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 with 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
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

### \( \geq 70\% \) ICA STENOSIS

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<th>Sens</th>
<th>Spec</th>
<th>Acc</th>
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Grant, Radiology: 1999
### SYMPTOMATIC PATIENTS

#### ≥ 70% ICA STENOSIS

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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 missing a stenosis (F-)
  may be more or less favorable than the consequences of performing unnecessary intervention (F+), depending upon the clinical situation
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
• Premise #2: missing a $\geq 70\%$ 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
≥ 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
  – $F^+ \text{ vs } F^-$ 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
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
PSV = 260 cm/s

? 70-95% stenosis

INCREASED PSV & NO PLAQUE
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
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
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
• 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
- 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
BILATERAL ↓ PSV & EDV in ICAs
BILATERAL $\downarrow$ 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
INTRA-AORTIC BALLOON PUMP

- Inflation of balloon causes 2\textsuperscript{nd} peak of forward flow during early diastole
INTRA-AORTIC BALLOON PUMP

- Inflation of balloon causes 2\textsuperscript{nd} 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 1\textsuperscript{st} OR 2\textsuperscript{nd} 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
• 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
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
CAS vs CEA

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

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 $\rightarrow$ 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
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

  - < 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
  - ≥ 80% stenosis: PSVR > 4.5, PSV > 325 cm/s
  - > 70% stenosis: PSVR > 4.0, PSV > 300 cm/s
CAS: Restenosis

  - > 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
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