Pre-and Post Procedure Non-Invasive Evaluation of the Patient with Carotid Disease

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Within the past 12 months, the presenter or their spouse/partner have had a financial interest/arrangement or affiliation with the organization listed below.

Company Name: Cordis Endovascular
Relationship: Consultant
Options for Non-Invasive Evaluation Prior to Carotid Revascularization

- Physical Examination
- Carotid Duplex Ultrasonography
- Magnetic Resonance Arteriography
- Computerized Tomographic Arteriography
Options for Non-Invasive Evaluation Prior to Carotid Revascularization

● Physical Examination
● Carotid Duplex Ultrasonography
● Magnetic Resonance Arteriography
● Computerized Tomographic Arteriography

Finding of a Cervical Bruit does NOT Define Presence or Severity of Extracranial Carotid Artery Stenosis
Options for Non-Invasive Evaluation Prior to Carotid Revascularization

- Physical Examination
- Carotid Duplex Ultrasonography
- Magnetic Resonance Arteriography
- Computerized Tomographic Arteriography
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
- DUS can determine anatomic high risk scenarios
  - High bifurcation lesion
  - Ostial CCA stenosis
  - Contralateral Occlusion
- DUS can determine cases suboptimal for CAS
  - Tortuosity
  - Thrombus
  - Dense calcification
Gray Scale Carotid Duplex Scan

- CCA
- ICA
- ECA

[Image of a carotid duplex scan with labeled vessels]
The Importance of a Correct Doppler Angle

The Angle should never exceed $60^\circ$
Carotid Duplex Ultrasonography
80-99% Internal Carotid Artery Stenosis
Modern Criteria for Duplex Ultrasound Determination of ICA Stenosis

<table>
<thead>
<tr>
<th>Velocity Criteria, cm/sec</th>
<th>Spectral Broadening</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-19%</td>
<td>≤ 105</td>
</tr>
<tr>
<td>20-39%</td>
<td>≤ 105</td>
</tr>
<tr>
<td>40-59%</td>
<td>&gt; 105, ≤ 150</td>
</tr>
<tr>
<td>60-79%</td>
<td>&gt; 150, ≤ 220</td>
</tr>
<tr>
<td>80-99%</td>
<td>&gt; 220 AND End Diastolic Velocity ≥ 135</td>
</tr>
<tr>
<td>Occluded</td>
<td>No Doppler Signal, Pre-Occlusive Thump</td>
</tr>
</tbody>
</table>
## SRU Consensus Panel Criteria for Grading ICA Stenosis

<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>&lt; 50</td>
<td>&lt;125</td>
<td>&lt;50</td>
</tr>
<tr>
<td>50–69</td>
<td>125–230</td>
<td>≥50</td>
</tr>
<tr>
<td>≥ 70 but less than near occlusion</td>
<td>&gt;230</td>
<td>≥50</td>
</tr>
<tr>
<td>Near occlusion</td>
<td>High, low, or undetectable</td>
<td>Visible</td>
</tr>
<tr>
<td>Total occlusion</td>
<td>Undetectable</td>
<td>Visible, no detectable lumen</td>
</tr>
</tbody>
</table>

*Plaque Estimate (%)*

Radiology 2003;229:340-346
CAVATAS DUS Criteria

<table>
<thead>
<tr>
<th>Stenosis (%)</th>
<th>PSV ICA (m/s)</th>
<th>EDV ICA (m/s)</th>
<th>PSV ICA/PSV CCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–29</td>
<td>&lt;1.0</td>
<td>&lt;0.4</td>
<td>&lt;3.2</td>
</tr>
<tr>
<td>30–49</td>
<td>1.1–1.3</td>
<td>&lt;0.4</td>
<td>&lt;3.2</td>
</tr>
<tr>
<td>50–59</td>
<td>&gt;1.3</td>
<td>&lt;0.4</td>
<td>&lt;3.2</td>
</tr>
<tr>
<td>60–69</td>
<td>&gt;1.3</td>
<td>0.4–1.1</td>
<td>3.2–&lt;4.0</td>
</tr>
<tr>
<td>70–79</td>
<td>&gt;2.1</td>
<td>1.2–1.4</td>
<td>≥4.0</td>
</tr>
<tr>
<td>80–95</td>
<td>&gt;2.1</td>
<td>&gt;1.4</td>
<td>≥4.0</td>
</tr>
<tr>
<td>96–99</td>
<td>String Flow</td>
<td>String Flow</td>
<td>String Flow</td>
</tr>
<tr>
<td>100</td>
<td>Occluded</td>
<td>Occluded</td>
<td>Occluded</td>
</tr>
</tbody>
</table>

Stroke 2005;36:281-6
Pitfalls of Carotid Duplex Imaging

- 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
- Distal ICA or ostial CCA stenosis
Can Carotid Duplex Ultrasonography Detect Vulnerable Plaque?
Prediction of Stroke with CAS—The ICAROS Trial

- 496 CAS procedures worldwide evaluated pre-intervention with duplex-US derived Gray Scale Median (GSM) scores
- 415 cases actually underwent CAS
  - 219 cases with embolic protection devices
- CAS Complications
  - 13 TIAs
  - 9 Minor CVAs
  - 6 Major CVAs
  - 0 Deaths

Circulation 2004;110:756-62
Prediction of Stroke with CAS—The ICAROS Trial

Gray Scale Median: Based on notion that echoluent plaques have higher embolicogenic potential than echodense plaques
Prediction of Stroke with CAS—
The ICAROS Trial

Circulation 2004;110:756-62
### Prediction of Stroke with CAS—The ICAROS Trial

#### Multiple Logistic Regression Analysis

<table>
<thead>
<tr>
<th></th>
<th>OR</th>
<th>P</th>
<th>95% CI</th>
</tr>
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<tbody>
<tr>
<td><strong>GSM</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤25 vs &gt;25</td>
<td>7.11</td>
<td>0.002</td>
<td>2.06–24.57</td>
</tr>
<tr>
<td><strong>Stenosis, %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥85 vs &lt;85</td>
<td>5.76</td>
<td>0.010</td>
<td>1.51–21.91</td>
</tr>
<tr>
<td><strong>Symptomatology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptomatic vs asymptomatic</td>
<td>2.92</td>
<td>0.061</td>
<td>0.95–8.93</td>
</tr>
<tr>
<td><strong>Brain CT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive vs negative</td>
<td>2.54</td>
<td>0.099</td>
<td>0.84–7.47</td>
</tr>
</tbody>
</table>

Circulation 2004;110:756-62
Carotid Duplex Ultrasonography
Post-CEA

LEFT INTERNAL CAROTID ARTERY
S/P CAROTID ENDARTERECTOMY 4/1/03

POST-STENOTIC TURBULENCE
Carotid Duplex Sonography of Endovascular Stents

**B-mode image: More important than in Native DUS**

- Evaluate stent from 2 views in gray scale
- Proximal and distal ends: apposition to wall
- Stent integrity
- Confirm abnormal findings from 2 views
- Include proximal and distal native vessel
Post-Stent Gray Scale B Mode is Critical
24 Hours Post-ICA Stent
Duplex Assisted Carotid Artery Stenting

J Vasc Surg 2005;41:409-15
Duplex Assisted Carotid Artery Stenting

J Vasc Surg 2005;41:409-15
Duplex Assisted Carotid Artery Stenting

J Vasc Surg 2005;41:409-15
Selection of Patients for Carotid Stenting Using DUS Findings

- Retrospective study of 139 patients with carotid DUS available hospital records
- Plaque Characteristics on DUS
  - 58% had irregular surfaces
  - 53% with heterogeneous findings
- Combination of irregular, heterogeneous plaques increased risk of ipsilateral neurologic events (p<0.0001)
- Implications for carotid stenting?

Problems with Carotid Duplex Ultrasonography in Stented Carotid Arteries

- No well performed, prospective trials validating carotid duplex US in carotid stents
- Early experience suggests that peak systolic velocities (PSV) after carotid stenting are elevated when compared to non-stented arteries
- Plaque shadowing
- Stent deployment issues
Carotid Duplex Ultrasonography-- Carotid Stent Imaging
DUS Follow-Up of Stented Carotid Arteries

- 114 patients
- Angiography immediately after carotid stent deployment
- DUS performed within 1 week of procedure

Four Criteria used
- 1) Peak in-stent SV >125 cm/s
- 2) ICA/CCA >3.0
- 3) Peak in-stent SV >170 cm/s
- 4) ICA/CCA >2.0
Carotid In-Stent Restenosis
# DUS Follow-Up of Stented Carotid Arteries

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Number of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV In Stent &gt;125 cm/s</td>
<td>36</td>
</tr>
<tr>
<td>ICA/CCA Ratio &gt;3.0</td>
<td>3</td>
</tr>
<tr>
<td>PSV In Stent &gt;170 cm/s</td>
<td>8</td>
</tr>
<tr>
<td>ICA/CCA Ratio &gt;2.0</td>
<td>14</td>
</tr>
</tbody>
</table>

Neurosurgery 2002;51:639-643
DUS Follow-Up of Stented Carotid Arteries

- No patient with DUS evidence of stenosis had angio evidence of >50% residual stenosis
- 3/9 with follow-up angio had restenosis
- In each of these 3 patients, all had increase in PSV >80% since post-stent DUS
CAVATAS
Restenosis: CEA vs Endo

Stroke 2005;36:281-6
CAVATAS
Restenosis: PTA vs Stent

Stroke 2005;36:281-6
CAVATAS

Restenosis: Endo vs Surgery

<table>
<thead>
<tr>
<th>Stenosis Severity</th>
<th>TIA/AF</th>
<th>RS</th>
<th>NDS</th>
<th>DS</th>
<th>FS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Endovascular patients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;70% (n=141)</td>
<td>7 (5.0)</td>
<td>1 (0.7)</td>
<td>0</td>
<td>0</td>
<td>3 (2.1)</td>
<td>11 (7.8)</td>
</tr>
<tr>
<td>≥70% (n=32)</td>
<td>4 (12.5)</td>
<td>0</td>
<td>1 (3.1)</td>
<td>0</td>
<td>0</td>
<td>5 (15.6)*</td>
</tr>
<tr>
<td><strong>Surgery patients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;70% (n=165)</td>
<td>5 (3.0)</td>
<td>0</td>
<td>3 (1.8)</td>
<td>2 (1.2)</td>
<td>0</td>
<td>10 (6.1)</td>
</tr>
<tr>
<td>≥70% (n=9)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
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</table>

*p=0.02

Stroke 2005;36:281-6
What are the Current Criteria for Carotid Stent Duplex Ultrasonography?

- Peak Systolic Velocity < 150 cm/sec
- ICA/CCA PSV Ratio < 2.16

Why Are Velocities Higher in the Stented ICA?

Compliance of the distal internal carotid artery (% mm Hg^-1 x 10^-2)

- Pre-CAS
- Post-CAS

p = 0.0004

Options for Non-Invasive Evaluation Prior to Carotid Revascularization

- Physical Examination
- Carotid Duplex Ultrasonography
- Magnetic Resonance Arteriography
- Computerized Tomographic Arteriography
Gd Enhanced MRA

- No ionizing radiation
- Non-invasive (no arterial catheterization)
- Non-nephrotoxic contrast
- Allergic reactions rare
- High accuracy
- 3D allows multiplanar reformatting
- Decreased cost
- SUPERIOR IMAGE QUALITY
- FAST IMAGING
Carotid MRA
Preoperative Evaluation of Carotid Artery Stenosis: Comparison of Contrast-MR Angiography and Duplex Ultrasonography with Digital Subtraction Angiography


71 vessels - 39 symptomatic patients

<table>
<thead>
<tr>
<th>Percent</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRA</td>
<td>94.9%</td>
<td>79.1%</td>
</tr>
<tr>
<td>Duplex</td>
<td>92.9%</td>
<td>81.9%</td>
</tr>
<tr>
<td>Combined</td>
<td>100%</td>
<td>81.4%</td>
</tr>
</tbody>
</table>

80% of vessels for identification of stenoses ≥ 70%
Nederkoorn et al. Stroke 2003

- Statistical review of DUS and MRA literature
- 63 publications (1994-2001) comparison to DSA

<table>
<thead>
<tr>
<th>% Stenosis</th>
<th>Pooled Sensitivity, % (95% CI)</th>
<th>Pooled Specificity, % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRA</td>
<td>DUS</td>
<td>MRA</td>
</tr>
<tr>
<td>70-99% vs. &lt; 70%</td>
<td>95 (92-97)</td>
<td>86 (84-89)</td>
</tr>
</tbody>
</table>
MRA has a better discriminatory power compared with DUS in diagnosing 70-99% stenosis and is a sensitive and specific test compared with DSA in the evaluation of carotid artery stenosis.

Nederkoorn et al. Stroke 2003
<table>
<thead>
<tr>
<th></th>
<th>DUS</th>
<th>MRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine &gt;70% Stenosis</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Determine 50-69% Stenosis</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Plaque Morphology</td>
<td>√</td>
<td>Not Yet</td>
</tr>
<tr>
<td>Assess Revascularization Adequacy: CEA</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Assess Revascularization Adequacy: CSSA</td>
<td>√</td>
<td>-</td>
</tr>
</tbody>
</table>
Options for Non-Invasive Evaluation Prior to Carotid Revascularization

- Physical Examination
- Carotid Duplex Ultrasonography
- Magnetic Resonance Arteriography
- Computerized Tomographic Arteriography
CT Angiography

- New and emerging technology
- Requires intravenous iodinated contrast
- Requires significant radiation exposure
- Allows for three dimensional wide field of view
- Able to detect and characterize calcification
Cerebrovascular CT Angiography
Modern Diagnostic Algorithm for Extracranial Carotid Disease

Suspicion of Extracranial Carotid Disease

- Carotid Duplex Ultrasonography
  - <50% Stenosis
    - Appropriate F/U DUS
  - 50-99% Stenosis in Appropriate Clinical Scenario
    - MRA/CTA
      - DUS/MRA/CTA Agree?
        - YES
          - CSSA
          - Med Rx
        - NO
          - Surgery
          - Med Rx
  - Occlusion
    - Appropriate F/U DUS
Who Needs a Carotid Arteriogram?

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