Carotid Duplex Ultrasonography: What Every Vascular Specialist Must Know

Michael R. Jaff, DO, FACP, FACC
Professor of Medicine
Harvard Medical School (leave of absence)
Chief Medical Officer
Boston Scientific Corporation

Michael R. Jaff, D.O. Conflicts of Interest

Part-Time Employee

Boston Scientific Corporation

Consultant

Gilde Healthcare

Equity Shareholder

Access Vascular
Boston Scientific
Efemoral
Embolitech
Gemini
Nectero
Primacea
PQ Bypass
Janacare
R3 Vascular
Vactronix
Venarum
Vascular Therapies

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Carotid Duplex Ultrasonography

- Highly accurate and reliable test
- **Advantages**
  - Direct visualization of the extracranial carotid arteries
  - Accurate determination of degrees of stenosis
  - Assess presence and morphology of plaque
  - Useful tool to evaluate revascularization procedures
  - Identify non-atherosclerotic carotid artery abnormalities
    - Carotid Dissection
    - Fibromuscular Disease
    - Trauma
- Despite criticisms, surgeons have *successfully* performed carotid endarterectomy on the basis of duplex ultrasonography alone

64 year old RH WM

- First routine physical exam in 20 years
- Obtained for reduction in insurance premiums
- Feels well
- No TIA/CVA symptoms
- No angina, DOE
- No intermittent claudication

64 yo RH WM

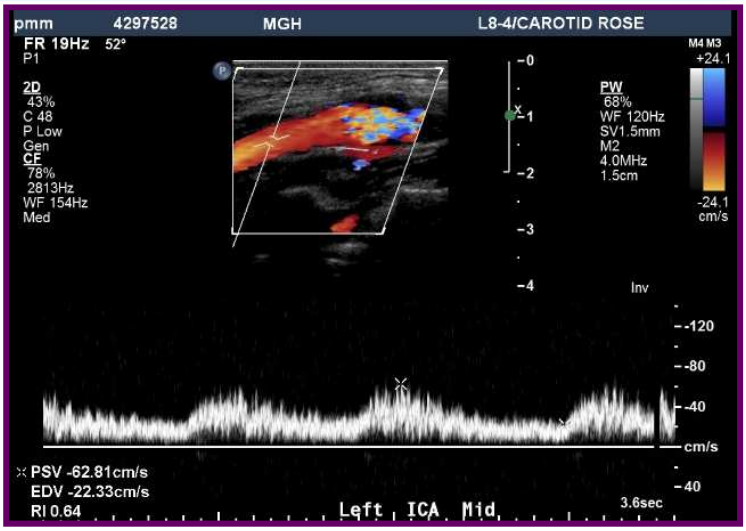
- Stopped smoking 2 years ago
  - Prior 1.5 PPD for 35 years
- No hyperlipidemia
- No diabetes mellitus
- “Borderline” hypertension 20 years ago
- No medications

64 yo RH WM

- Blood Pressure 160/106 bilateral
- Pulse 82
- Harsh left cervical systolic bruit at angle of jaw
- No right cervical bruit
- No diastolic bruit
- No cardiac murmur
- No palpable AAA
- Normal lower extremity pulses

Carotid Duplex Ultrasonography Ipsilateral to Bruit

Post-Stenotic Turbulence



Indications for Cerebrovascular Duplex Scanning

- Cervical bruit in an asymptomatic individual
- Amaurosis Fugax
- Transient Ischemic Attack
- Stroke in a potential candidate for CEA or stent
- Follow-up of known stenosis (>20%) in asymptomatic individuals
- Follow-up after carotid endarterectomy or stent
- Intraoperative assessment of carotid endarterectomy
- Drop attacks (rare)

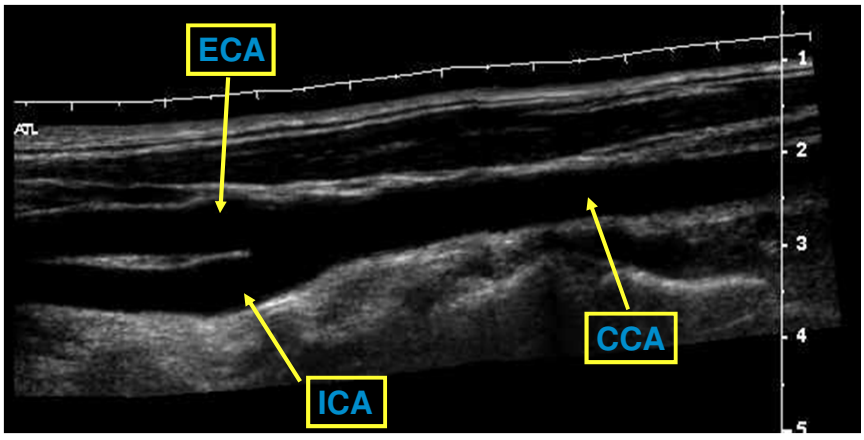
Carotid Duplex Ultrasonography—The Steps

- Evaluate anatomy/plaque morphology with B-mode imaging
- Evaluate hemodynamic patterns by spectral analysis of pulsed Doppler flow signals
- Small sample volume allows characterization of flow patterns at specific sites in the arterial lumen

Carotid Duplex Ultrasonography

- Technique--Gray Scale, Color, Doppler
  - Common Carotid Artery
    - – Proximal, Mid-, Distal Vessel
      - Transverse, Longitudinal View
  - Carotid Bifurcation
    - – Transverse, Longitudinal View
  - Internal Carotid Artery
    - – Proximal, Mid-,Distal Vessel
      - Transverse, Longitudinal View
  - External Carotid Artery
    - – Proximal Vessel

Gray Scale Carotid Duplex Scan

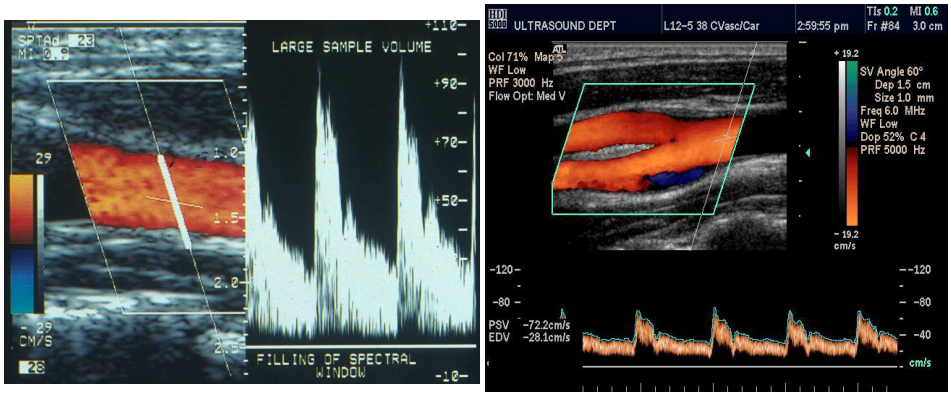


Basics of Carotid Duplex Ultrasound

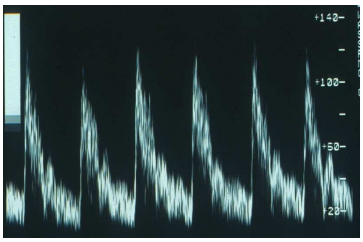
(Spectral Analysis and Color Flow Imaging)

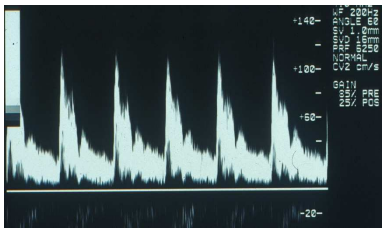
- Spectral waveforms are represented with Doppler velocity shift on the vertical axis.
- Time is represented on the horizontal axis
- Amplitude is indicated by a gray scale
  - amplitude is proportional to the number of blood cells passing through the sample volume
- Normal center stream arterial flow is laminar
  - spectral waveforms show a narrow band of frequencies
- Arterial lesions disturb normal flow
  - spectral broadening represents flow occurring at a wider range of frequencies and amplitudes

Sample Volume



Spectral Broadening





Spectral Waveform Characteristics

- Internal Carotid Artery
  - Low Resistant Vascular Bed
    - Persistent End-Diastolic Flow
- External Carotid Artery
  - High Resistant Vascular Bed
    - Minimal End-Diastolic Flow
- Common Carotid Artery
  - Reflects flow in both the Internal and External Carotid Artery
- Vertebral Artery
  - Low Resistant Vascular Bed
    - Persistent End-Diastolic Flow

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Normal Carotid DUS

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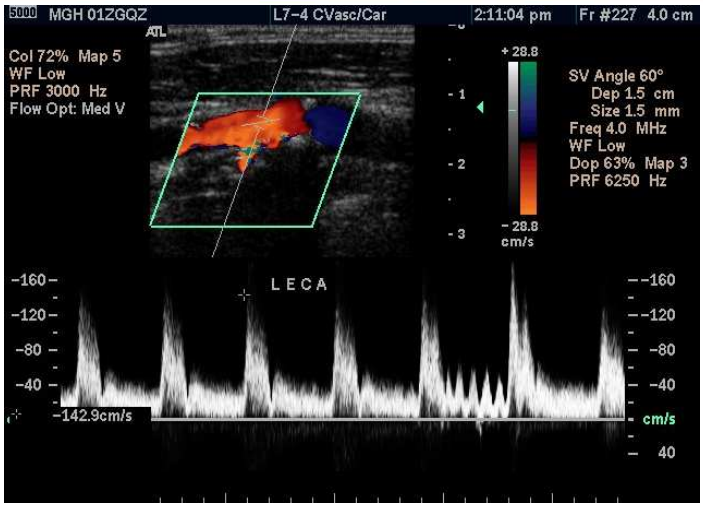
Normal Carotid DUS

Temporal Tap



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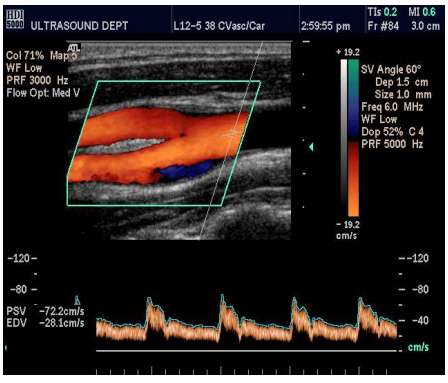
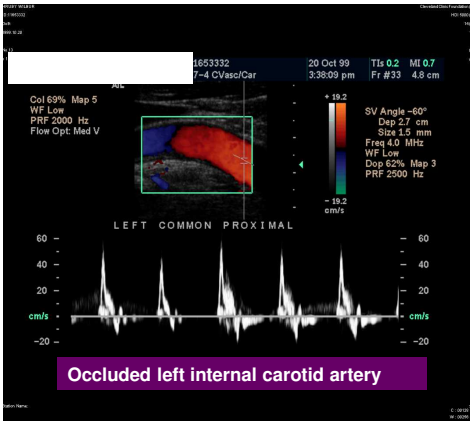
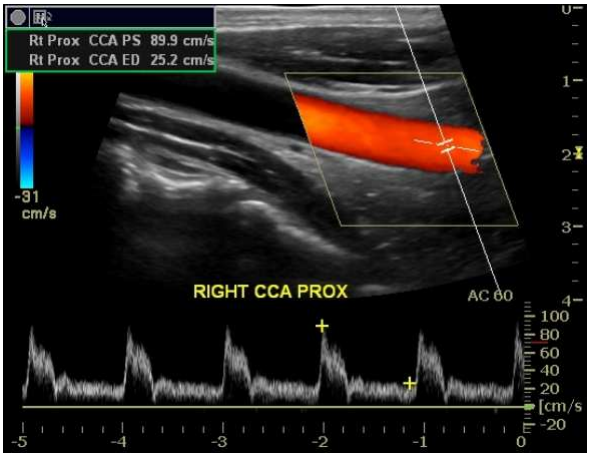
Normal Carotid DUS

Common Carotid Artery

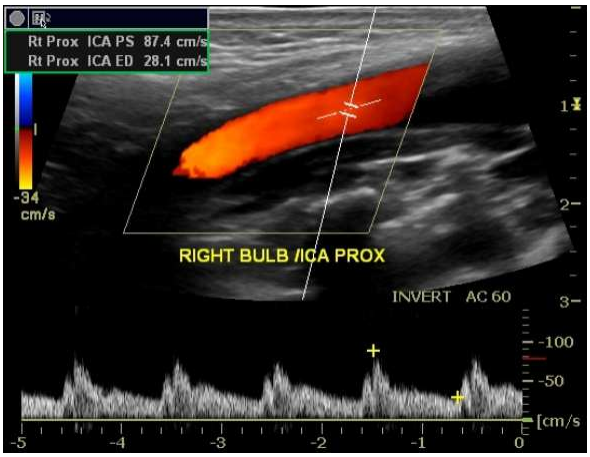




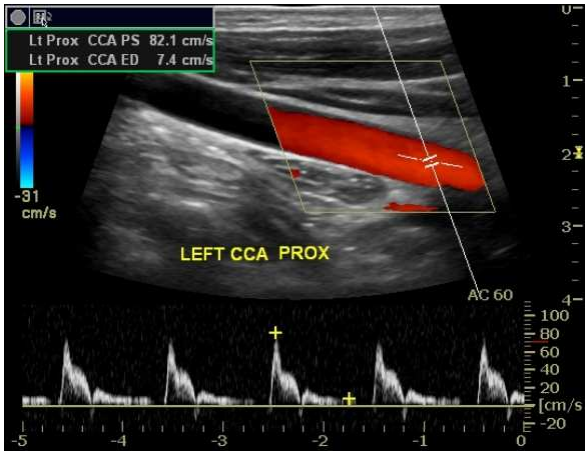
Normal common carotid waveform



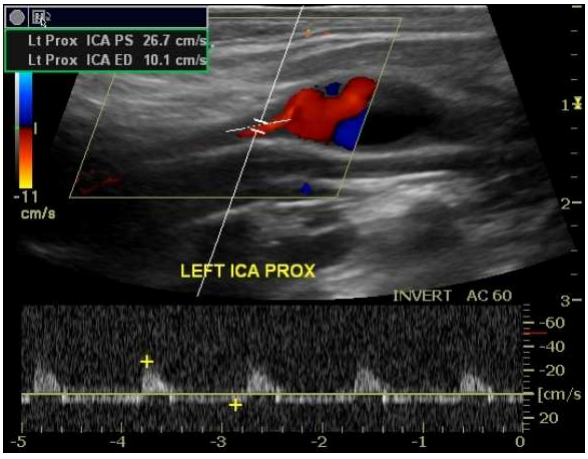
Normal internal carotid artery waveform



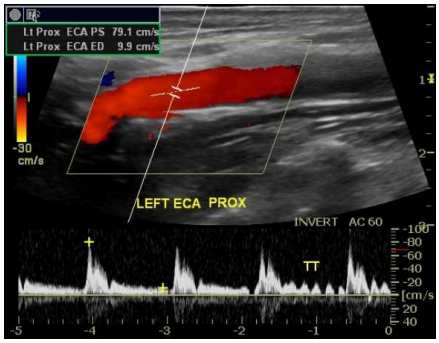
Externalized common carotid artery waveform



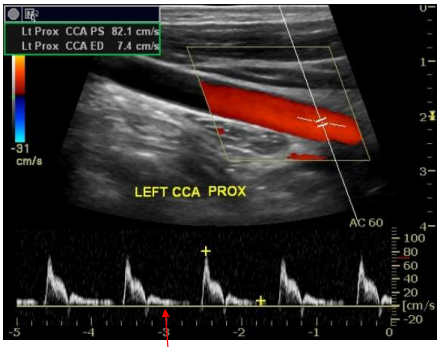
Internal carotid artery pre-occlusion



Externalization means “to look like the external carotid artery”

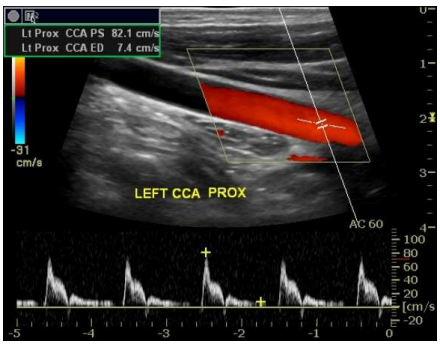


This signifies high resistance “upstream” such as internal carotid artery occlusion.



High resistance waveform with low diastolic flow.

Compare these common carotid artery waveforms



More diastolic flow

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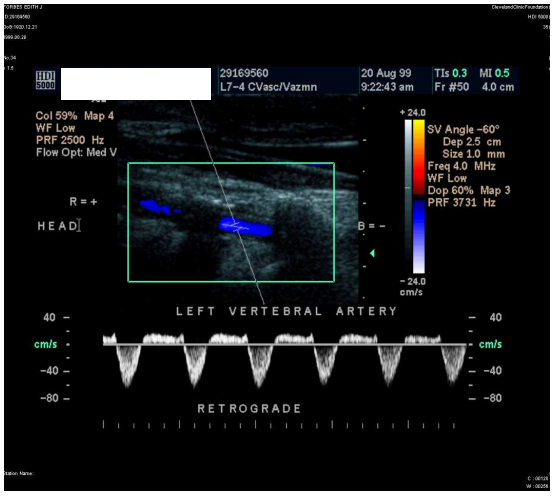
- Vertebral Artery
  - Low Resistant Vascular Bed
    - – Persistent End-Diastolic Flow

Normal Vertebral Artery

Vertebral Artery

- Origin is often difficult to visualize because of its location under the clavicle
- Lies deep to CCA and is located between the spinous processes
- Low resistance waveform
- Assess direction of flow (i.e. subclavian steal)

Subclavian Steal

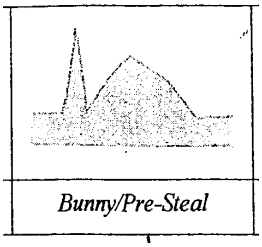


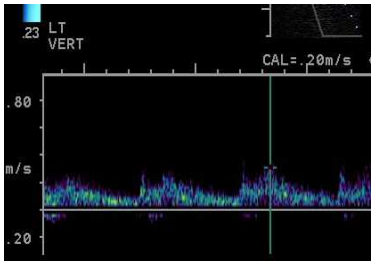
Latent or occult subclavian steal

Vertebral artery flow:

- **Initial systolic peak with antegrade flow**
- **Brief retrograde flow/ systolic deceleration or 'pre-steal"**
- **Prolonged antegrade diastolic flow**

Convert: to a complete steal with reactive hyperemia via a BP cuff applied for 3 min [with release] or arm exercise

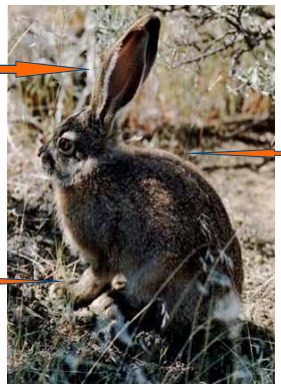




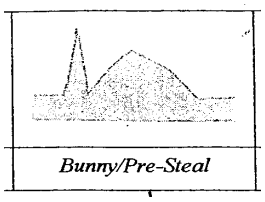
The Vertebral Artery: *Latent* or *occult* subclavian steal

Initial systolic peak with antegrade flow

Brief retrograde flow/ systolic deceleration or 'pre-steal"



Prolonged antegrade diastolic flow



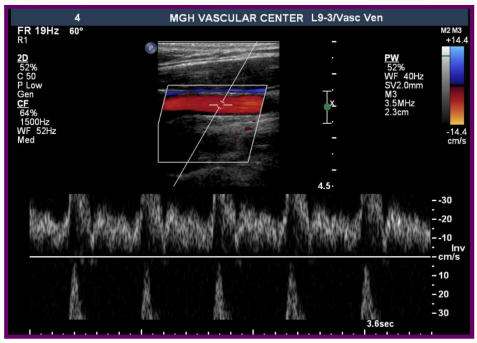
Basics of Carotid Duplex Ultrasound
(Spectral Analysis and Color Flow Imaging)

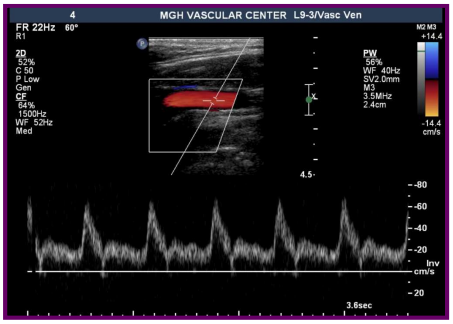
- Color flow imaging is based on pulsed Doppler ultrasound and thus is subject to the same physical limitations as pulsed Doppler imaging with spectral analysis
  - Doppler frequency shift depends on beam to vessel angle
  - Color assignments will only be accurate if the angle is set properly and remains constant along the length of the vessel
  - Since vessels are rarely straight, color differences may represent true velocity changes or variations in frequency shift resulting from changes in Doppler angle

Basics of Carotid Duplex Ultrasound
(Spectral Analysis and Color Flow Imaging)

- Aliasing
  - Spectral analysis
    - abrupt loss of waveform above the Nyquist limit, with the missing portion appearing below the baseline as flow in the reverse direction
- Color flow image
    - high-velocity jets are assigned colors that indicate flow in the direction opposite to the arterial flow

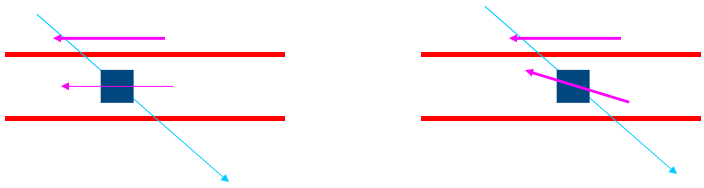
Aliasing



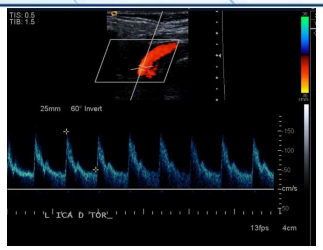


Carotid Duplex Ultrasound

- Pulsed Doppler Evaluation
- *DOPPLER ANGLE REQUIREMENTS*
  - **≤60%**
  - **Angle correction**
  - **Cursor aligned parallel to vessel wall**
  - **Follow-up exams use same Doppler angles of insonation**



The Importance of a Correct Doppler Angle

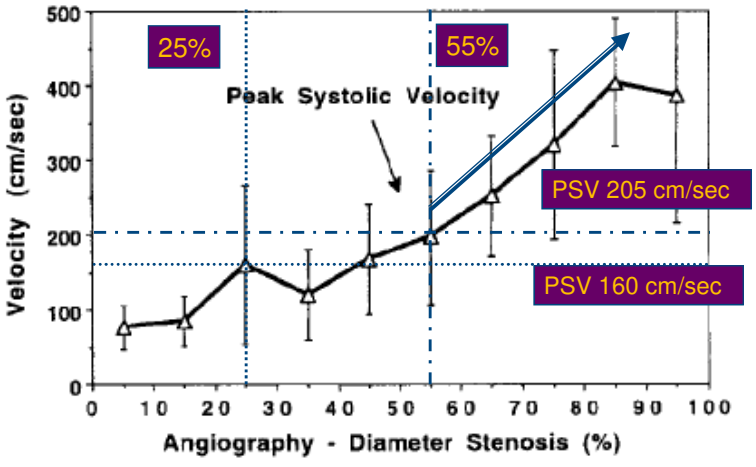


CV Doppler Measurements

	PS cm/s	ED cm/s	S/D	TAV cm/s	PI	RI	Angle °
R Prox CCA	50.5	15				0.7	60
R Dist CCA	61.3	16.2				0.74	60
R Prox ICA	-83	-26.5				0.68	60
R Dist ICA	-110.6	-34.9				0.68	60
L Prox CCA	71.6	16.8				0.77	60
L Dist CCA	66.7	14.4				0.78	60
L Prox ICA	-83	-24.1				0.71	60
L Dist ICA	-148.6	-50.2				0.66	60

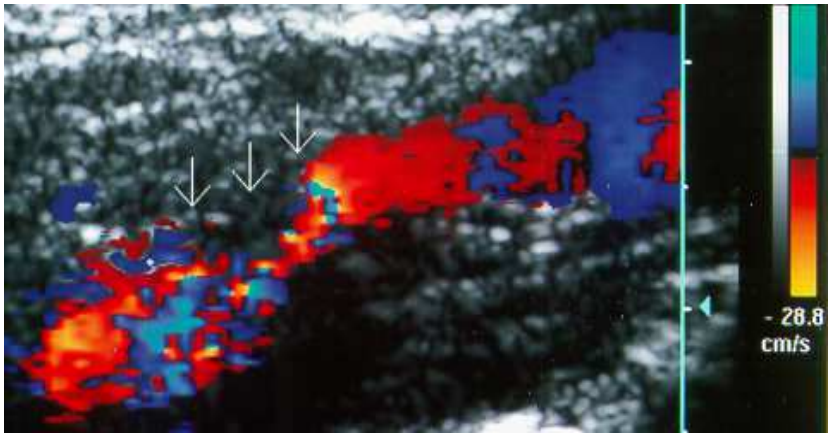
The angle should never exceed 60^0

What is the Relationship Between PSV and Carotid Arteriographic Stenosis

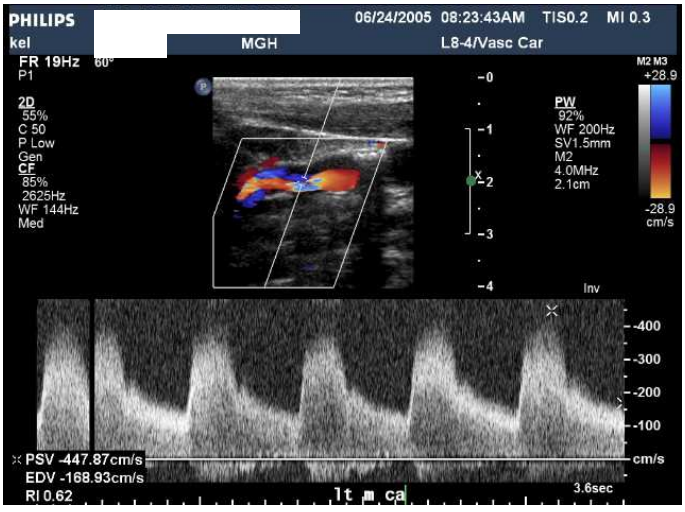


Radiology 2000;214:247-252

Carotid Duplex Ultrasonography



80-99 % Internal Carotid Artery Stenosis



Cleveland Clinic Criteria for Duplex Ultrasound Determination of ICA Stenosis

	Velocity Criteria, cm/sec	Spectral Broadening
0-19%	≤ 105	No
20-39%	≤ 105	Yes
40-59%	> 105, ≤ 150	Yes
60-79%	> 150, ≤ 220	Yes
80-99%	> 220 ***AND*** End Diastolic Velocity ≥ 135	Yes
Occluded	No Doppler Signal, Pre-Occlusive Thump	'High Resistant' CCA signal

SRU Consensus Panel Criteria for Grading ICA Stenosis

Consensus Panel Gray-Scale and Doppler US Criteria for Diagnosis of ICA Stenosis

	Primary Parameters		Additional Parameters	
Degree of Stenosis (%)	ICA PSV (cm/sec)	Plaque Estimate (%)*	ICA/CCA PSV Ratio	ICA EDV (cm/sec)
Normal	<125	None	<2.0	<40
<50	<125	<50	<2.0	<40
50–69	125–230	≥50	2.0–4.0	40–100
≥70 but less than near occlusion	>230	≥50	>4.0	>100
Near occlusion	High, low, or undetectable	Visible	Variable	Variable
Total occlusion	Undetectable	Visible, no detectable lumen	Not applicable	Not applicable

Radiology 2003;229:340-346

MGH Criteria

ICA Qualitative Stenosis	% Stenosis	PSV	EDV	ICA / CCA Ratio
Normal	0-19%	<105 cm / sec	---	---
Mild	20-49%	≥ = 105 – <150 cm / sec	---	---
Moderate	50-69%	≥ =150 – <250 cm / sec	---	≥2.0-<4.0
Severe	70-89%	≥ 250 cm /sec	<135 cm/ sec	≥ 4.0
Very severe	90-99%	≥ 250 cm/ sec	≥135 cm /sec	≥ 5.0
Occluded	100%	---	---	---

No Surprise That There Are *So Many* Different Diagnostic Criteria….

Publication	Grayscale imaging[†]	PSV (cm/s)	EDV (cm/s)	ICA-to-CCA PSV ratio	St Mary ratio[§]	Prestenotic flow (CCA EDV)	Poststenotic flow disturbances	Collateral flow
>50% stenosis								
Grant *et al.* 2003 (29)	+	>125	>40	>2.0	–	–	–	–
Oates *et al.* 2009 (43)	–	>125	–	>2.0	>8.0	–	–	–
Arning *et al.* 2010 (45)	–	>200	–	>2.0	–	–	Moderate	Not present
von Reutern *et al.* 2012 (36)	+	>125	–	>2.0	–	–	Moderate	Not present
Jogenstrand *et al.* 2012 (46)	–	> 230	–	–	–	–	–	–
Mozzini 2016 *et al.* (47)	–	>200	–	>2.0	–	–	–	–
>70% stenosis								
Grant *et al.* 2003 (29)	+	>230	>100	>4.0	–	–	–	–
Oates *et al.* 2009 (43)	–	>230	–	>4.0	>14.0	–	–	–
Arning *et al.* 2010 (45)	–	>300	>100	>4.0	–	–	Present	Present
von Reutern *et al.* 2012 (36)	–	>230	>100	>4.0		Reduced	Present	Present
Jogenstrand *et al.* 2012 (46)	–	>320	–	–	–	–	–	–
Mozzini 2016 *et al.* (47)	–	>300	>100	>4.0	–	Reduced	–	–

Ann Translational Med 2020;8(19): 1270

Pitfalls of Carotid Duplex Imaging

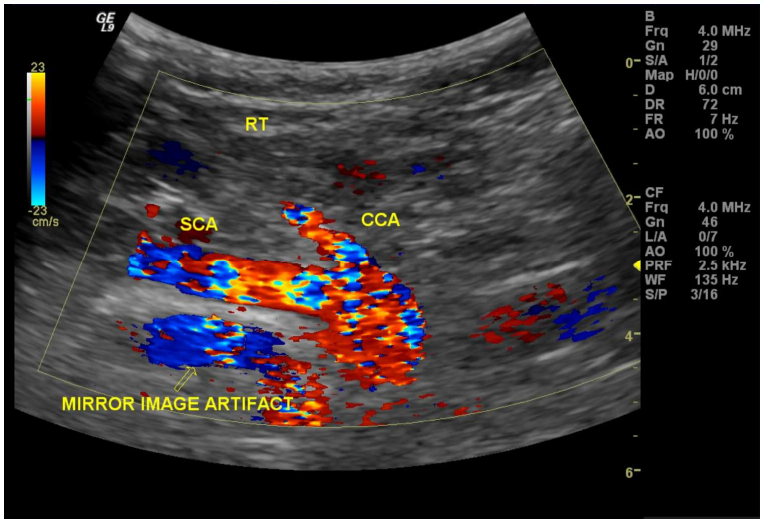
- Multiple instruments/probes
- Multiple Doppler angles
- Misidentification of a pulsatile vein for the internal carotid artery
- Misidentification of the external carotid as the internal carotid artery
  - i.e. External carotid artery with significant stenosis
- Tortuous vessels
- Failure to survey the distal internal carotid artery
- Failure to interrogate the common carotid or innominate arteries
- Near total occlusion ("string sign")
- Calcification
- Spot Doppler assessment

Interpretation Errors

- Using published criteria without internal validation
- Effect of cardiac output
- Effect of intracranial ICA occlusion
- Tandem lesions
- Contralateral disease
- Extensive disease in
- Systolic decel
- Innomin
- C ythmias
- of patch angioplasties
- Effect of stent in ICA
- Using visual means for determining degree of stenosis

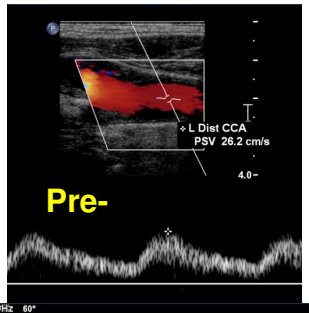
Only Looking at Numbers on a Report!!!

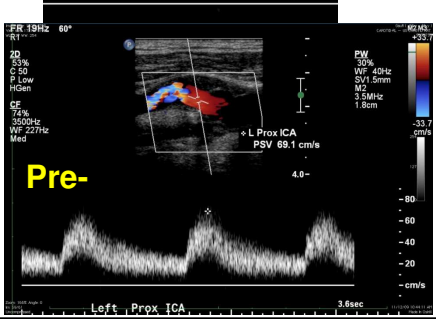
Mirror Image Artifact



To Avoid Making Interpretation Mistakes, Look for **Three** Components:

1





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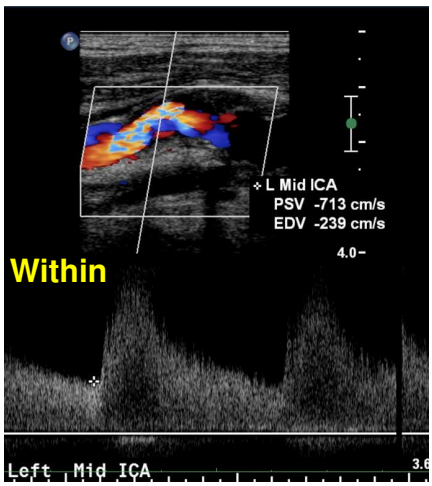
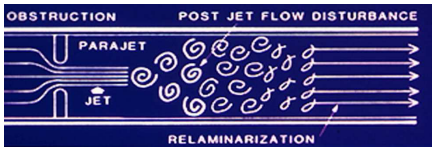
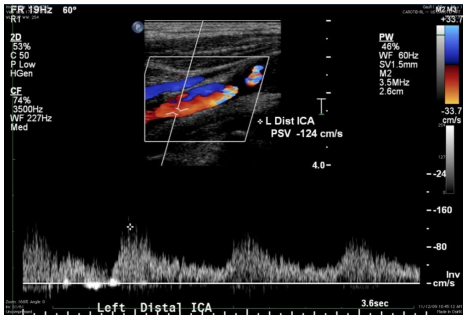


Distal to the Stenosis

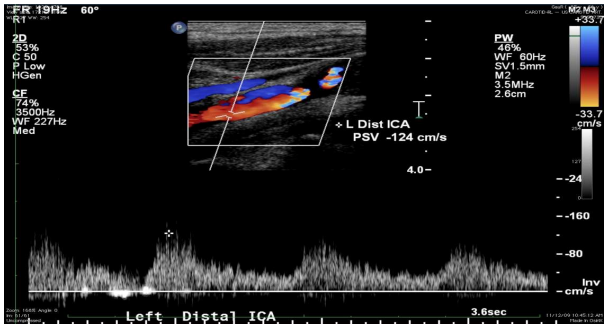
- Change from *small lumen to large lumen* destabilizes flow
  - Jet spreads out
- *High velocity* also destabilizing
  - Frank breakdown of regular flow disturbed flow (and evenually turbulence)

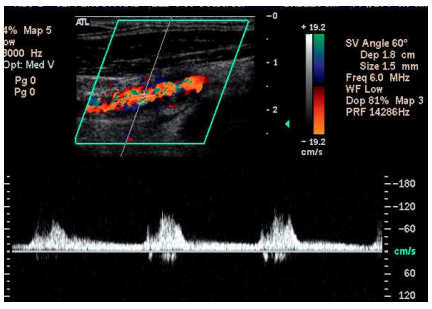




3

Post-stenotic Turbulence





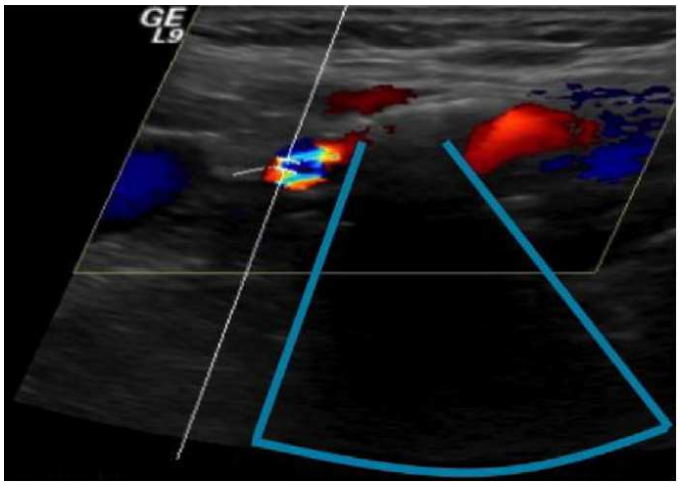
What about the Dreaded Acoustic Shadowing?

Acoustic shadowing impairs accurate characterization of stenosis in carotid ultrasound examinations

Jahan Mohebali, MD, MPH,[a] Virendra I. Patel, MD, MPH,[a,b] Javier M. Romero, MD,[c] Kathleen M. Hannon, MS,[d] Michael R. Jaff, DO,[b,d] Richard P. Cambria, MD,[a,b] and Glenn M. LaMuraglia, MD,[a,b] *Boston, Mass*

J Vasc Surg 2015;62:1236

Acoustic Shadowing due to Calcified Plaque



J Vasc Surg 2015;62:1236

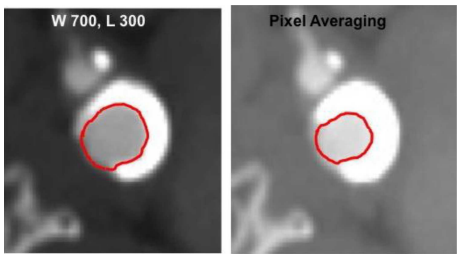
What about the Dreaded Acoustic Shadowing?

- July 2012-December 2013
  - 8570 carotid DUS at MGH
  - 550 with acoustic shadowing (6.5%)
- 85 had carotid CTA performed within 6 months of the DUS
- 17 classified as severe on DUS
- 31 classified as moderate on DUS
- 37 classified as mild on DUS

J Vasc Surg 2015;62:1236

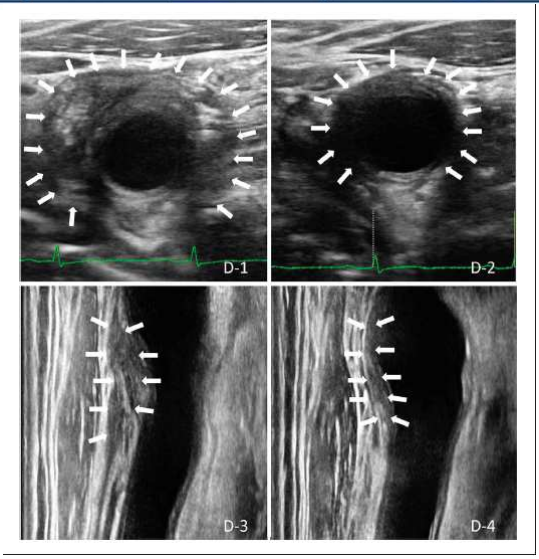
Acoustic Shadowing due to Calcified Plaque

	Duplex performance parameter			
Standard method	*Sensitivity*	*Specificity*	*Positive predictive value*	*Negative predictive value*
MD-CTA-ECST	22.7 (13.6-34.9)	89.4 (65.4-98.1)	88.2 (62.2-97.9)	25 (15.6-37.2)
MD-CTA-NASCET	32.5 (19.0-49.2)	91.1 (77.8-97.1)	76.4 (49.7-92.1)	60.2 (47.6-71.7)



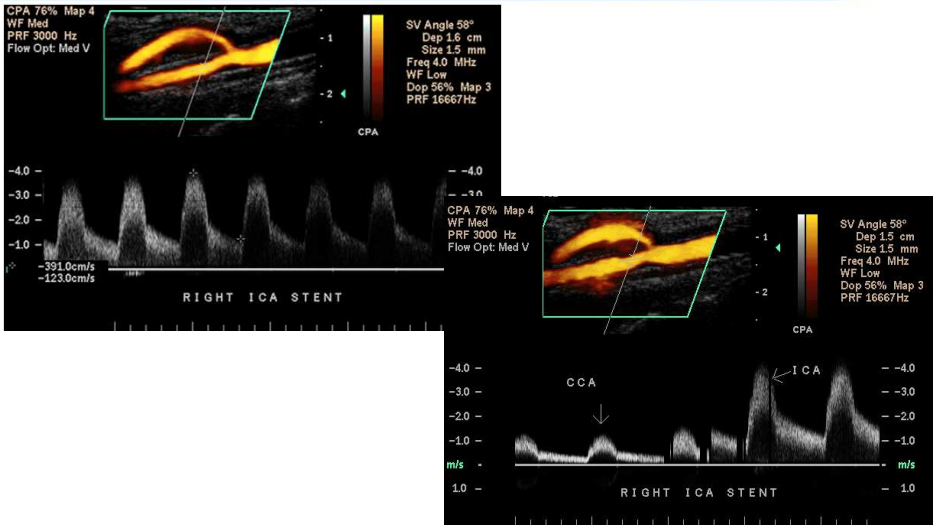
J Vasc Surg 2015;62:1236

What About Giant Cell Arteritis?

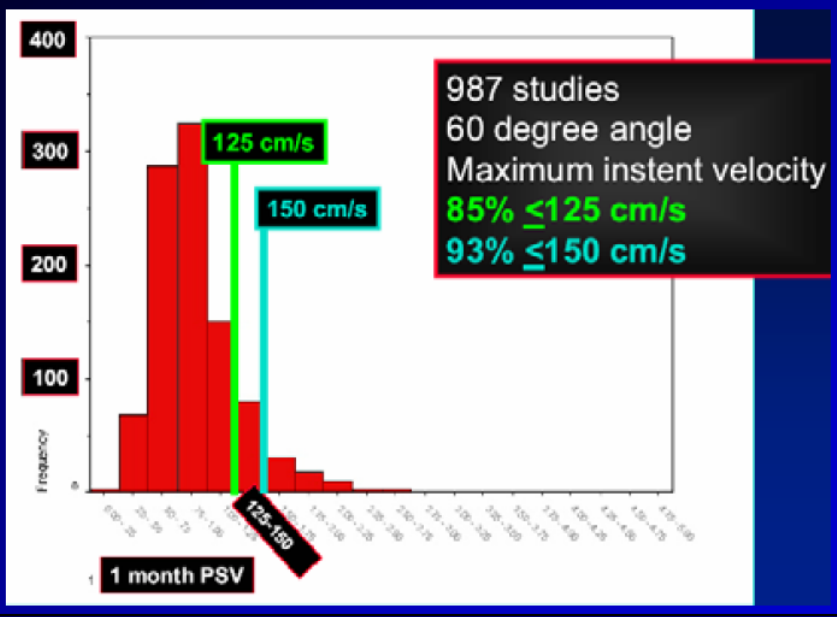


Vasc Med 2021

Carotid In-Stent Restenosis



CREST Core Lab Data – 1 month after CAS



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Carotid Stent Duplex US Criteria

Study (Reference)	Number of Patients	% Stenosis	PSV (cm/sec)	EDV (cm/sec)	ICA/CCA	Sensitivity (%)	Specificity (%)	Accuracy
Lal [18]	26	≥20	>150	N/A	≥ 2.16	100	98	
Peterson [1]	158	>50	>170	>120	N/A	100	100	
Stanziale[2]	118	≥70	≥350	N/A	≥4.75	100	96	
Chi[3]	260	≥70	≥450	N/A	≥4.3	67		85
AbuRahma [4]	93	≥30	>155	N/A	N/A	100	90	
Zhou[5]	237	>70	>300	>90	>4.0	94	50	
Setacci[7]	814	≥70	≥300	≥140	≥3.8	99	98	

[1] Peterson BG, Longo GM, Kibbe MR, et al. Duplex ultrasound remains a reliable test even after carotid stenting. Ann Vasc Surg 2005;19:793-7.
[2] Stanziale SF, Wholey MH, Boules TN, et al. Determining in-stent stenosis of carotid arteries by duplex ultrasound criteria. J Endovasc Ther 2005;12:346-53.
[3] Chi YW, White CJ, Woods TC, Goldman CK. Ultrasound velocity criteria for carotid in-stent restenosis. Cath Cardiovasc Intervent 2007;69:349-54.
[4] AbuRahma AF, Maxwell D, Eads K, et al. Carotid duplex velocity criteria revisited for the diagnosis of carotid in-stent restenosis. Vascular 2007;15:119-25.
[5] Zhou W, Felkai DD, Evans M, et al. Ultrasound criteria for severe in-stent restenosis following carotid artery stenting. J Vasc Surg 2008;47:74-80.
[6] Lal BK, Hobson RW, Tofighi B, et al. Duplex ultrasound velocity criteria for the stented carotid artery. J Vasc Surg 2008;47:63-73.
[7] Setacci C, Chisci E, Setacci F, et al. Grading carotid intrastent restenosis: a 6-year follow up study. Stroke 2008;39. (available electronically)

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Is it Appropriate to Perform Surveillance Carotid DUS Following CEA/CAS?

- Appropriate: (Score 7-9) Appropriate maneuver/test/treatment for specific indication (generally acceptable and is a reasonable approach for the indication
- May Be Appropriate: (Score 4-6) Uncertain for specific indication (may be acceptable and reasonable for the indication. Implies that more research and/or patient information is needed
- Rarely Appropriate: (Score 1-3) Inappropriate test for the indication (is not generally acceptable and is not reasonable for the indication.

Appropriateness of Surveillance Following CEA/CAS

Indication		Appropriate Use Score (1–9)		
25.	• Baseline (within 1 month) after carotid intervention	A (8)		
Asymptomatic or Stable Symptoms After Baseline Study, Surveillance Frequency During First Year		At 3 to 5 months	At 6 to 8 months	At 9 to 12 months
26.	• Following normal ipsilateral ICA baseline study	I (2)	A (7)	A (7)
27.	• Following abnormal ipsilateral ICA baseline study	U (4)	A (7)	U (5)
Asymptomatic or Stable Symptoms After Baseline Study, Surveillance Frequency After First Year		Every 6 months	Every 12 months	Every 24 months or greater
28.	• Following normal ipsilateral ICA baseline study	I (2)	A (7)	U (5)
29.	• Following abnormal ipsilateral ICA baseline study	U (4)	A (7)	U (5)

J Am Coll Cardiol 2012;60:242-76

Carotid Duplex Ultrasound Velocity Measurements Versus Intravascular Ultrasound in Detecting Carotid In-Stent Restenosis

Bryan P. Yan, MBBS; David J. Clark, MBBS; Michael R. Jaff, DO; Thomas J. Kiernan, MD; Robert M. Schainfeld, DO; Sara Lessio, MD†; Kenneth Rosenfield, MD

- 39 patients (40 carotid stents)
- Followed with baseline and 6-month DUS, and 6-month IVUS for suspected ISR
  - 20% of stents developed ≥50% diameter stenosis
  - 25% of stents developed ≥75% lumen area stenosis

Circ Cardiovasc Interv 2009;2:438

Carotid Duplex Ultrasound Velocity Measurements Versus Intravascular Ultrasound in Detecting Carotid In-Stent Restenosis

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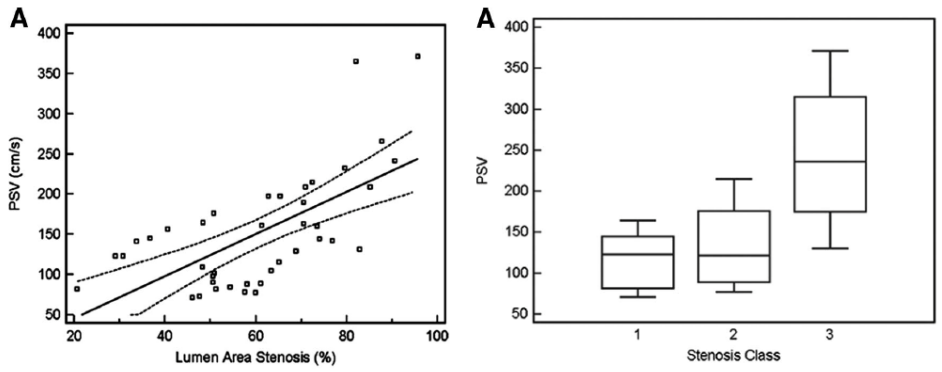

Circ Cardiovasc Interv 2009;2:438

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Carotid Duplex Ultrasound Velocity Measurements Versus Intravascular Ultrasound in Detecting Carotid In-Stent Restenosis

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	Sensitivity, % (95% CI)	Specificity, % (95% CI)
PSV ≥197 cm/s	75 (35–96)	93 (79–99)
PSV+EDV	75 (35–96)	93.9 (80–99)
PSV+ICA/CCA	75 (35–96)	90.6 (75–98)
PSV+%ΔPSV	37.5 (9–75)	96.9 (84–100)
EDV+ICA/CCA	100 (63–100)	84.4 (67–95)
PSV+EDV+ICA/CCA	77.7 (38–97)	90.3 (75–98)

Detect ≥75% Area Lumen Reduction:
Sensitivity: ICA/CCA >2 PLUS EDV > 41 cm/sec
Specificity: >98% Increase in PSV

Circ Cardiovasc Interv 2009;2:438

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Treated Type 4 Fracture

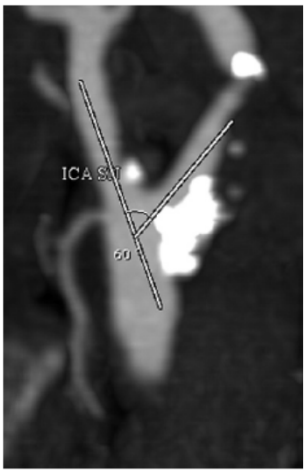
Type 4

Carotid artery stent fracture identification and clinical relevance

- 341 consecutive patients with CAS
  - Plain X-Ray at 12 months
- Stent Fracture Prevalence 3.4%
  - Strongly associated with dense calcification
  - Strongly associated with vessel angulation
- No association with neurologic events/mortality
- Strongly associated with ISR

J Vasc Surg 2010;51:1397-405

Carotid artery stent fracture identification and clinical relevance

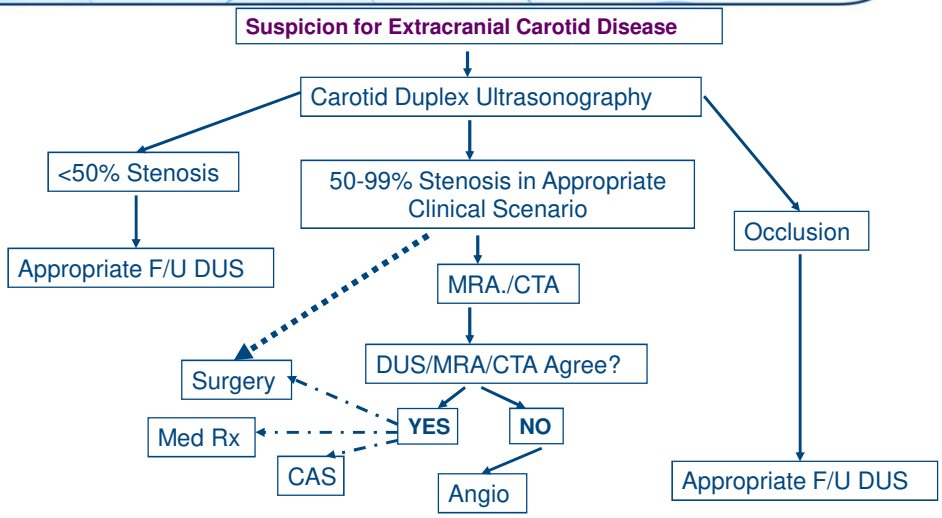


Complications, No. (%)	*No stent fracture No. (%)*	*With stent fracture No. (%)*	P[a]
Neurologic complications (>30 d)	2 (1)	0 (0)	>.5
Disabling stroke	1		
Nondisabling Stroke	1		
Reintervention (re-PTA)	1	1[b]	>.5
Conversion		1	>.5
Mortality (>12 mon)	7 (2)	0 (0)	>.5
Contralateral stroke	2		
Ruptured AAA	1		
Cancer	2		
Respiratory insufficiency	1		
Unknown	1		
Restenosis, %			<.001
<20	298 (96)	7 (64)	
20-50	9 (3)	0 (0)	
>50-80	4 (1)	2 (18)	
>80	1 (<1)	2 (18)	

J Vasc Surg 2010;51:1397-405

CTA

Modern Diagnostic Algorithm for Extracranial Carotid Disease



Who Needs a Carotid Arteriogram?

- Discordance between DUS and MRA/CTA
- Poor quality DUS, MRA, or CTA in patient considered for revascularization
- DUS suggestive of high grade ICA stenosis and decision to treat with CAS
- Atypical presentation in symptomatic patients
  - ie FMD, Trauma