Instructor's Digital Curriculum Resource-

For Techniques in Noninvasive Vascular Diagnosis-4th edition.

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Chapter 3. Carotid Criteria and Interpretation

Techniques In Noninvasive Vascular Diagnosis-4th edition

Definitions for this chapter

- **Heterogeneous-** mixed echoic patterns in plaque
- **Homogeneous-** similar appearance to texture within plaque
- **IPH- intraplaque hemorrhage –** a bleed within the plaque resulting in a plaque hematoma
- **Sens. –Sensitivity-** the ability of a test to determine that there is disease present
- **Spec. specificity-** the ability of a test to determine when there is no disease present

Definitions for this chapter

- **Endarterectomy-** surgical intervention to remove plaque from an artery. Usually the intima and media are removed.
- **TEA-**Thromboendarterectomy- see above
- **SX-** symptom or symptomatic

Interpretation Caveat #1

- **BEFORE any velocity criteria is applied to quantitate stenosis:**
  - **You must identify focal velocity acceleration over a plaque AND post-stenotic turbulence.**
- **THEN apply criteria**

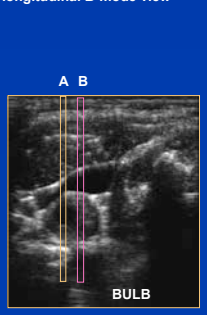
Velocity criteria is used to quantitate stenosis and NOT to define normalcy.

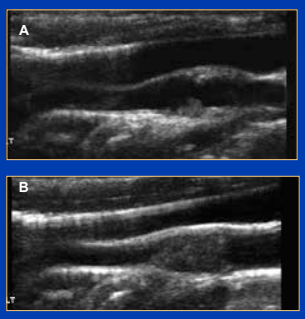
Interpretation Caveat #2

- **Image is superior to Doppler for stenosis of < 50% diameter (bulb method).**
- **Spectral Doppler is superior to image for stenoses of >50% diameter reduction.**

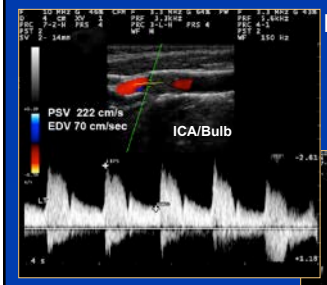
Use caution when assessing degree of stenosis from longitudinal B-mode view

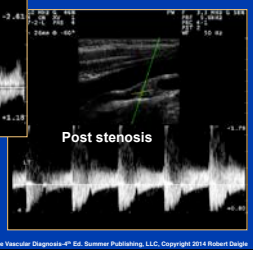
Patient: A.C.





50-69% ICA stenosis based on Doppler





Patient: A.C.

Original (outdated) Carotid Frequency Criteria

Strandness - Roederer 1981-84

- A. Normal
- B. 1-15%
- C. 16- 49 %

Based on spectral broadening

- D. 50-79%: peak systolic frequency > 4.0 KHz (≥125 cm/sec)
- D+. 80-99%: end diastolic frequency > 4.5 KHz (≥140 cm/sec)
- E. Occluded. No ICA signal, CCA diastolic flow to zero

Known as the University of Washington Criteria or the Strandness Criteria

Carotid Velocity Criteria

Daigle, Stavros, 1983, 1987

0-19 %
20-39%
40-59%

Based on B-Mode image and cross-sectional diameter calculation

60-79% : PSV ≥ 125, ICA/CCA ratio ≥ 2.0, EDV < 105.

80-95% : EDV ≥105, DR ≥ 5.6, PSV ≥ 250

95% versus occlusion: no flow in ICA, etc.

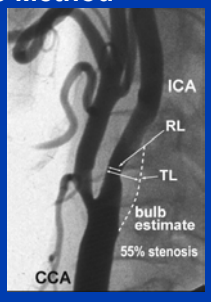
These criteria were used in a multicenter study, and later became known as the Bluth criteria (after the first author alphabetically)

Univ of WA and the "Bluth" ultrasound criteria were established by comparing velocity data to contrast angiography measured with the "bulb" method

Percent Stenosis, Bulb Measure Method

$$\% \text{ Stenosis} = 100 \times \left(1 - \frac{\text{Residual Lumen}}{\text{True Lumen}}\right)$$

True lumen is the estimated size of bulb at the point of maximum narrowing.



NASCET

North American Symptomatic Carotid Endarterectomy Trial

Large multicenter study performed to determine the benefit of carotid endarterectomy at various degrees of stenosis

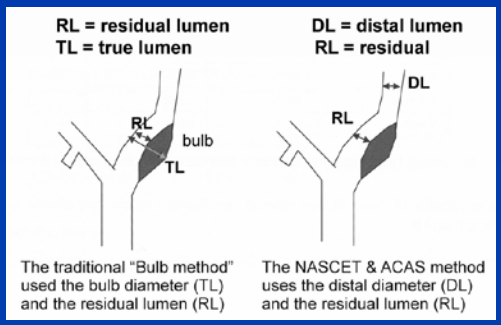
NASCET Results

- **1991**
  Benefit to carotid endarterectomy (CEA) in SX patients with > 70% DR stenosis.
- **1998 –re-published**
  Benefit to CEA in SX patients (specific SX) with 50 -69% DR stenosis

DR = Diameter Reduction

Asymptomatic Carotid Atherosclerosis Study (ACAS)

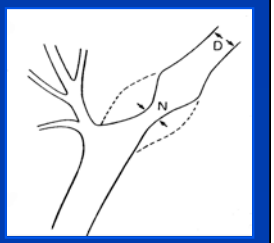
- **Showed CEA reduced stroke risk by 5.8% over 5 yrs. in ASX MALE patients with ≥ 60 % diameter ICA stenosis.**
- **CEA = carotid endarterectory**



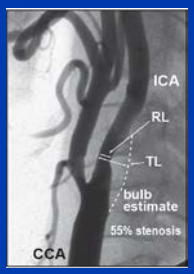
NASCET- ACAS Method of Measuring Angiogram

% Stenosis =

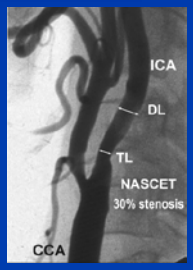
$$100 \times \left(1 - \frac{\text{Residual Lumen (N)}}{\text{Normalized distal ICA diameter (D)}}\right)$$



NASCET Angiogram Measurement Method

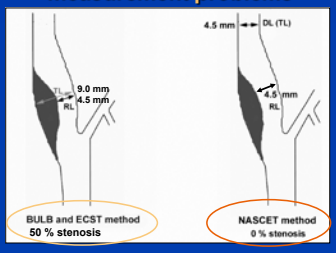


Bulb = 55%



NASCET = 30%

NASCET - ACAS
measurement problems



Most traditional duplex ultrasound criteria do not agree with the NASCET angiogram percent diameter stenosis.

Following publication of the NASCET study, investigators established velocity criteria for the "new" ≥ 70% stenosis category.

Current NASCET >70% Criteria

Author	PSV cm/s	EDV cm/s	ICA/CCA
Moneta	> 325		≥ 4.0 best
Fraught, Hood	>130 & edv	>100	
Neale	≥ 270 plus	≥ 110	
Winkelaar			≥ 3.6

The studies above used the NASCET measurement method to establish criteria for the all-important 70% stenosis.

Comment

Confusion occurs when the traditional criteria becomes integrated with the NASCET criteria without an understanding that they are based on a different "gold standard" method. Rjd.

SRU Criteria- 2003

Primary Parameters			Additional Parameters	
Degree of stenosis %	ICA PSV (cm/s)	Plaque estimate % *	ICA/CCA PSV Ratio	ICA EDV (cm/s)
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 < near total occlusion	> 230	> 50	> 4.0	> 100
Near total occlusion	High, low or undetectable	Visible	Visible	Visible
Total occlusion	Undetectable	Visible, no detectable lumen	N/A	N/A

 # controversial (RJD)

Grant EG, et al.Carotid Artery Stenosis: Gray-scale and Doppler US Diagnosis-Society of Radiologists in Ultrasound Consensus Conference. Radiology 2003;229:340-346

SRU Recommendations

- Exams should be performed with gray scale imaging, color and spectral Doppler in a protocol recommended by an accrediting organization.
- Doppler waveforms should be obtained at angles of 60 degrees or less.
- The ICA should be interrogated with the Doppler sample volume from the bulb region to the distal segment so that the maximum stenotic region can be located.

SRU Recommendations

- The final report should discuss the velocity measurements, B-mode image and color Doppler findings and comments on ***any technical limitations*** that may have occurred or be present.
- Comparisons to previous studies, if available, should be contained in the body of the report.
- The conclusion or final impression should contain an estimate of the degree of ICA stenosis according to the stratification parameters illustrated in the Table.

SRU Recommendations

- On angiograms, the carotid stenosis should be measured according to the **NASCET method**.
- Every test center should have systems in place for both quality assurance and internal validation.

Controversial Category..

Primary Parameters			Additional Parameters	
Degree of stenosis %	ICA PSV (cm/s)	Plaque estimate % *	ICA/CCA PSV Ratio	ICA EDV (cm/s)
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 < near total occlusion	> 230	> 50	> 4.0	> 100
Near total occlusion	High, low or undetectable	Visible	Visible	Visible
Total occlusion	Undetectable	Visible, no detectable lumen	N/A	N/A

The 50% threshold uses OLD "bulb" criteria!

New Criteria for 50-69% "NASCET" carotid stenosis

Author	PSV cm/s	EDV cm/s	ICA/CCA ratio
AbuRama	≥ 140 *	≥ 60	≥ 2.12
Filis (50-59%)	150-200	50-70	≥ 2.2
Winkelaar	> 150		≥ 2.0 *
Sabeti	150-249		2.0-3.9

* = best criteria (most accurate within the respective study).

With Latest Criteria Included- Revised SRU (1/2009)

Primary Parameters			Additional Parameters	
Degree of stenosis %	ICA PSV (cm/s)	Plaque estimate % *	ICA/CCA PSV Ratio	ICA EDV (cm/s)
Normal	< 125	none	< 2.0	< 40
< 50	< 150	< 50	< 2.0	
50-69	> 150	> 50	2.0 - 4.0	60 - 100
≥ 70, but < near total occlusion	> 230	> 50	> 4.0	> 100
Near total occlusion	High, low or undetectable	Visible	Visible	Visible
Total occlusion	Undetectable	Visible, no detectable lumen	N/A	N/A

* Plaque estimates (diameter reduction) with gray scale and color Doppler US.

Summary of Important ICA Stenosis Criteria

- **If plaque/stenosis is present:**
- **< 50% stenosis**
  - **PSV < 150 cm/sec = < 50% stenosis**
- **50-69% ICA stenosis**
  - **PSV > 150 cm/sec, EDV < 100 cm/sec, VR >2.0 but less than 4.0**
- **>70% ICA stenosis**
  - **VR ≥ 4.0, EDV > 100**

Key Interpretation Points

- According to the Bernoulli principle, significant velocity increase will occur over a lesion ≥ 50% diameter stenosis
- Turbulent, chaotic blood flow is almost always present immediately distal to a ≥ 50%; this appears as spectral broadening in the Doppler waveform.

Key Interpretation Points

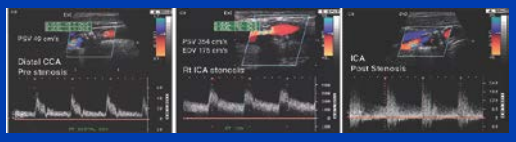
- If a stenosis measures 50% or greater from the B-mode image (using measurement calipers), but there is no focal velocity acceleration over the plaque, that stenosis is less than 50% in diameter.
- If a stenosis measures or appears less than 50% by image/caliper method but velocity acceleration with post stenotic turbulence occurs, that lesion is greater than 50%.

Carotid criteria is meaningless, unless the following 3 conditions exist:

1) You can visualize plaque within the artery.
2) There is focal velocity acceleration over the plaque.
3) Post-stenotic turbulence exists distal to the plaque.

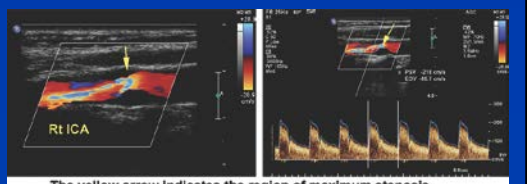
Once these conditions have been recognized, then criteria can be applied.

"Mapping" 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.

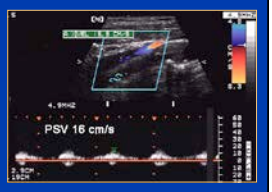
Sample not taken from maximum stenosis

THE most important goal of carotid imaging:

- **Identify stenosis, estimate severity**
  - **obtained velocity measurements from Maximum stenosis**
- **This concept should be foremost in all carotid protocols**

> 95% Stenosis-Subjective Indicators

- Difficulty in obtaining a complete spectral waveform from stenosis. (Reduced blood volume passing through the tight stenosis yields a weaker returning Doppler signal).
- Low velocity distal to the stenotic region.



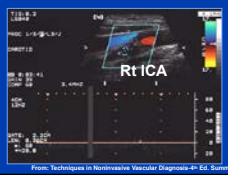
Low velocity - distal ICA

ICA Total Occlusion Diagnosis.

1. Determine that there is no flow in the ICA, sample at multiples ICA sites.
2. Use color Doppler (and power Doppler if available) at normal and low PRF.
3. Observe extensive thrombus within the ICA, note that there is some length of the thrombus
4. The ICA may be contracted in appearance if chronically occluded; look carefully.

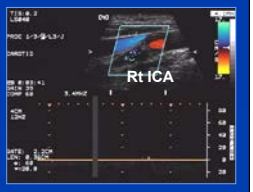
ICA Total Occlusion diagnosis.

5. Technical problems such as inappropriate color Doppler gain, PRF, and steering angle must be avoided.
6. Observe carefully in transverse plane to determine the course of a tortuous ICA.

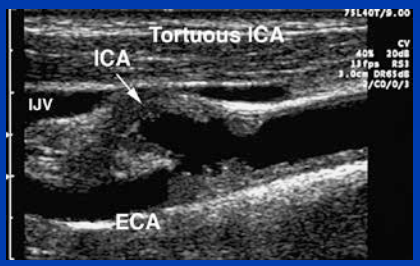


ICA total occlusion diagnosis can be tricky, but important!

- If the ICA is "almost" occluded, it can be operated upon (carotid endarterectomy).
- Once occluded, the ICA thromboses intracranially and is not amenable to surgery.
- If in doubt on the ultrasound diagnosis, say so, and recommend a definitive invasive diagnostic procedure

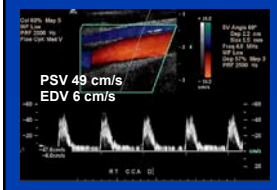


This ICA is tortuous, but it's not occluded

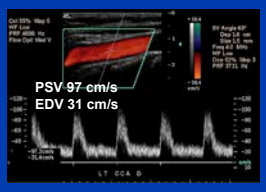


Continuity of the vessel, nor length of thrombus, has been demonstrated

CCA velocities (especially EDV) on the side of the ICA occlusion may be lower, but it depends on the extent of the ECA flow.



Rt CCA flow with occluded Rt ICA, EDV 6 cm/s



Lt CCA flow on non-occluded side, EDV 31 cm/s

The "Water Hammer" Effect

Composite image demonstrating the "water hammer" effect

Moving thrombus may cause a "to & fro" Doppler shift

Video Demonstration of a > 90% stenosis

- Note low, high resistance flow just before ICA stenosis.
- Note low velocity and abnormal waveforms in distal ICA
- Note difficulty in obtaining a good Doppler sample at max stenosis

>90% Stenosis

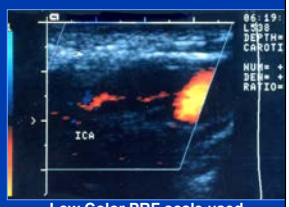
When in PowerPoint Show. click on link below for video demo on youtube.

http://youtu.be/NMiyY6TW1Qc

Cdrei-ICA-90-dubbed.sm.wmv.

Trickle flow in a nearly occluded ICA

- Very low velocity may occur in a near-total occlusion.
- Use a low PRF color scale
- Use Power Doppler



Low Color PRF scale used, otherwise flow was not seen.

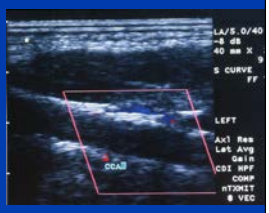
If a trickle-flow situation is discovered, it should be reported to the referring physician ASAP. WHY?

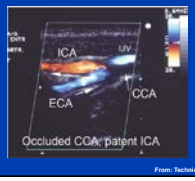
CCA Stenosis

- No established criteria
- If the PSV increased over the stenosis by a factor of 2 (a doubling of velocity), it's probably a > 50% stenosis.

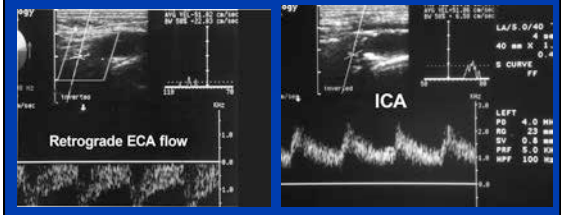
CCA Occlusion

- Verify no flow in CCA.
- Evaluate ICA and ECA and note direction.
- The ICA often remains open with blood supplied by retrograde ECA flow.



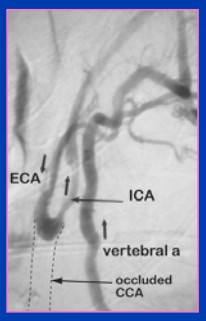


Occluded CCA



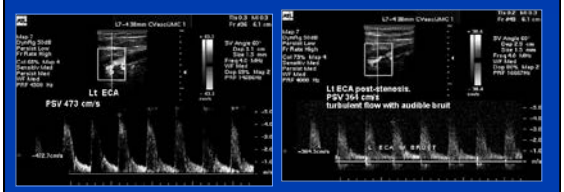
Occluded CCA

- A vertebral artery branch communicates with ECA branches
- Retrograde ECA flow supplies the ICA.
- This is an angiogram with a vertebral injection to demonstrate the patent ICA.



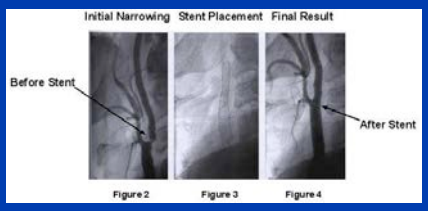
ECA Stenosis

- No established criteria
- Abrupt increase in velocity, with post-stenotic turbulence = > 50% sten.



Carotid Artery Stents (CAS)

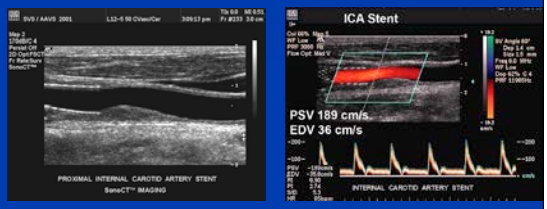
- Carotid stents are used as an alternative to carotid endarterectomy in high-risk patients



Carotid Stents

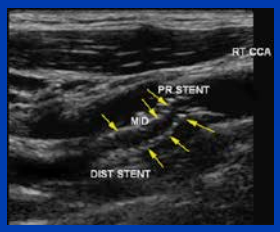
- Follow-up ultrasound exams are required to detect re-stenosis and complications

Normal Stent



Stent Problems

- Poor deployment
- Stent shift
- Distal stenosis



Poorly deployed stent

Stent Re-stenosis

- Blood flow velocity (BFV) criteria for re-stenosis after carotid artery stenting are less reliable than is the change in BFV over time. [1]
- An immediate post-stenting Doppler study must be obtained to serve as a reference value for future follow-up evaluation.

1. Ringer et al see ref 26 in book

Post-op Carotid Stent Ultrasound Exam

- Expect higher velocities in an ICA stent. Stents usually do not restore arterial lumen diameter to normal size so velocities tend to be higher than in a normal carotid.
- Increased "stiffness" contributes to higher velocities
- Flow may or may not be present in the ECA; it depends on the type of stent (covered or uncovered).
- Check for stent stenosis, shift or movement, and increased distal disease.

Criteria for Carotid Artery Stents (CAS)- Post-Op

Criteria for carotid stent re-stenosis				
	50-69%		≥ 70%	
Author	PSV cm/s	Ratio	PSV cm/s	Ratio
AbuRahma	> 155			
Chi	> 240	> 2.45	> 450	> 4.3
Stanziale	> 225	> 2.5	> 350	> 4.75
Armstrong	> 150	> 2	(75%) > 300	

References are listed in Chapter 2

Best Stent Stenosis Criteria

- Stanziale

50-69% stenosis		> 70% stenosis	
PSV cm/ sec	Ratio	PSV cm/ sec	Ratio
≥ 225	≥ 2.0	≥ 350	> 4.75

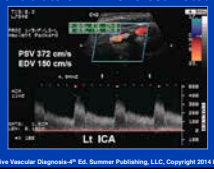
Stanziale SF, Wholey MH, Boules TN, Selzer F, Mararoun MS. Determining in-stent stenosis of carotid arteries by duplex ultrasound criteria. J Endovasc Ther. 2005 Jun;12(3):346-53

Severe Contralateral Disease

- Flow volume may increase in the side contralateral to a high-grade ICA stenosis or occlusion
- Stenosis on this side may be overestimated due to higher velocities

Occluded ICA

Contralateral ICA- Overestimated??



Severe Contralateral Disease

- The compensatory effect may not be present and it's variable from patient to patient.
- Some studies have recommended increasing velocity thresholds for a contralateral >70% stenosis by 24% [1]

1.Heijenbrok-Kal MH, Nederkoorn PJ, Buskens E, van der Graaf Y, Myriam -Hunink MG. Diagnostic performance of duplex ultrasound in patients suspected of carotid artery disease: the ipsilateral versus contralateral artery. Stroke 2005;36:2105-2109.

Optimum velocity values for ipsilateral & contralateral stenosis

Heijenbrok-Kal Criteria Set for 70-99% Carotid Ipsilateral & Contralateral Stenosis.[38]

	PSV cm/s	Sens. %	Spec. %	Acc. %
Maximum Accuracy				
Ipsilateral	280	84.7	69.5	78
Contralateral	370	71.1	97.8	94

Plaque Morphology

Plaque Characterization

- Morphology, echodensity and surface characteristics
- Attempts have been made to determine which plaques are "risky"
- Controversial: methods are subjective, and no clear consensus
- Predominate trend: Hypoechoic plaques are more likely to be symptomatic.

Plaque Morphology

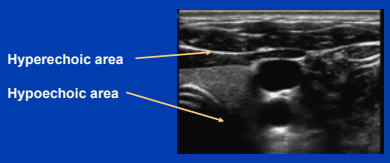
Definitions

- **ANECHOIC** - Describes the property of being echo-free or without echoes (e.g.. a fluid-filled cyst).
- **ECHOLUCENT**- same as above
- **SONOLUCENT**- Allowing passage of ultrasonic waves without echoes
- **ISOECHOIC**- Areas which have similar echogenicity to each other. An isoechoic "property" makes it more difficult to see the desired tissue structure

Plaque Morphology

Definitions

- **ECHOGENICITY**- Echogenic: the ability to create an ultrasound echo
- **HYPERECHOIC** - Producing echoes of higher amplitude than normal for the surrounding medium.
- **HYPOECHOIC** - Producing echoes of lower amplitude than normal for the surrounding medium



Plaque Morphology

Gray-Weale Scale[1]

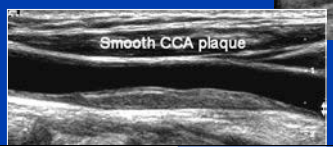
1) Dominantly echolucent
2) Substantially echolucent with small areas of echogenicity
3) Dominantly echogenic with small areas (<25%) of echolucency
4) Uniformly echogenic
5) Invisible because of heavy calcification

1. Carotid artery atheroma: comparison of preoperative B-mode ultrasound appearance with carotid endarterectomy specimen pathology. Gray-Weale AC, Graham JC, Burnett JR, Byrne K, Lusby RJ J Cardiovasc Surg (Torino). 1988 Nov-Dec;29(6):676-81

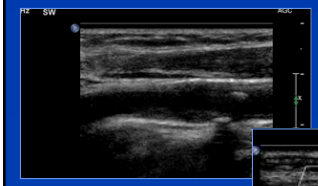
Surface Contour

Grey-Weale 4.

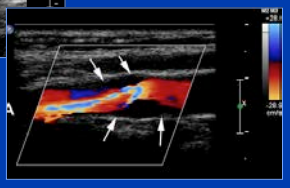
Uniformly echogenic



Heterogeneous
Gray-Weale # 1, 2

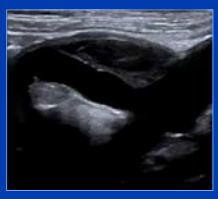


Mixed echogenicity with hypoechoic regions



Heterogeneous
Gray-Weale # 1, 2

1) Dominantly echolucent
2) Substantially echolucent with small areas of echogenicity



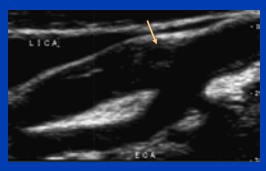
Heterogeneous

3. Dominantly echogenic with small areas (<25%) of echolucency

Heterogeneous plaques with mixed echogenicity

Plaque Characterization

- Intraplaque hemorrhage (IPH)
  - sonolucent or hypoechoic region with thin fibrous cap
  - eggshell pattern

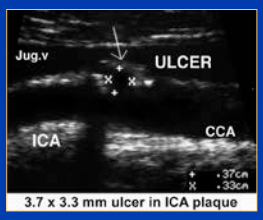


Calcified Plaque
Gray-Weale #5

5. Invisible because of heavy calcification.

Plaque Characterization

- Ulceration
  - heterogeneous
  - sharp, irregular borders
  - ≥ 2 mm defect
  - Could be IPH



3.7 x 3.3 mm ulcer in ICA plaque

Ultrasound is not very accurate at determining plaque ulceration

Plaque Characterization

- There is no clear cut evidence that ultrasound can determine plaque ulceration or intraplaque hemorrhage with consistency.