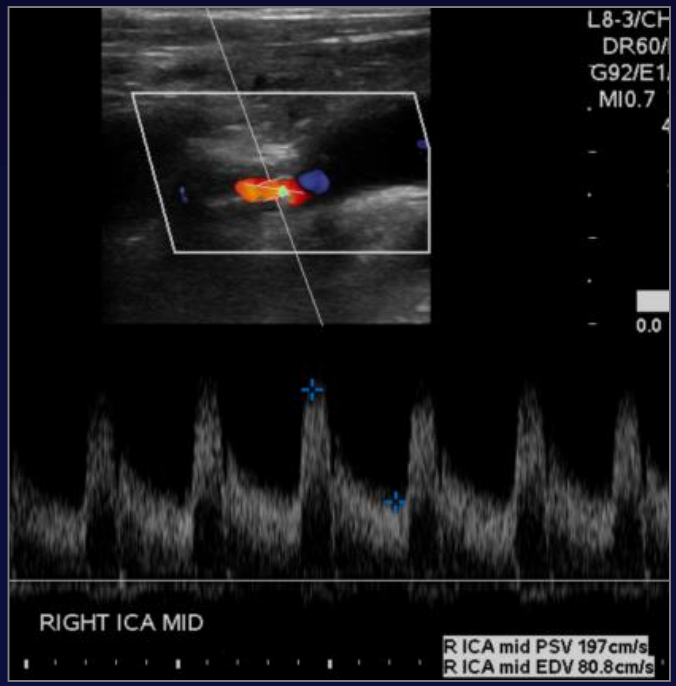
- US diagnosis is problematic
- Surgery changes hemodynamics
  - ↑ diameter 2^0 to creation of patch ⟶ decreased PSV
  - vessel wall compliance is different



CEA: Restenosis

- Can’t use same pre-op Doppler criteria
  - PSV likely lower
  - look more carefully at PSVR and grayscale, color Doppler appearance
- Consider correlative imaging





CEA: Restenosis

- 64 yr old woman 8 yrs s/p bilateral CEAs, Rt neck bruit

CEA: Restenosis

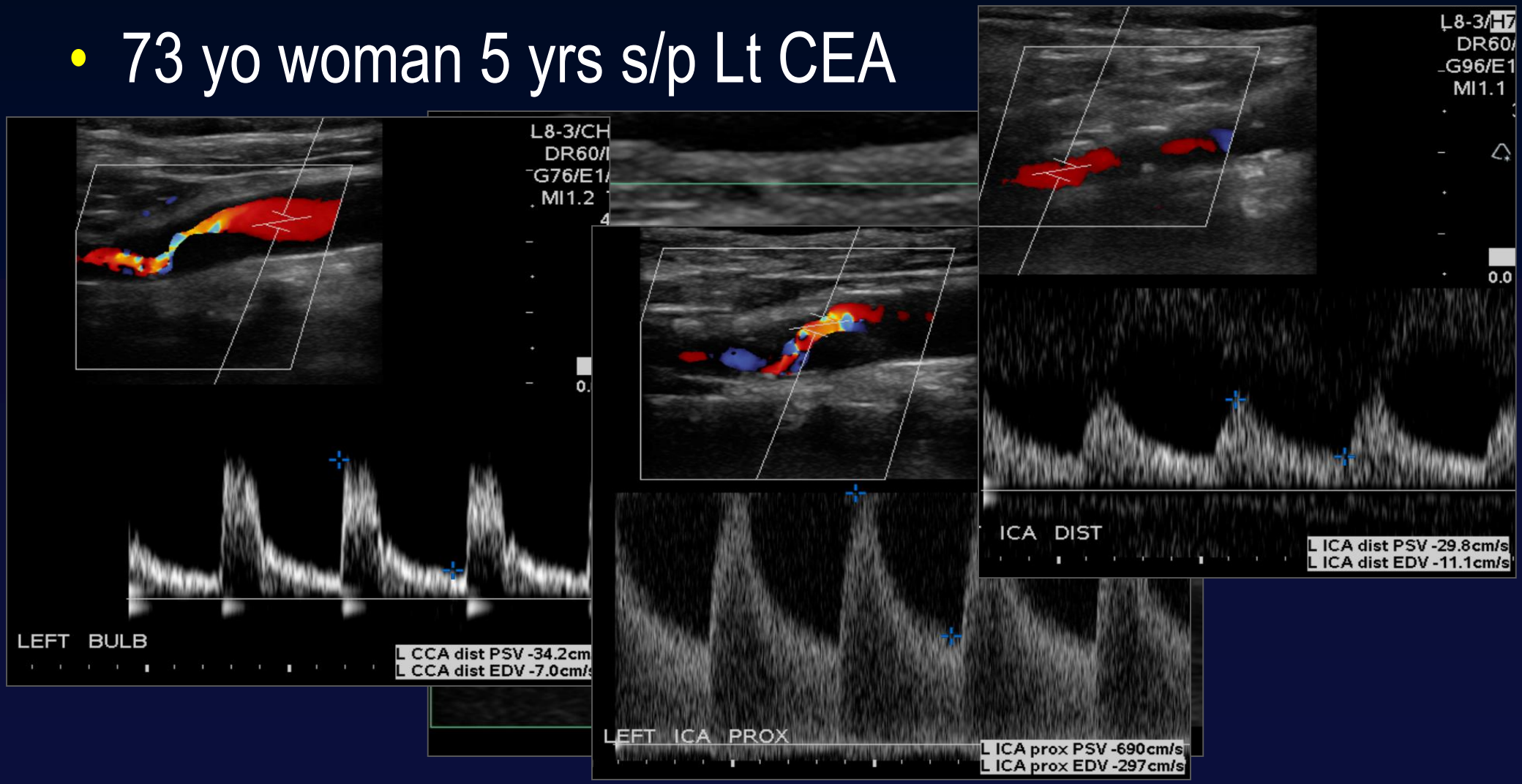
- 64 yr old woman 8 yrs s/p bilateral CEAs, Rt neck bruit

CEA: Restenosis

- 64 yo woman s/p bilateral CEAs

CEA: Restenosis

- 73 yo woman 5 yrs s/p Lt CEA

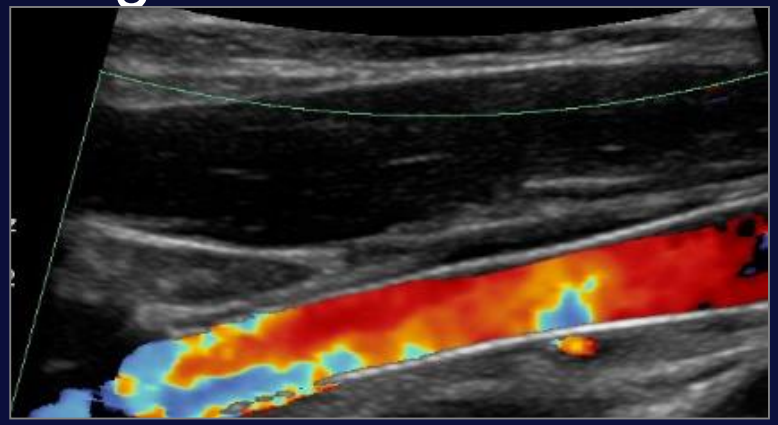


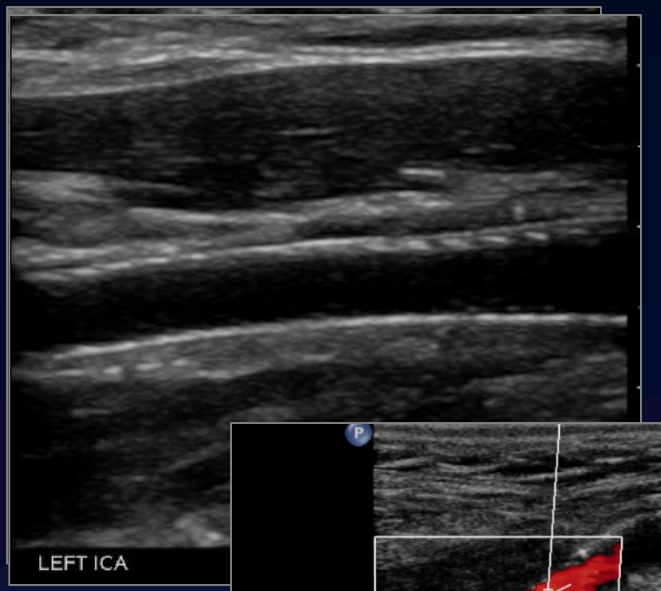
CAROTID STENTS: Restenosis

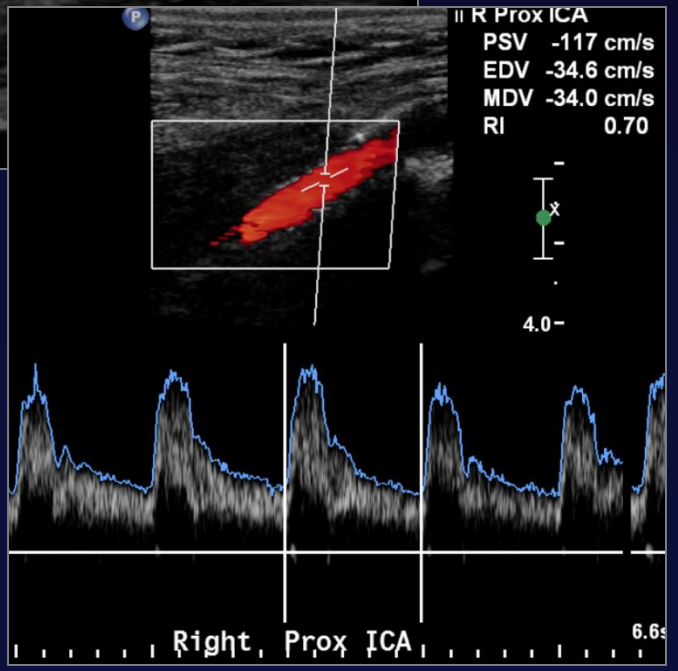
- Similar incidence c/w CEA
  - usu assx, 6 to 14 mo
  - may stabilize after 12 months
- Risk factors: residual stenosis following stent placement, hx of cervical XRT, prior CEA, age, DM, smokers
- F/U recommended every 6 months
  - if stable after 18 months → yearly
  - 50-70% stenosis → continue 6 mo F/U schedule
  - > 75% stenosis or Sx → intervention

CAROTID STENTS

- Change in hemodynamics
- ↑ PSV
  - ↓ compliance of vessel wall
  - partial occlusion of ECA → shunting of blood into ICA

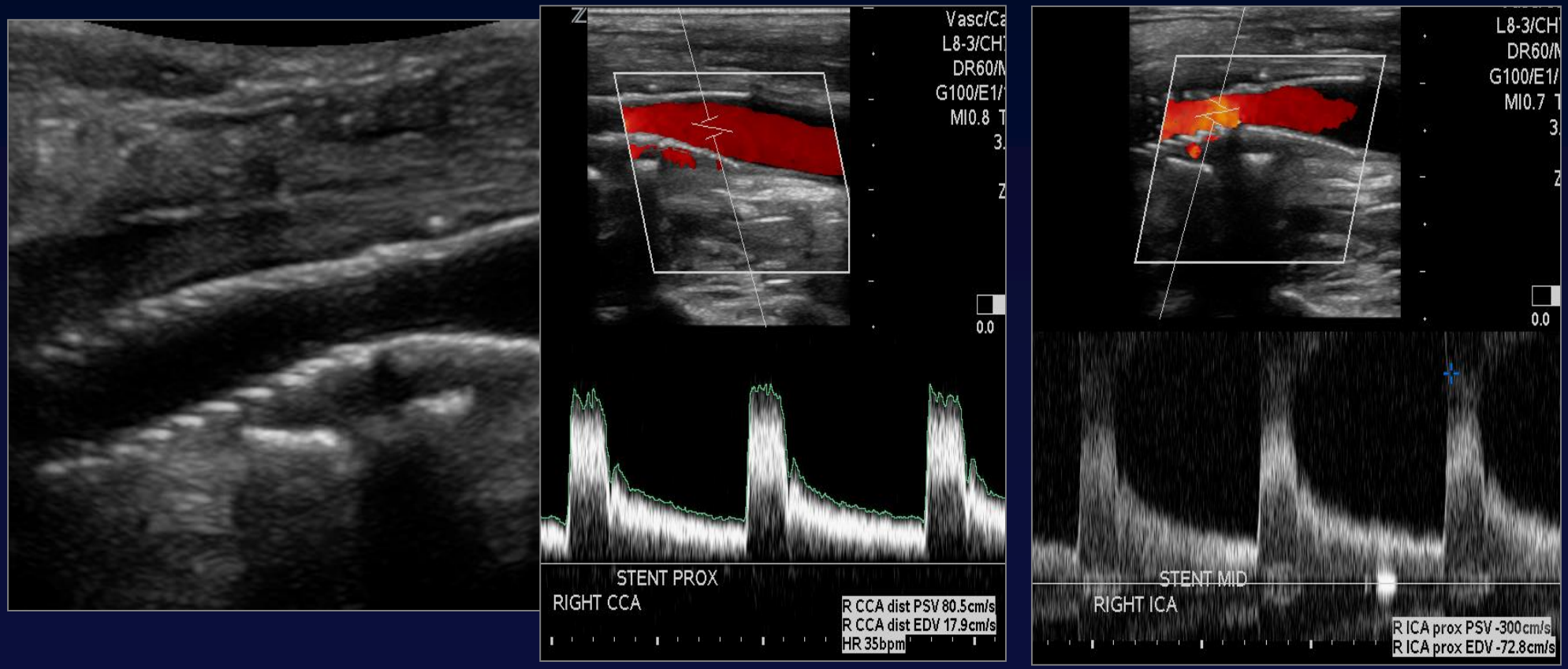






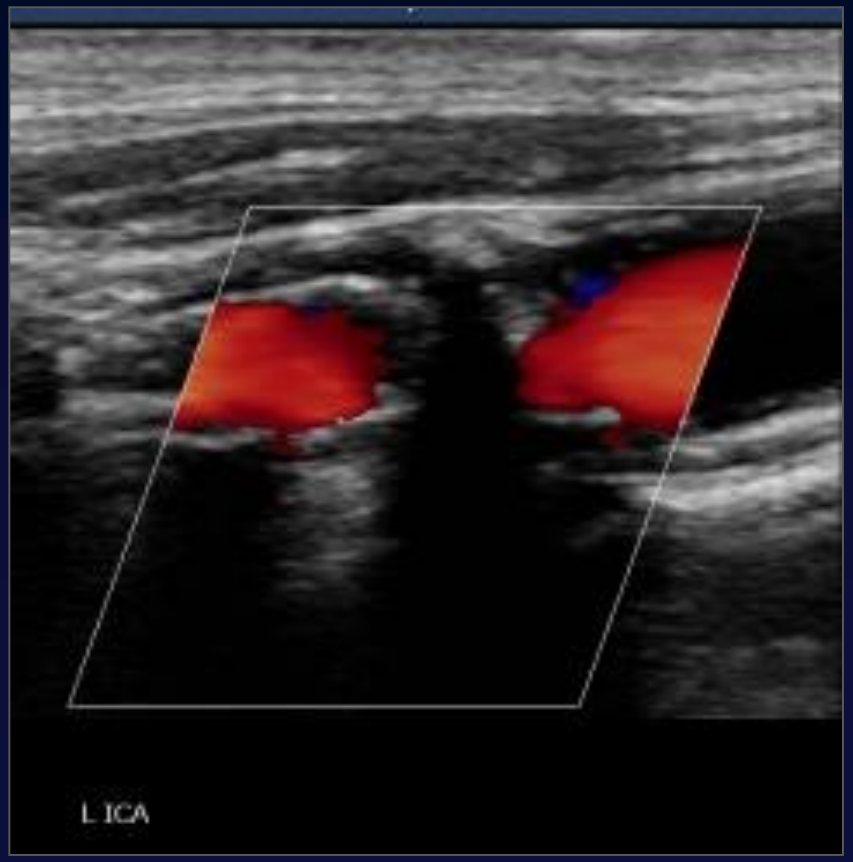
CAROTID STENTS

- Residual “waisting” common

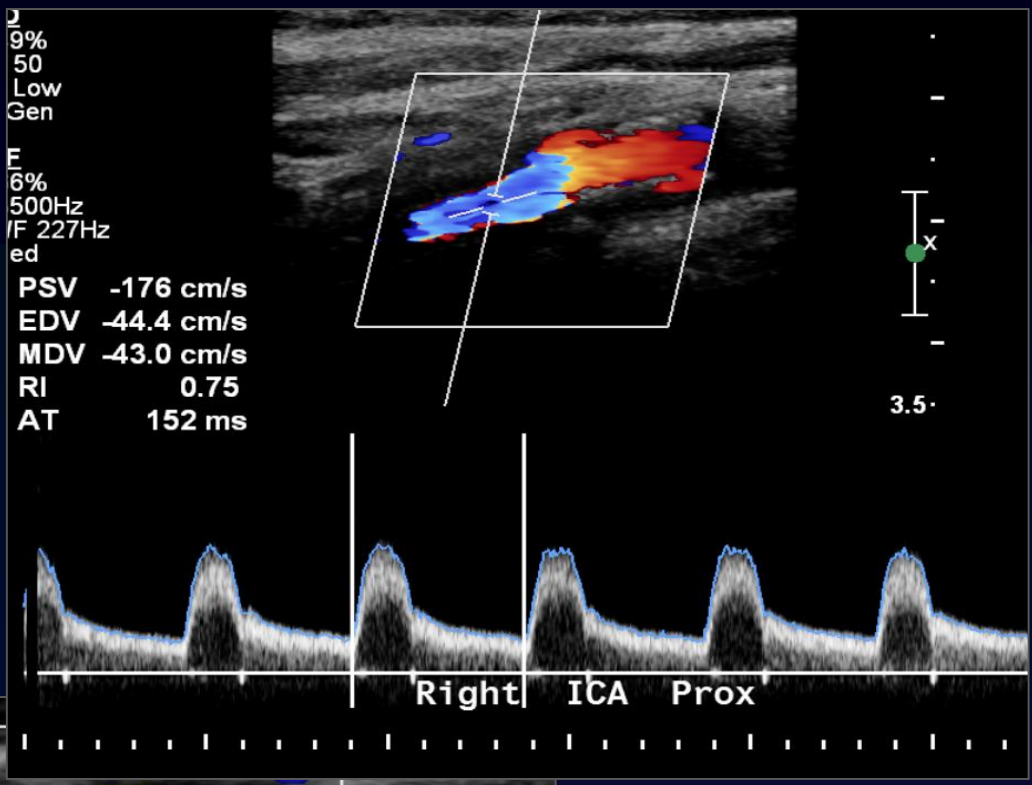


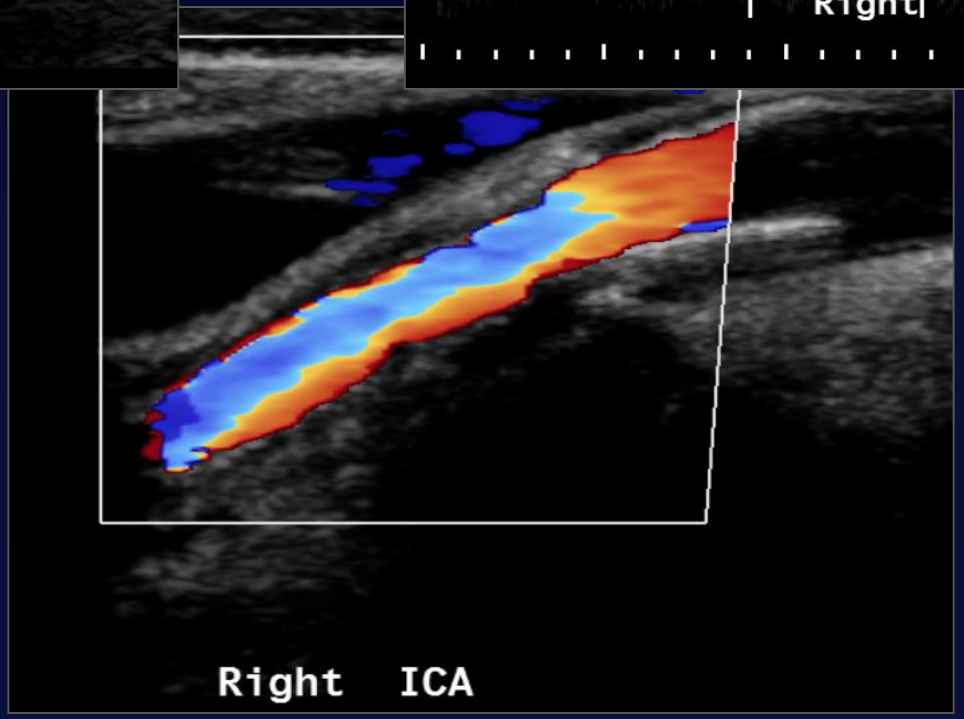
POST-OP APPEARANCE: Carotid Stents

- Excluded, calcified plaque



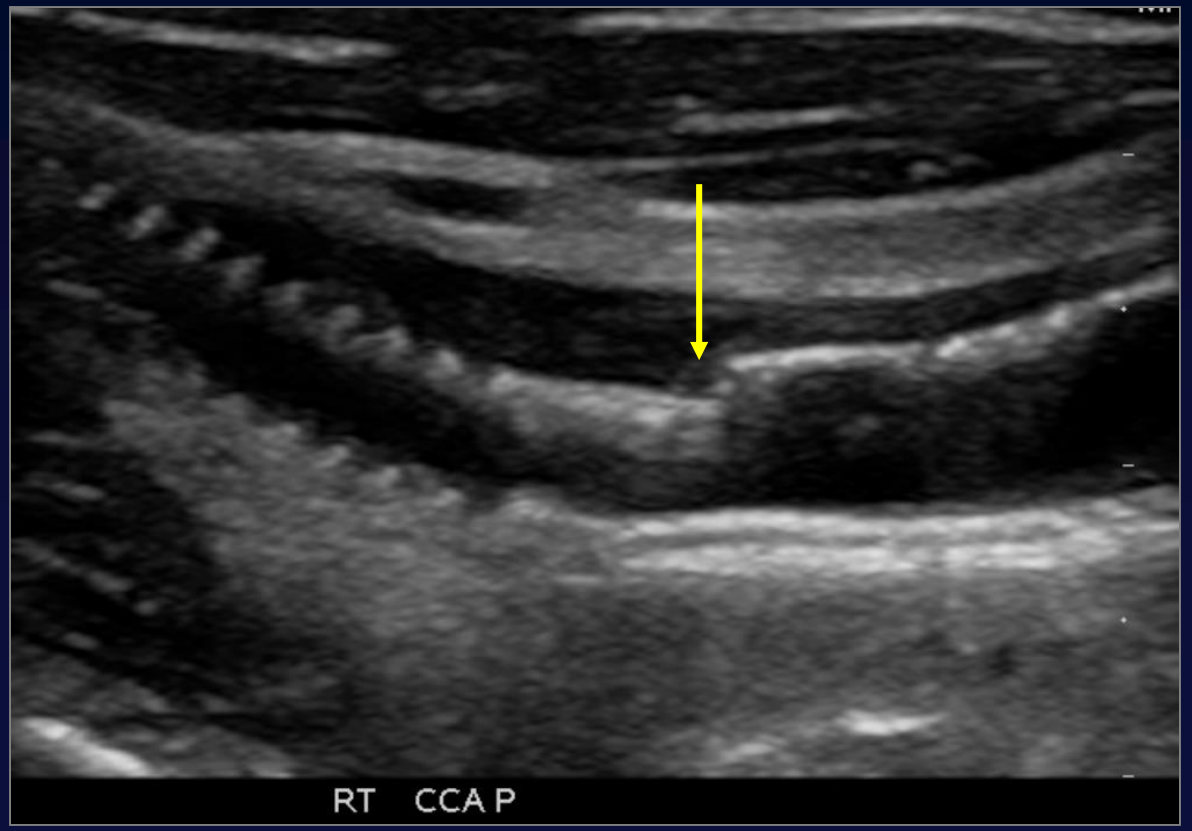

Right ICA Prox Long


9%
50
Low
Gen
F
6%
500Hz
/F 227Hz
ed
PSV -176 cm/s
EDV -44.4 cm/s
MDV -43.0 cm/s
RI 0.75
AT 152 ms
3.5
Right ICA Prox


Right ICA

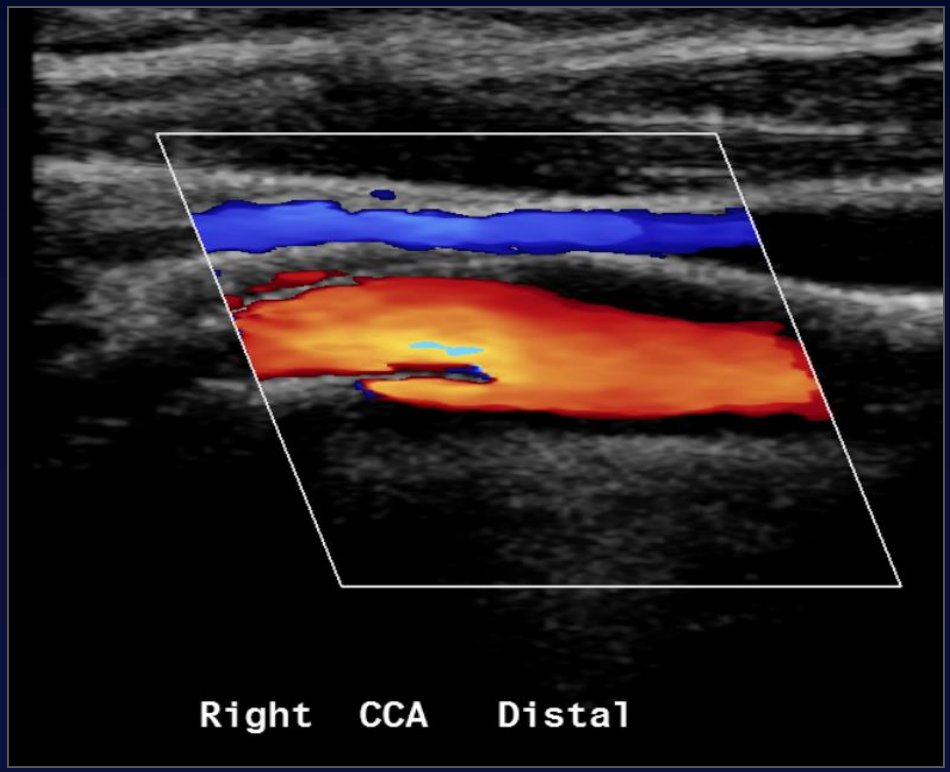
POST-OP APPEARANCE: Carotid Stents

- Overlapping stents
  - step off is NOT a good outcome



POST-OP APPEARANCE: Carotid Stents

- Incomplete apposition of stent to arterial wall
  - NOT a good outcome



CAS: Restenosis

- Lal, J Vasc Surg: 2004
  - < 50% stenosis: PSV < 150 cm/s, PSVR < 2.2
- Chi, CCI: 2007
  - 50-69% stenosis: PSVR >2.45, PSV 240 cm/s
  - > 70% stenosis: PSVR > 4.3, PSV > 450 cm/s
- AbuRahma, J Vasc Surg: 2008
  - ≥ 80% stenosis: PSVR > 4.5, PSV > 325 cm/s
- Zhou, J Vasc Surg: 2008
  - > 70% stenosis: PSVR > 4.0, PSV > 300 cm/s

CAS: Restenosis

- Armstrong, J Vasc Surg: 2007
  - > 50% stenosis: PSV > 150 cm/s
    PSVR > 2.0
  - > 75% stenosis: PSV > 300 cm/s
    EDV > 125 cm/s
    PSVR > 4.0
  - intervene when stenosis is > 75-80%
  - more moderate restenoses are not typically assoc w/ bad clinical outcome

CAS: Restenosis

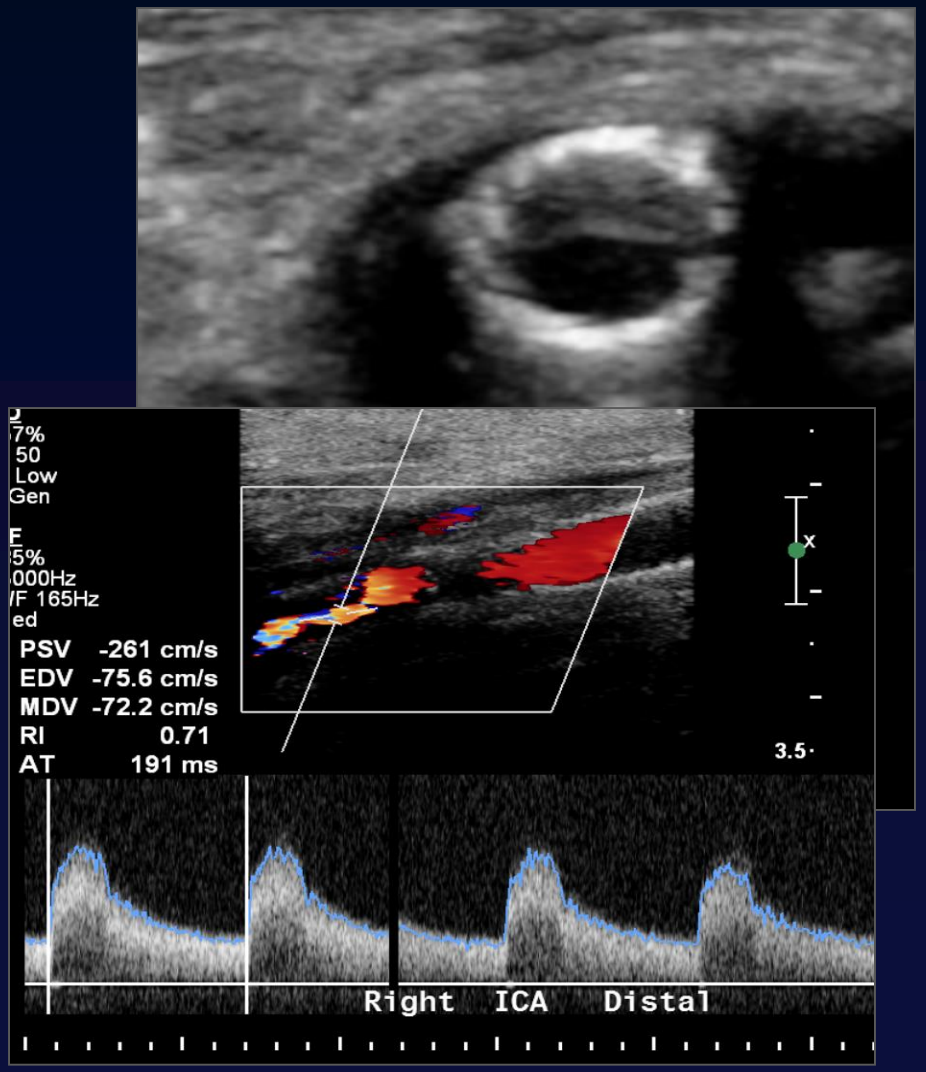
- Ringer, Neurosurgery: 2002
  - absolute PSV not important
  - look for ↑ over time c/w baseline US exam
- Stanziale, J Endovasc Ther: 2005
  - 50-69% stenosis: PSV >225 cm/s
    PSVR > 2.5 – more accurate
  - ≥ 70% stenosis: PSV > 350 cm/s
    PSVR > 4.75 – but low PPV
  - use color Doppler and grey scale images

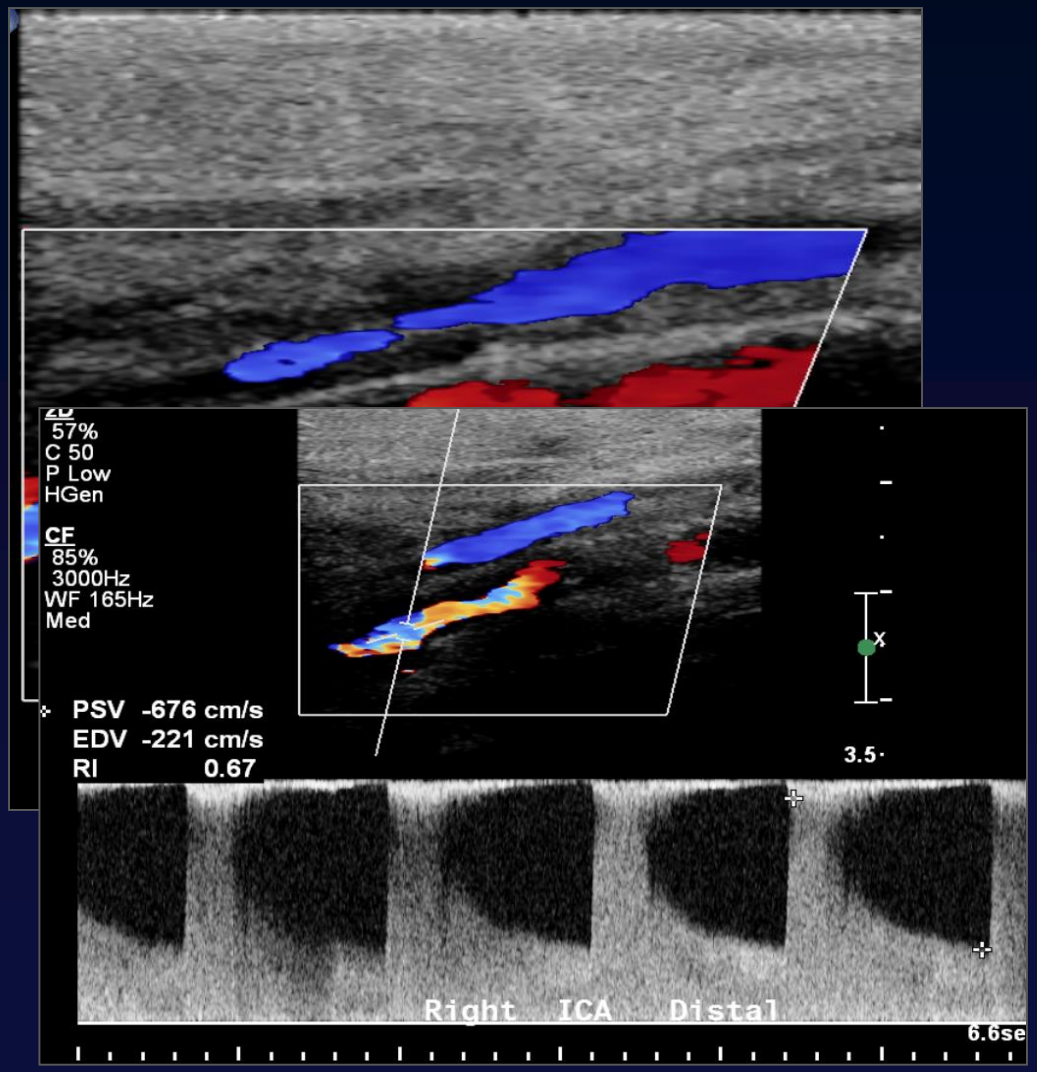
CAROTID STENTS: Restenosis

- All studies agree that PSV and PSVR threshold numbers are likely higher s/p stent placement for a given % stenosis than for the native vessel
- No agreement on numbers
  - may be lab and stent type specific
- Look for ↑ PSV over time
- Correlate carefully with grayscale and color imaging

CAROTID STENTS: ? Restenosis

CAS: Restenosis & Progression of Distal Native Dxs

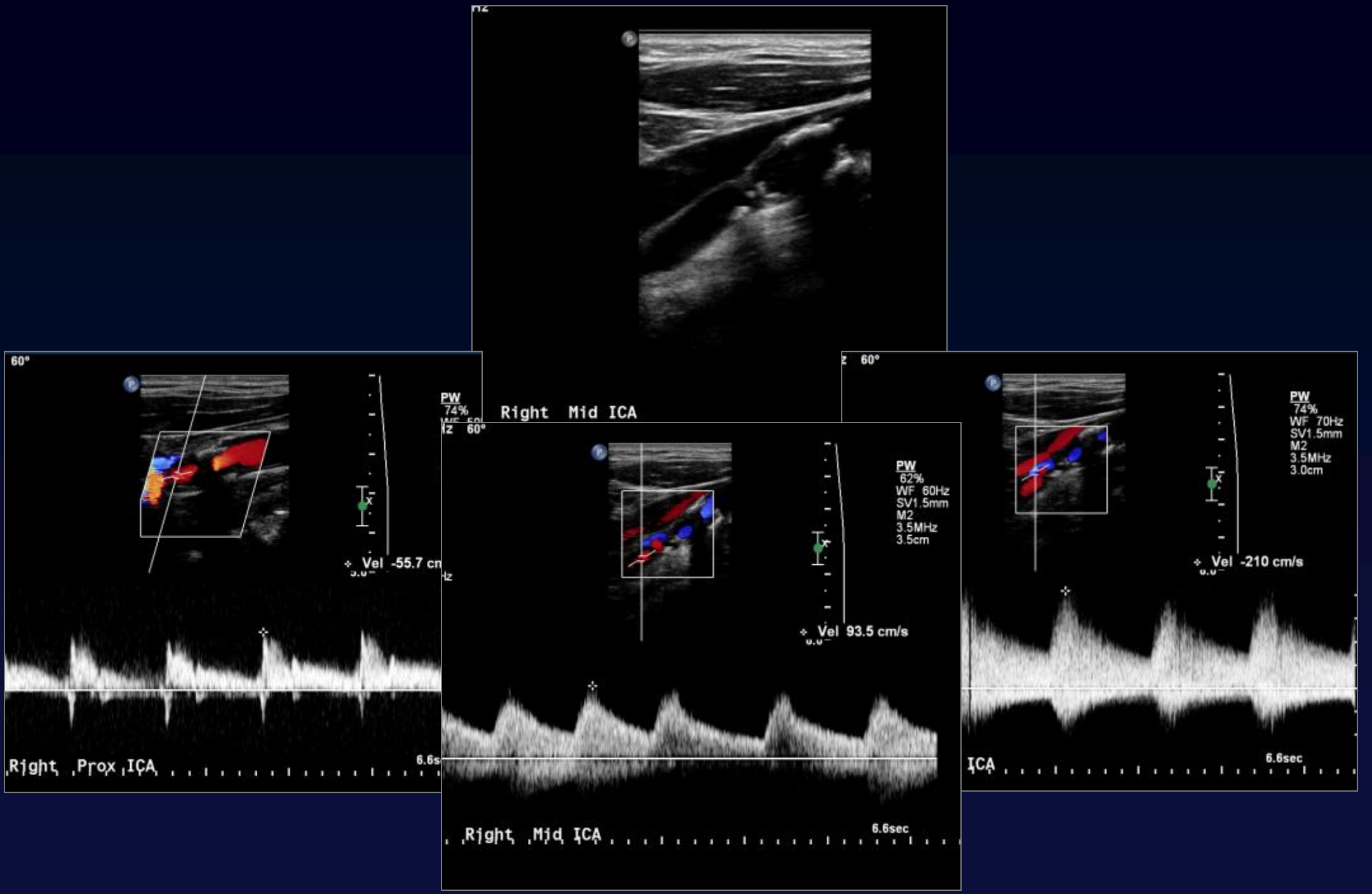




CAROTID STENTS: Progression of Distal Dxs

SUMMARY

- Standard charts aren't going to work for:
  - High or low output states
  - Tortuous vessels, contralateral stenosis/occlusion
  - Tandem lesions, long segment stenoses, near occlusive lesions
- ALWAYS correlate velocity measurements with grayscale/color images as well as waveform analysis


60°
PW
74%
Vel -55.7 cm
Right Prox ICA
6.6s
Right Mid ICA
60°
PW
62%
WF 60Hz
SV1.5mm
M2
3.5MHz
3.5cm
Vel 93.5 cm/s
Right Mid ICA
6.6sec
60°
PW
74%
WF 70Hz
SV1.5mm
M2
3.5MHz
3.0cm
Vel -210 cm/s
ICA
6.6sec

SUMMARY

- Clues for a tight stenosis
  - Lots of plaque
  - TP waveform distally
  - High resistance waveform proximally

SUMMARY

- Tardus Parvus Waveform: Proximal stenosis
  - distribution will tell you where
  - bilateral, all vessels ⟶ severe aortic stenosis
- "Knocking" waveform pattern: Distal obstruction
  - unilateral ⟶ distal occlusion/high grade stenosis
  - bilateral ⟶ ↑ ICP, cerebral edema, vasospasm, bilateral distal occlusions
- Bilateral ↓ EDV w/ ↑ PSV ⟶ aortic regurgitation

SUMMARY

- Doppler thresholds for diagnosis of restenosis s/p CEA and CAS placement are yet to be determined
  - PSV s/p CEA probably lower
  - PSV w/in CAS probably higher
- No consensus
  - look carefully at grayscale and color Doppler
  - change over time
- May be laboratory and stent type specific