Carotid artery stenosis: ultrasound diagnosis. How to do it

Franco Accorsi
Carotid artery stenosis: ultrasound diagnosis. How to do it.

INTRODUCTION

The echocolor Doppler of the carotid plaque is performed to have information about its degree of stenosis and its composition/surface. The degree of stenosis is the most correlated clinical event: the greater is the stenosis, the greater is the risk of TIA/stroke and the benefit of surgery. Therefore, particular care should be used to evaluate the percentage of stenosis.

The main parameters that should be used in diagnosing and grading internal carotid artery stenosis are the peak systolic velocity and the presence of plaque on grayscale and/or color Doppler/duplex US images.

Although CDU cannot precisely define the percentage of stenosis diameter, a range of stenosis diameters may be estimated.

In this lesson the methodology of the echocolor Doppler study of the degree of carotid stenosis is presented.
STUDY OF CAROTID STENOSIS:
ANGIOGRAPHIC METHODS

- the two large carotid endarterectomy trials (NASCET and ECST) measured the degree of angiographic ICA stenosis differently:
  a. ECST method
  b. NASCET method
DEGREE OF ANGIOGRAPHIC ICA STENOSIS

1. NASCET method: \( B - A / B \times 100 \)

   B is the ICA diameter in the disease-free ICA distal to the stenosis, while A is the residual lumen at the point of maximum stenosis.

2. ECST method: \( C - A / C \times 100 \)

   C is the original normal arterial diameter that would have been at the point of maximum stenosis as angiography only shows the residual lumen.
DEGREE OF ANGIOGRAPHIC ICA STENOSIS

1. NASCET method: $B - A/B \times 100$
   
   $B$ is the ICA diameter in the disease-free ICA distal to the stenosis, while $A$ is the residual lumen at the point of maximum stenosis.

2. ECST method: $C - A/C \times 100$
   
   $C$ is the original normal arterial diameter that would have been at the point of maximum stenosis as angiography only shows the residual lumen.
correlation between the NASCET and ECST method in the evaluation of the degree of ICA stenosis

- the evaluation of the degree of stenosis according to the NASCET method is underestimated compared to the method ECST
- a 60% ECST stenosis corresponds to 30% NASCET stenosis
- a 70% ECST stenosis corresponds to 50% NASCET stenosis
- and so on
DEGREE OF STENOSIS
ANGIOGRAPHIC METHODS

ULTRASOUND STUDY
OF CAROTID STENOSIS
1. color Doppler US of extracranial carotid artery is performed:
   a) to localize the possible stenosis/occlusion
   b) to have information about the degree of stenosis
   c) to have information about the composition/surface of the plaque

2. the measurement of the degree of stenosis is crucial in the management of patients with carotid stenosis

3. the degree of stenosis is the most correlated clinical event: the greater is the stenosis, the greater is the risk of TIA/stroke and the benefit of surgery
to study the degree of stenosis is necessary a high-resolution linear array transducer (7–12 mHz)

**Three modalities must be used:**

1. **B-mode gray scale imaging** (on transverse and longitudinal planes)
2. **color flow Doppler** (on transverse and longitudinal planes)
3. **spectral Doppler velocities** (on longitudinal planes)
CAROTID ARTERY STENOSIS:
US DIAGNOSIS

THE DEGREE OF CAROTID STENOSIS
U.S. STUDY

- these three criteria (B-mode, color Doppler, spectral Doppler) however, also associated with each other, can not certify a single degree of stenosis, but only stratify various categories of stenosis related to the range of B-mode, color, spectral Doppler corresponding values

- diagnostic information about the degree of stenosis (from the various evaluation criteria) must be consistent

- the operator's ability is to integrate the informations from these three modalities
CAROTID ARTERY STENOSIS: US DIAGNOSIS

US IN THE STUDY OF CAROTID PLAQUE:
1. B-MODE GRAY SCALE IMAGING
2. COLOR FLOW DOPPLER
3. SPECTRAL DOPPLER VELOCITIES
1. B-MODE GRAY SCALE IMAGING
   the carotid plaque must be studied
   a. on longitudinal planes
   b. on transverse planes
STUDY OF THE PLAQUE ON LONGITUDINAL SCAN

B-MODE GRAY SCALE IMAGING

- for the assessment of the reduction of the ICA lumen in the longitudinal scan, two U.S. different modes, angiographic-like, have been proposed:
  a. ECST method
  b. NASCET method
- the US ECST/NASCET methods have proved, in clinical practice, to be equivalent to the angiographic ECST/NASCET methods
DEGREE OF STENOSIS
B-MODE GRAY SCALE IMAGING

RESIDUAL LUMEN DETERMINED IN US LONGITUDINAL SECTION

1. residual lumen at the point of maximum stenosis (A)
2. original normal arterial diameter at the point of maximum stenosis (C)
3. ICA diameter in the disease-free ICA distal to the stenosis

RESIDUAL LUMEN DETERMINED IN US LONGITUDINAL SECTION
(angiographic-like methods)

1. NASCET method (B-A/B x 100)
2. ECST method (C-A/C x 100)
B-MODE GRAY SCALE IMAGING

- the residual lumen can also be determined in transverse section (area or diameter reduction)
B. TRANSVERSE SCAN
(US % stenosis measure in area)
The evaluation of the residual lumen in area, obtained with transverse scan, overestimates the linear, angiographic-like, measure obtained with longitudinal scan.

For example:
- a diameter reduction of 30% corresponds to a reduction in area of about 50%
- a diameter reduction of 70% corresponds to a reduction in area of about 90%
- and so on

These considerations involve, as consequence, the need to specify the scan used in the evaluation of the stenosis
ASSESSMENT OF % OF STENOSIS:
the longitudinal (linear) assessment of the % of stenosis is different from the transverse (area) assessment of the % of stenosis

MEASUREMENT OF % OF STENOSIS IN GRAYSCALE
- transverse scan (measurement of the residual lumen in area) vs longitudinal scan (linear measure)

in this example:
a) area stenosis is about 80%
b) linear stenosis (angiographic-like) is about 65%
DEGREE OF STENOSIS
COLOR DOPPLER IMAGING

US IN THE STUDY OF CAROTID PLAQUE:

1. B-MODE GRAY SCALE IMAGING
2. COLOR FLOW DOPPLER
3. SPECTRAL DOPPLER VELOCITIES
2) COLOR DOPPLER IMAGING

- for the color Doppler imaging the same considerations are valid as for images obtained with the gray scale

The degree of carotid stenosis can be evaluated:

1. with longitudinal scan (linear angiographic-like, ECST/NASCET, method)
2. or with transverse scan (area or diameter reduction)
for the color Doppler imaging the same considerations are valid as for images obtained with the gray scale.

### DEGREE OF STENOSIS

**COLOR DOPPLER MEASURE**

**(ECST VS NASCET METHOD)**

In this case, the degree of stenosis is:

a) **NASCET method** \( \frac{B-A}{B \times 100} = 50\% \)

b) **ECST method** \( \frac{C-A}{C \times 100} = 70\% \)

### DEGREE OF STENOSIS

**COLOR DOPPLER MEASURE**

**(LINEAR VS AREA METHOD)**

The evaluation of the residual lumen in area, obtained with transverse scan, overestimates the linear, angiographic-like, measure obtained with longitudinal scan.

**In this example:**

a) area stenosis is about 60%

b) linear stenosis (angiographic-like) is about 40%
COLOR DOPPLER IMAGING

- In case of stenosis hemodynamics, is present aliasing

ALIASING

- Color Doppler sonography is especially useful for identifying hemodynamic stenosis.
- Areas of stenosis are seen as a reduced lumen with a red to blue shift due to “aliasing,” a Doppler artifact occurring when the velocities of the blood cells are higher than half of the pulse repetition frequency (PRF).
- Red represents flow toward the transducer, within the range of the PRF, whereas blue is not a reverse flow but represents velocities beyond the range of the PRF.
- Poststenotic areas may have a mosaic color Doppler pattern due to multiple velocities and flow reversal.
IN PRESENCE OF CAROTID HEMODYNAMIC STENOSIS:

- it is difficult to measure the residual lumen with the color or B mode (in this case the degree of stenosis must be evaluated primarily with spectral analysis)

- color Doppler sonography areas of hemodynamic stenosis are seen as a reduced lumen with a red to blue shift due to “aliasing,” with "mosaic" pattern due to multiple flow velocities
POWER DOPPLER
STUDY OF THE CAROTID PLAQUE

- in the study with power-Doppler, the signal amplitude is determined by the density of blood cells
- in this case the signal is independent from the angle, from the direction of the flow and from the velocity, therefore can not recognize the acceleration and the direction of the flow
- this method is more sensitive than color Doppler and may allow a better definition of the marginal signal
HEMODYNAMIC PLAQUE
COLOR VS POWER DOPPLER
- color Doppler: presence of aliasing with "mosaic" pattern due to multiple flow velocities and flow reversal
- power Doppler: this signal does not distinguish the acceleration of the flow (aliasing) and the direction of the red blood cells
HEMODYNAMIC PLAQUE
COLOR vs POWER DOPPLER

a) color Doppler: presence of aliasing with "mosaic" pattern due to the presence of multiple flow velocities
b) power Doppler (various modes): impossibility of distinguishing both acceleration (aliasing) and direction of the flow. It is present a better definition of the margins of the plaque
PLAQUE ASSESSED WITH GRAY SCALE AND DIRECTIONAL POWER-DOPPLER

1) with the gray scale image is obtained a good characterization of the plaque
2) with the directional power-Doppler the excellent sensitivity of the power image is associated with the directional discrimination typical of the color Doppler
CAROTID ARTERY STENOSIS: US DIAGNOSIS

US IN THE STUDY OF CAROTID PLAQUE:

1. B-MODE GRAY SCALE IMAGING
2. COLOR FLOW DOPPLER
3. SPECTRAL DOPPLER VELOCITIES
SPECTRAL ANALYSIS

- spectral waveform analysis of blood flow by Doppler US is a noninvasive method to investigate blood hemodynamics
- flow velocity is the main parameter for evaluating the severity of carotid stenosis
- flow velocity must be sampled through the whole area of the stenosis to ensure that the site of the highest velocity has been detected
- the angle between the Doppler beam and the direction of blood flow must be < 60 °
SPECTRAL DOPPLER ULTRASOUND

1. this three-dimensional curve associates:
   a. the frequency (represented on the ordinate)
   b. the time (represented on the abscissa)
   c. the amplitude, which, through a sonogram consisting of many pixels as the velocities of the blood cells, displays the amount of blood cells traveling at the same speed

2. a variation in blood flow leads to a variation of both the position of the pixels and their intensity
3) SPECTRAL ANALYSIS

- the systo-diastolic velocity increases with the increase of the degree of stenosis: in case of hemodynamic stenosis there is a correlation between the peak systolic velocity and the degree of stenosis
- over 90% reduction of the diameter the velocity decreases

**the spectral analysis is the main parameter to assess (and classify) the severity of stenosis hemodynamics**
spectral analysis changes in relation to the flow rate of the red blood cells in the arteries

3. SPECTRAL ANALYSIS IN CASE OF STENOSIS:

- the spectral curve is progressively modified in relation to the degree of stenosis:
  
a. first the upper contour of the spectrum becomes less net,
  
b. this is followed by a broadening of the spectrum toward the high velocities and by a progressive filling of the “black window”
  
c. in high degrees of stenosis: enlargement of the spectrum not only upwards but also downwards (to the low flow in the tight stenosis) and finally negative velocities appear, indicating reflux and marked turbulences
SPECTRAL ANALYSIS

- in case of stenosis hemodynamics, aliasing is present
ALIASING

- observed both in pulsed Doppler and color Doppler
- artifact related to the pulsed Doppler that appears when the velocity of the blood cells exceeds the Nyquist limit which is reached when the Doppler frequencies in the vessels are higher than half of the PRF
ALIASING

a) waveforms with aliasing: the systolic peak appears "cut off", with abrupt termination of the systolic peak and display this peak below the baseline.

b) color Doppler stenosis: reduction of the lumen and the colors are from red to blue. The high velocities are represented in reverse to the real and the post-stenotic areas have a mosaic pattern color Doppler to the multiple velocities.
the spectral curve is progressively modified in relation to:

1. laminar flow (physiological)
2. presence of hemodynamic stenosis
3. high degree stenosis
1. LAMINAR FLOW (PHYSIOLOGICAL)

- spectral analysis: concentration of brightness in the upper part of the spectral curve (most of the erythrocytes moves to a velocity close to maximum). Presence of "black window" below (area where there are no blood cells flowing at the corresponding velocity)

- color: slower velocities near the wall have a color shade darker than in the center (with higher velocities)
2. IN PRESENCE OF HEMODYNAMIC STENOSIS

- **spectral analysis:** the spectral curve is progressively modified in relation to the degree of stenosis:
  1. first the upper contour of the spectrum becomes less net
  2. then the spectral curve shows an enlargement of the spectrum toward the high velocities and a progressive filling of the "black window"

- **color:** reduction of the lumen with the appearance of aliasing
3. IN HIGH DEGREE STENOSIS

- **spectral analysis**: a broadening of the spectrum appears, not only upwards but also downwards (to the low velocities in the tight stenosis) and finally negative velocities appear, indicating reflux and marked turbulences

- **color**: reduction of the lumen with the appearance of aliasing
SPECTRAL ANALYSIS

1. primary US parameters: ICA PSV
2. additional US parameters: ICA/CCA PSV ratio and ICA EDV
   - these US primary and secondary parameters have been correlated with the degree of ICA stenosis (ECST / NASCET method)
   - differences between the ECST / NASCET methods!
1) the same velocity range corresponds to different degree of stenosis, according to the method used. For example: the PSV between 120-150 cm./sec. corresponds to a degree of stenosis between 50 and 70% for the ECST m. and <50% for the NASCET m., and so on.

2) the velocities related to a angiographic diameter stenosis show a considerable spread of values. This means that for each degree of angiographic stenosis, a wide range of associated blood flow velocities is recorded!
SPECTRAL ANALYSIS IN NON-HEMODYNAMIC PLAQUE

- power-Doppler allows a good evaluation of the morphology of the plaque
- spectral analysis (PSV = 55.9 cm. / sec., allows to exclude the presence of a hemodynamic plaque

**in this case the degree of stenosis cannot be assessed with spectral analysis (but only with longitudinal and cross-scan)**
SPECTRAL ANALYSIS IN HEMODYNAMIC PLAQUE

- plaque studied with color/power Doppler and spectral analysis
- the flow velocity is fundamental to assess the severity of the ICA stenosis

\[
\text{PSV} = 261 \text{ cm./sec. corresponding to NASCET stenosis } > 80\% \text{ and ECST stenosis } > 90\%
\]
IN PRESENCE OF A SEVERE ICA STENOSIS, US FEATURES ARE:

1. B-mode gray scale imaging: plaque ≥50% lumen diameter reduction
2. color Doppler sonography/pulsed wave Doppler spectral analysis:
   a. PSV greater than 230 cm/sec and EDV greater than 100 cm/sec.
   b. spectral broadening
   c. color aliasing and color bruit artifact in the surrounding tissue of the stenotic artery
   d. post stenotic turbulence at color Doppler and pulsed wave Doppler
CAROTID ARTERY STENOSIS: US DIAGNOSIS

US FEATURES IN A SEVERE LT. ICA STENOSIS

a) B-mode gray scale imaging/color Doppler sonography: plaque ≥50% lumen diameter reduction and color aliasing
b) PSV = 464 cm/sec and EDV = 167 cm/sec.
c) post stenotic turbulence
d, e) siphon low velocity flow (lt. siphon PSV = 43 cm/s. vs lt. siphon PSV = 137 cm/s
it is important to measure correctly the flow velocity, with angle aligned with the flow vector!
• the flow velocity must be sampled along the whole extent of the stenosis
• the angle between the Doppler beam and the direction of blood flow must be < 60 °

ICA PLAQUE: LOCATION AND ANGLE OF THE SAMPLE VOLUME

The angle of the sample volume:
• must not be aligned with the ICA wall contour (A)
• but with the flow vector (the contour of the plaque) (B)
the angle between the Doppler beam and the direction of blood flow must be < 60°

ICA PLAQUE: LOCATION AND ANGLE OF THE SAMPLE VOLUME

a) angle of the sample volume incorrectly aligned with the wall contour of the ICA (= 60°) resulting in overestimation of the degree of stenosis (PSV = 311 cm./sec. corresponding to stenosis NASCET > 70-80%)

b) angle of the sample volume correctly aligned with the flow vector, the contour of the plaque (= 45°). The resultant ICA PSV is 191 cm/sec. (the degree of stenosis is reclassified as NASCET stenosis between 50 and 69%)
DEGREE OF STENOSIS
SPECTRAL ANALYSIS

it is important to measure correctly the flow velocity, with angle aligned with the flow vector!

a) angle of the sample volume incorrectly aligned with the wall contour: PSV = 311 cm./sec. (NASCET stenosis > 70-80%)

VS

b) angle of the sample volume correctly aligned with the flow vector: PSV = 191 cm./sec. (NASCET stenosis = 50-69%)

CAROTID ENDOARTERECTOMY FOR SYMPTOMATIC ICA STENOSIS

OBJECTIVES: to determine the balance of benefit versus risk of endarterectomy plus best medical management compared with best medical management alone in patients with a recent symptomatic carotid stenosis

SELECTION CRITERIA: randomised controlled trials

CONCLUSIONS: Endarterectomy is:

• of some benefit for 50% to 69% (es: PSV = 191 cm/sec) symptomatic stenosis (ARR = 4.6%)

and

• highly beneficial for 70% to 99% stenosis (es: PSV = 311 cm/sec) without near-occlusion (ARR = 16.0%)

VELOCITY CRITERIA MAY BE INACCURATE IN SOME CLINICAL CONDITIONS

A. possible underestimation of the degree of stenosis in:
   1. cardiac arrhythmia
   2. aortic valve insufficiency
   3. tandem plaques
   4. recent hemispheric stroke
   5. carotid dilatation or aneurysm

B. possible overestimation of the luminal narrowing in:
   1. carotid coiling or kinking
   2. arteriovenous malformations
   3. carotid body tumors
   4. contralateral severe stenosis or occlusion
WHEN IS USEFUL THE ADDITIONAL PARAMETER
PSV ICA/CCA RATIO?

Velocity criteria may be inaccurate in a number of clinical conditions (so the PSV is only partially related to the degree of stenosis)

for example:

- in hyperdynamic states
- in severe bilateral ICA stenosis
- in tandem lesions
- in stenosis of the proximal CCA
- probably the most important use of the PSV ICA/CCA ratio is in patients with low cardiac output (with PSV very low, not proportional to the degree of stenosis)
in this case (patient with hyperthyroidism, so PSV is only partially correlated to the degree of stenosis):

- PSV = 167 cm/sec. → stenosis ECST = 75-85% (not consistent with the B mode assessment)
- PSV IC/CC = <1.5 → ECST stenosis <60% (most likely, consistent with the B mode assessment)
WHEN IS USEFUL THE ADDITIONAL PARAMETER PSV ICA/CCA RATIO?

- probably the most important use of the PSV ICA/CCA ratio is in patients with low cardiac output (with PSV very low, not proportional to the degree of stenosis)

PSV conditioned by other diseases

- patient with aortic stenosis: PSV is untrusted (ICA and AV flows demodulated, influenced by aortic valve disease)
CONCLUSIONS

DEGREE OF ICA STENOSIS

1. a careful study must always include:
   1. assessment in B mode (black and white)
   2. assessing color Doppler or power
   3. the study of the flow velocity

2. the best diagnostic accuracy:
   is the combination of these three techniques which, however, can not define a single value of stenosis but only stratify a range of values of stenosis

3. the diagnostic information from the various evaluation criteria, about the degree of stenosis, must be consistent
CAROTID ARTERY STENOSIS:
US DIAGNOSIS

DEGREE OF ICA STENOSIS:
CONSIDERATIONS AND DOUBTS
CAROTID ARTERY STENOSIS: US DIAGNOSIS

DEGREE OF ICA STENOSIS: CONSIDERATIONS AND DOUBTS

1. the problem is not yet completely solved:
   - there is no uniformity in the interpretation between the different centers
   - or between the professionals of the same center

2. confusion in the interpretation of data:
   - the different "primary" or "secondary" parameters associated with
   - the different ECST/NASCET angiographic-like measurement have produced some confusion in the interpretation of data with the risk of over/underestimating the degree of ICA stenosis
CAROTID ARTERY STENOSIS: US DIAGNOSIS

DEGREE OF ICA STENOSIS
HOW TO DO?
DEGREE OF ICA STENOSIS
HOW TO DO?

1. CONSENSUS 2003

- a multidisciplinary group of experts proposed, in 2003, recommendations in order to provide reproducible and reliable information regarding the diagnosis and the degree of ICA stenosis

*Carotid Artery Stenosis: Gray-Scale and Doppler US Diagnosis—Society of Radiologists in Ultrasound Consensus Conference. Radiology 2003*
### CAROTID ARTERY STENOSIS: US DIAGNOSIS

<table>
<thead>
<tr>
<th>Degree of Stenosis (%)</th>
<th>Primary Parameters</th>
<th>Additional Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICA PSV (cm/sec)</td>
<td>Plaque Estimate (%)*</td>
</tr>
<tr>
<td>Normal</td>
<td>&lt;125</td>
<td>None</td>
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<tr>
<td>&lt;50</td>
<td>&lt;125</td>
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<tr>
<td>50–69</td>
<td>125–230</td>
<td>≥50</td>
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<tr>
<td>≥70 but less than near occlusion</td>
<td>&gt;230</td>
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<td>Near occlusion</td>
<td>High, low, or undetectable</td>
<td>Visible</td>
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<td>Total occlusion</td>
<td>Undetectable</td>
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<td></td>
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<td>ICA/CCA PSV Ratio</td>
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<td>&lt;2.0</td>
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<td>2.0–4.0</td>
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<tr>
<td>&gt;4.0</td>
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* plaque estimate (diameter reduction) with gray-scale and color Doppler US

### CONSENSUS CONFERENCE 2003

The degree of stenosis determined at gray-scale and Doppler US should be stratified into six categories: 1) normal (no stenosis); 2) < 50% stenosis; 3) 50%–69% stenosis; 4) ≥ 70% stenosis to near occlusion; 5) near occlusion; 6) total occlusion.

1. primary US parameters
   a) ICA PSV
   b) presence of plaque on gray-scale and/or color Doppler US images

2. additional US parameters
   a) ICA/CCA PSV ratio
   b) ICA EDV
CAROTID ARTERY STENOSIS: US DIAGNOSIS

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ICA/CCA PSV Ratio ICA E (cm/s)

<2.0 <40
<2.0 <40
2.0-4.0 40-100
>4.0 >100

CONSENSUS CONFERENCE 2003
SOCIETY OF RADIOLOGISTS IN ULTRASOUND

1. ICA should be diagnosed as normal when ICA PSV is < 125 cm/sec and no plaque or intimal thickening is visible
   a) color: no plaque is visible
   b) ICA PSV = 69 cm/sec (< 125 cm/sec)

CONCLUSION: ICA NORMAL
CAROTID ARTERY STENOSIS: US DIAGNOSIS

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ICA EDV (cm/sec)

CONSSENSUS CONFERENCE 2003
SOCIETY OF RADIOLOGISTS IN ULTRASOUND

2. ICA should be diagnosed as <50% stenosis when ICA PSV is < 125 cm/sec and plaque or intimal thickening is visible

a) power: plaque is visible (diameter reduction < 50%)
b) ICA PSV = 50 cm./sec. (< 125 cm/sec)

CONCLUSION: DEGREE OF STENOSIS < 50%
### Carotid Artery Stenosis: US Diagnosis

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### Consensus Conference 2003

**Society of Radiologists in Ultrasound**

3. ICA should be diagnosed as 50%–69% stenosis when ICA PSV is 125–230 cm/sec and plaque is visible

- a) color: plaque is visible (diameter reduction ≥ 50%)
- b) ICA PSV = 219 cm/sec

**Conclusion:** Degree of Stenosis 50-69%
CAROTID ARTERY STENOSIS:
US DIAGNOSIS

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<tr>
<td>&lt;50</td>
<td>&lt;125 (cm/sec)</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>50-69</td>
<td>125-230 (cm/sec)</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>≥70 but less than near occlusion</td>
<td>&gt;230 (cm/sec)</td>
<td>2.0-4.0</td>
</tr>
<tr>
<td>Near occlusion</td>
<td>High, low, or undetectable</td>
<td>40-100</td>
</tr>
<tr>
<td>Total occlusion</td>
<td>Undetectable</td>
<td>&gt;4.0</td>
</tr>
</tbody>
</table>

ICA PSV: 273 cm/sec (> 230 cm/sec)

CONSENSUS CONFERENCE 2003
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4. ICA should be diagnosed as ≥70% stenosis to near occlusion when PSV is > 230 cm/sec and visible plaque and lumen narrowing are seen

a) color: visible plaque and lumen narrowing are seen (diam. reduction ≥ 50%)
b) ICA PSV = 273 cm/sec (> 230 cm/sec)

CONCLUSION: STENOSIS ≥70% BUT NOT NEAR OCCLUSION
CAROTID ARTERY STENOSIS: US DIAGNOSIS

CONSENSUS CONFERENCE 2003
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5. ICA should be diagnosed as near occlusion when there is a markedly narrowed lumen at color US. ICA PSV may be high, low or undetectable
   a) B-mode: markedly narrowed lumen
   b) ICA PSV high and low (in this case)

CONCLUSION: NEAR OCCLUSION
CAROTID ARTERY STENOSIS: US DIAGNOSIS

<table>
<thead>
<tr>
<th>Degree of Stenosis (%)</th>
<th>Primary Parameters</th>
<th>Additional Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICA PSV (cm/sec)</td>
<td>Plaque Estimate (%)*</td>
</tr>
<tr>
<td>Normal</td>
<td>&lt;125</td>
<td>None</td>
</tr>
<tr>
<td>50-69</td>
<td>125-230</td>
<td>≥50</td>
</tr>
<tr>
<td>≥70 but less than</td>
<td>&gt;230</td>
<td>≥50</td>
</tr>
<tr>
<td>Near occlusion</td>
<td>High, low, or</td>
<td>Visible</td>
</tr>
<tr>
<td>Total occlusion</td>
<td>undetectable</td>
<td>Visible, no</td>
</tr>
<tr>
<td></td>
<td></td>
<td>detectable lumen</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>ICA/CCA PSV Ratio</td>
<td>ICA EDV (cm/sec)</td>
</tr>
<tr>
<td>Normal</td>
<td>&lt;2.0</td>
<td>&lt;40</td>
</tr>
<tr>
<td>50-69</td>
<td>&lt;2.0</td>
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</tr>
<tr>
<td>Near occlusion</td>
<td>&gt;4.0</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

CONSENSUS CONFERENCE 2003
SOCIETY OF RADIOLOGISTS IN ULTRASOUND

6. ICA should be diagnosed as total occlusion when there is no detectable patent lumen at B-mode and no flow at spectral, power, color Doppler US
a) B-mode/color US: no detectable patent lumen (longitudinal and transverse scan)
b) CCA spectral analysis: high resistance flow for the ICA occlusion

CONCLUSION: OCCLUSION
### CAROTID ARTERY STENOSIS: US DIAGNOSIS

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<td>Visible</td>
</tr>
<tr>
<td>Total occlusion</td>
<td>Undetectable</td>
<td>Visible, no detectable lumen</td>
</tr>
</tbody>
</table>

**CRITICAL APPRAISAL OF THE CONSENSUS CRITERIA IN THE DIAGNOSIS OF ICA STENOSIS (PUBLISHED IN 2003)**

- the CDUS and angiography results of 376 carotid arteries were analyzed
- the consensus criteria for diagnosing **50% to 69%** stenosis can be significantly improved by using an **ICA PSV of 140 to 230 cm/s**, with a sensitivity of 94%, specificity of 92%, and overall accuracy of 92%

DEGREE OF ICA STENOSIS
HOW TO DO ?

2. CONSENSUS 2012

- A group of experts, with the aim to summarize the internationally available experience with US grading of carotid stenosis, including a consensus approved (in 2010) by all German medical societies active in the field of carotid ultrasound, proposed some recommendations, in 2012

*Grading carotid stenosis using ultrasonic methods. Neurosonology research group of the world federation of neurology. Stroke 2012*
CONSENSUS 2012

Consideration 1: there are many reasons why the PSV criterion is frequently in disagreement with the angiographic result and is of limited value taken alone

1. there is the morphology of the stenosis (area versus diameter, irregularities ill-represented by all imaging modalities)
2. the possibility of the same velocity in a moderate stenosis and a nearly occluded artery
3. the angle can be estimated fairly well in laminar flow conditions but it is difficult with disturbed flow, where stream lines differ from the vessel course
4. the influence of collateral flow. Velocities in a stenosis depend on collateral flow toward the territory supplied by the stenosed artery
5. the Doppler spectrum generated by a short stenosis is typically composed by high-frequency (velocity) components representing the jet, and low-frequency ones attributable to vortices and flow separation. This can lead to underestimation of the PSV

Taking into consideration all these factors, it seems evident that PSV as a single simplified diagnostic parameter is insufficient.

Grading carotid stenosis using ultrasonic methods. Stroke 2012
CONSENSUS 2012

Consideration 2: the sole criterion of the PSV has limitations

- any decision based only on a carotid scan at the neck level and a single velocity (PSV) value has serious limitations
- diagnostic ultrasound has the potential to classify and grade carotid disease with high reliability, taking into account morphological and complex hemodynamic parameters
- these parameters represent physiological variables correlating with prognosis

*Grading carotid stenosis using ultrasonic methods. Stroke 2012*
RECOMMENDATIONS 1

- the NASCET method of measuring a stenosis should be the standard; the local narrowing (ECST) can be measured in addition, but it must be declared as such

*Grading Carotid Stenosis Using Ultrasonic Methods. Stroke 2012*
RECOMMENDATIONS 2

in low to moderate degrees of stenosis:

- grading of carotid stenosis by diagnostic US should be primarily based on morphological information (B-mode, color flow)
- in addition to degree of narrowing, plaque thickness, plaque length, and residual lumen should be reported

*Grading Carotid Stenosis Using Ultrasonic Methods. Stroke 2012*
RECOMMENDATIONS 2

**Moderate from a severe (70% NASCET) stenosis**

- Velocity measurements in a stenosis (PSV and carotid ratio) alone are not sufficient to differentiate a moderate from a severe (70% NASCET) stenosis with sufficient clinical reliability.

- It is recommended a search for collateral flow: ophthalmic artery branches (CW Doppler) or the anterior cerebral artery (TCCD).

- It is recommended that the poststenotic flow velocity distal to flow disturbances is examined, in which a reduction of velocities (comparison with the unaffected contralateral side or absolute reduction) allows additional grading within the category of severe stenosis.

- Hemodynamic criteria are appropriate for grading moderate to severe stenoses. Criteria should be considered in a hierarchical order. Established collateral flow is the most powerful criterion, excluding a less than severe stenosis irrespective of PSV.

*Grading Carotid Stenosis Using Ultrasonic Methods. Stroke 2012*
RECOMMENDATIONS 3

- special care is recommended for converting Doppler frequencies into velocity by measuring the angle of incidence (Doppler angle)
- measurements should be taken using the lowest possible angle of insonation (made in relation to the direction of the jet visualized by color velocity flow and not the vessel course)
- with an irregular stenosis, overestimation of velocities attributable to disturbed or helical flow has to be taken into consideration

*Grading Carotid Stenosis Using Ultrasonic Methods. Stroke 2012*
CAROTID ARTERY STENOSIS: US DIAGNOSIS

CASE REPORT: BILATERAL ICA SEVERE STENOSIS
(the flow velocity distal to the stenosis allows additional grading in severe stenosis)

- bilateral ICA stenosis: PSV ICA rt.=2,59 m/s; ICA lt.=2,36 m/s (=70% NASCET)
- lt. siphon, distal to the stenosis: poststenotic parvus flow (PSV = 0,56 m/s; IR=0,48)
- rt. siphon flow: regular flow (PSV = 1,25 m/s; IR=0,57)
- presence of collateral supply via anterior communicating artery (rt.→lt.)
- ACM with asymmetric velocity flows (lt. PSV = 0,71 m/s; rt. PSV = 1,90 m/s)
CASE REPORT: BILATERAL ICA SEVERE STENOSIS
(collateral flow is the most powerful criterion)
In this case the ICA PSV are similar (rt. = 2,59 m/s; lt. = 2,36 m/s).

BUT

a) the reduction of the ICA/siphon lt. flow velocity (compared with the contralateral side)
b) the presence of collateral supply via anterior communicating artery (rt→lt)
c) the low ACM lt flow (compared with ACM rt. flow)

mean a more severe stenosis on the lt side
short videos and playlists on echocolor Doppler study of carotid artery stenosis are available on my youtube channel:
http://www.youtube.com/channel/UCij561sX0bQoEjXIWKuPnKg