CAROTID DUPLEX CRITERIA: What Have We Learned in 40 Years?

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DISCLOSURE

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No Relevant Financial Relationship Reported
NONINVASIVE CAROTID TESTING

Indirect Methods

- 1970s and 1980s (now mostly of historical interest)
- Detect pressure/flow changes in distal branches and collateral vessels

Oculoplethysmography (OPG)

Periorbital Doppler

Oculoplethysmography (OPG)
NONINVASIVE CAROTID TESTING

Direct Methods

- Obtained information from the diseased arterial segment

Pulsed Doppler Arteriography (mid 1970s)

- Multiple-gate pulsed Doppler transducer on a position-sensing arm
- Points of flow “stored” on a video screen
- Provided a “flow image”

Hokanson Ultrasonic Arteriograph
NONINVASIVE CAROTID TESTING

Direct Methods

- Real-time B-mode (2D) Ultrasound

Is this internal carotid artery patent or occluded?

University of Washington
Circa 1974

Occluded
NONINVASIVE CAROTID TESTING

The Duplex Concept

B-mode Imaging

Pulsed Doppler Flow Detection

Anatomy + Physiology
DUPLEX SCANNING

Prototype System

University of Washington - 1978

Instrument Rack

Spectrum Analyzer

Scanhead
CAROTID DUPLEX CRITERIA

Applying the Duplex Concept

B-Mode Image

Pulsed Doppler Spectral Waveforms

Identify vessels for Doppler interrogation (detect calcification, plaque, thrombus)

Evaluation of flow patterns

CRITERIA FOR CLASSIFICATION OF DISEASE
CAROTID DUPLEX CRITERIA

Normal and Abnormal Flow Patterns

- Flow disturbances with stenosis:
  - Increased PSV and EDV
  - Spectral broadening
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“Validation Studies”

- Spectral waveforms were correlated with carotid arteriograms (PSV, EDV, spectral broadening)
- Bi-planar, cut films, measured with calipers
- Estimated carotid bulb diameter used as the reference site
- Large categories of disease (ranges of stenosis)
- Phases I, II, and III (≈1979 to 1984)
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University of Washington Criteria
Phases I and II

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackshear 1979</td>
<td>Breslau 1982</td>
</tr>
<tr>
<td>Fell 1981</td>
<td>Langlois 1983</td>
</tr>
<tr>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>1-10%</td>
<td>1-15%</td>
</tr>
<tr>
<td>10-49%</td>
<td>16-49%</td>
</tr>
<tr>
<td>50-99%</td>
<td>50-99%</td>
</tr>
<tr>
<td>Occluded</td>
<td>Occluded</td>
</tr>
</tbody>
</table>

Primary criterion:
- ≥50% ICA stenosis
  \[
  PSV \geq 125 \text{ cm/s}
  \]

Secondary criterion:
- Normal vs. <50% stenosis
  \[
  \text{Spectral broadening (minimal vs. complete)}
  \]
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Carotid Bulb Flow Patterns

Spectral Waveforms

Color-flow Image

Flow Separation

Right Bulb
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University of Washington Criteria
Phase III

Primary criteria:
- ≥50% ICA stenosis
  \[ PSV \geq 125 \text{ cm/s} \]
- 80-99% ICA stenosis
  \[ EDV \geq 140 \text{ cm/s} \]

Secondary criteria:
- Normal vs. 1-15% stenosis
- 1-15% vs. 16-49% stenosis
  \[ Flow \text{ separation} \]
- 50-99% stenosis
  \[ Spectral \text{ broadening} \]
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University of Washington Criteria

Stenosis Categories:

- **A** Normal
- **B** 1-15%
- **C** 16-49%
- **D** 50-79%
- **D+** 80-99%
- **E** Occluded

Based on 60° Doppler angle and 5 MHz Doppler

Doppler-shift frequency (KHz):

- 4 KHz = 125 cm/s
- 4.5 KHz = 140 cm/s
### CAROTID DUPLEX CRITERIA

University of Washington Validation - Duplex vs. Arteriography

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>99%</td>
</tr>
<tr>
<td>Specificity</td>
<td>84%</td>
</tr>
<tr>
<td>Overall Accuracy</td>
<td>85%</td>
</tr>
<tr>
<td>Accuracy for 50-99% stenosis or occlusion</td>
<td>93%</td>
</tr>
<tr>
<td>Radiologist 1 vs. Radiologist 2 for 50-99% stenosis</td>
<td>85%</td>
</tr>
</tbody>
</table>
## CAROTID DUPLEX CRITERIA
### University of Washington Criteria - Current

<table>
<thead>
<tr>
<th>Diameter Reduction</th>
<th>Velocity</th>
<th>Spectral Broadening</th>
<th>Plaque</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> Normal</td>
<td>PSV &lt;125 cm/s</td>
<td>None</td>
<td>None</td>
<td>Flow Separation in the bulb</td>
</tr>
<tr>
<td><strong>B</strong> 1-15%</td>
<td>PSV &lt;125 cm/s</td>
<td>Minimal (late systole)</td>
<td>Wall thickening</td>
<td>Note: A vs. B vs. C may be subjective</td>
</tr>
<tr>
<td><strong>C</strong> 16-49%</td>
<td>PSV &lt;125 cm/s</td>
<td>Throughout systole</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td><strong>D</strong> 50-79%</td>
<td>PSV ≥125 cm/s, EDV &lt;140 cm/s</td>
<td>Throughout systole</td>
<td>Present</td>
<td>ICA/CCA ratio ≥4.0 = ≥70% NASCET stenosis</td>
</tr>
<tr>
<td><strong>D+</strong> 80-99%</td>
<td>EDV ≥140 cm/s</td>
<td>Throughout systole</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td><strong>E</strong> Occlusion</td>
<td>No Flow in ICA</td>
<td>---</td>
<td>---</td>
<td>“Flow to zero” in ipsilateral CCA</td>
</tr>
</tbody>
</table>
We have always used velocity thresholds to classify the severity of internal carotid stenosis.

Velocity criteria have traditionally been validated by comparison with the “gold standard” of arteriography.

**BUT**

What is the relationship between velocity and % arteriographic stenosis?
PSV does increase with increasing stenosis severity… but with wide variability

“Scattergrams” of velocities (PSV) vs. stenosis severity

19 articles with 22 data sets published from 1995 and 2010

Both native and stented internal carotid arteries

Total of 2,996 PSV measurements

Beach et al. Vasc Endovascular Surg 2012
The duplex scanner combined real-time B-mode imaging (anatomy) and pulsed Doppler flow detection (physiology) in a single device that started the field of direct vascular ultrasound imaging.

Classification of disease severity was (and still is) based primarily on analysis of flow patterns (spectral waveforms).

B-mode image findings have assumed a larger diagnostic role as the technology has improved (plaque characterization).

Velocity is proportional to stenosis severity, **but with wide variability**.

Further refinements in Doppler velocity criteria will **not** lead to improved correlation with angiographic stenosis.