Carotid Stenosis: Imaging

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Learning Objectives
- Describe relationship between carotid stenosis and stroke
- Compare carotid imaging techniques
- Interpret carotid imaging results and consider implications for management
- Discuss stroke risk stratification with advanced imaging

Carotid Stenosis and Stroke
- Stroke → 3rd leading cause of death
- Atherosclerosis → 15-20% of strokes
- Carotid stenosis is a major risk factor

Atherosclerotic Plaque Progression
- Normal vessel
- Fatty streak
- Fibro-fatty plaque
- Advanced or Vulnerable plaque

Clinically silent | May be symptomatic

MRI
DWI
CTA
North American Symptomatic Carotid Endarterectomy Trial, 1991

- Severe stenosis (70-99%)
  - *Significant benefit at 2 yrs*: CEA 9% vs MM 26%

- Moderate stenosis (50-69%)
  - *Moderate benefit at 5 yrs*: CEA 16% vs MM 22%

- Mild stenosis <50%
  - *No benefit at 5 yrs*: CEA 15% vs MM 19%

NASCET Measurement Criteria

Stenosis Calculation:

\[
1 - \frac{A}{B} \times 100 = \text{Stenosis} \%
\]

\[
1 - \frac{1.6}{6.1} \times 100 = 74\%
\]

Lumen diameter:
A: Narrowest ICA diameter
B: Normal distal ICA diameter

Carotid Duplex Ultrasound

- Asymptomatic patient, suspected stenosis
  - Carotid bruit, history of PAD or CAD, risk factors

- Symptomatic patient, suspected stenosis
  - Hemispheric stroke, TIA, amaurosis fugax

- Follow-up, known stenosis (>50%)
### Ultrasound Stenosis Grading
- **Severe Stenosis (70-99%)**
  - Peak systolic flow velocity (PSV): >230 cm/s
  - End diastolic velocity (EDV): >100 cm/s
  - ICA:CCA PSV ratio: >4

### Advantages of Ultrasonography
- No radiation
- No IV contrast
- Cost effective
- Best screening test
- Best for serially following patients on therapy

### Limitations of Ultrasonography
- Operator dependent
- Limited field-of-view
  - No arch, intracranial
- Calcific shadowing
- Stenosis estimated based upon velocity
- Confirmatory test often needed prior to revascularization

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### Ultrasound Stenosis Grading
- **Severe Stenosis (70-99%)**
  - Peak systolic flow velocity (PSV): >230 cm/s
  - End diastolic velocity (EDV): >100 cm/s
  - ICA:CCA PSV ratio: >4

- **Moderate Stenosis (50-99%)**
  - Peak systolic flow velocity (PSV): 125 – 230 cm/s
  - End diastolic velocity (EDV): 40 – 100 cm/s
  - ICA:CCA PSV ratio: 2 – 4
**Indications for CTA or MRA**

- **Acute ischemic neurologic symptoms, and**
  - Ultrasound cannot be obtained, equivocal or non-diagnostic
  - No carotid stenosis on ultrasound, search for intracranial vascular disease
  - Confirmation of severe carotid stenosis or planning for revascularization procedure

**CT Angiography**

- Rapid (seconds of imaging)
- Available 24/7 emergency
- Aorta to Circle of Willis
  - Vessel origins
  - Tandem lesions
  - Distal embolus
- Plaque composition
- Brain imaging

**Advantages of CT Angiography**

**Limitations of CT Angiography**

- Requires IV contrast
  - Allergy
  - Renal failure
  - Radiation dose
- May overestimate stenosis
  - Densely calcified plaques
  - Stents
### MR Angiography

- **Advantages of MR Angiography**
  - No radiation
  - Possible without IV contrast
  - Aorta to Circle of Willis
    - Vessel origins
    - Tandem lesions
    - Distal embolus
  - Brain imaging (MRI diffusion-weighted imaging)

### Limitations of MR Angiography

- Relatively lengthy (~15 min)
- Sensitive to motion artifacts
- Claustrophobia
- Ferromagnetic metal implants (pacemaker, etc)
- Best with IV contrast
  - Renal failure
- Lumen imaged only, without specialized sequences

### Advanced Imaging Risk Stratification

- **Carotid plaque imaging (MRI, CT, US)**
  - Ulceration, thin or ruptured fibrous cap
  - Intra-plaque hemorrhage
  - Lipid rich or necrotic core
  - Angiogenesis, leads to hemorrhage
  - Plaque inflammation (PET)

- **Cerebrovascular reserve imaging**
  - Acetazolamide challenge paired with perfusion imaging (SPECT, MRI or CT)
  - “Stress test” for the brain
CASE 1

56 y/o male with 3 month history of recurrent TIAs characterized by left sided weakness, sensory symptoms

- History of iodinated contrast allergy
- No metallic implants
- Not claustrophobic

Carotid Duplex Ultrasound

Right carotid duplex indicates 70-99% stenosis of internal carotid artery.

Left carotid duplex indicates <50% stenosis of internal carotid artery.

Carotid Duplex Ultrasound Table

<table>
<thead>
<tr>
<th>Segment</th>
<th>PSV</th>
<th>EDV</th>
<th>Ratio</th>
<th>% Stenosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prox CCA</td>
<td>50.7</td>
<td>15.3</td>
<td></td>
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<tr>
<td>Dist Com Carotid</td>
<td>43.2</td>
<td>13.8</td>
<td></td>
<td></td>
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<tr>
<td>Prox. ICA</td>
<td>350</td>
<td>157</td>
<td>8.1</td>
<td>70-99%</td>
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<tr>
<td>Mid. ICA</td>
<td>266</td>
<td>81.7</td>
<td>6.16</td>
<td>50-69%</td>
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<tr>
<td>Dist. ICA</td>
<td>122</td>
<td>22.6</td>
<td>2.82</td>
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<tr>
<td>Ext Carotid</td>
<td>145</td>
<td>27.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertebral</td>
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Carotid Duplex Ultrasound Table (continued)

<table>
<thead>
<tr>
<th>Segment</th>
<th>PSV</th>
<th>EDV</th>
<th>Ratio</th>
<th>% Stenosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prox CCA</td>
<td>55.9</td>
<td>33</td>
<td></td>
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<tr>
<td>Dist Com Carotid</td>
<td>50.4</td>
<td>31.4</td>
<td></td>
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<tr>
<td>Prox. ICA</td>
<td>89.8</td>
<td>27</td>
<td>0.77</td>
<td>&lt; 50%</td>
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<tr>
<td>Dist. ICA</td>
<td>86.2</td>
<td>38.1</td>
<td>1.06</td>
<td></td>
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<tr>
<td>Ext Carotid</td>
<td>114</td>
<td>24.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertebral</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Video #1  MR Angiography

WITHOUT Gadolinium (2D TOF)  WITH Gadolinium (3D TOF)

Severe ICA stenosis, treated with carotid endarterectomy
65 y/o male with history of diabetes mellitus, hypertension, and 50 pack year smoking history. Assessment of operative risk prior to planned colectomy for mass found on colonoscopy.

• What is the best test in this case?

**CASE 2**

**Doppler Ultrasound**

Interpretation: Right ICA appears occluded or near occluded, extreme acoustic shadowing from calcification.

**CT Angiography: Curved Planar Reformat**

Patency Confirmed

Curved Planar Reformat

True axial reconstruction

Lumen quantification

**CT Angiography: Advanced Visualization**

Common Processing Techniques:
- 3D Volume Rendered (3D VR)
- Maximum Intensity Projection (MIP)
- Multiplanar Reformat (MPR)
- Curved Planar Reformat (CPR)

VIDEO #3
CASE 3

64 y/o female with acute right-sided weakness and aphasia, presented to Emergency Department after hours

• No metallic implants
• Not claustrophobic

What is the best test in this case?

CT Angiography: Left Carotid Bifurcation

Axial source images  Curved planar reformat

64 y/o female with acute right-sided weakness and aphasia

MRI and MRA

64 y/o female with acute right-sided weakness and aphasia

Post-Treatment CT Angiography

DAY 0: Presentation  DAY 16: post tPA, antiplatelet

Axial CTA Left Carotid

Intra-arterial thrombus resolved with medical therapy
Key Points

• Stroke risk increases with:
  • Carotid stenosis severity
  • Plaque vulnerability
• Ultrasound: Screening test
• CTA or MRA: Confirmatory; Acute setting
• Advanced imaging may stratify individual risk beyond stenosis

Carotid Stenosis: Diagnosis and Management

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Treatment of Carotid Artery Disease

• Even patients undergoing interventions for carotid artery disease need best medical therapy (BMT)
**Best Medical Therapy**

- **Blood Pressure Control**
  - Asymptomatic extracranial carotid or vertebral atherosclerosis, below 140/90 mm Hg
  - For Symptomatic treatment is probably indicated but specific target has not been established
    - risk of exacerbating cerebral ischemia in acute stroke
  - Multiple Meta analysis, epidemiologic studies, and randomized trials have demonstrated 20-40% reduction in stroke with antihypertensive treatment

- **Smoking Cessation**
  - Smoking increases relative risk of ischemic stroke by 25% - 50%
  - Stroke risk decreases within 5 years of quitting compared with continuing smokers

- **Treatment with a statin medication is recommended for all patients with extracranial carotid or vertebral atherosclerosis**
  - Low-density lipoprotein (LDL) cholesterol below 100 mg/dL for asymptomatic
  - Near or below 70 mg/dL in those who sustain ischemic stroke, or diabetics
  - Add bile acid sequestrants medications or niacin for patients who do not tolerate statins or can't achieve above levels.

- **Meta-analysis of 26 trials (90 000 patients)**
  - statins reduced the risk of all strokes by approximately 21% (Amarenco P, et al, Stroke. 2004;35:2902–9)
  - Another meta-analysis of 9 trials (>65 000 patients)
    - 22% reduction in ischemic stroke per 1-mmol/L (40-mg/dL) reduction in serum LDL cholesterol (Baigent C, et al, Lancet. 2005;366: 1267–78.)
  - A randomized trial, SPARCL (Stroke Prevention by Aggressive Reduction in Cholesterol Levels)
      - reduced the absolute risk of stroke at 5 years by 2.2%
      - RR of ischemic stroke by 22%.
### Best Medical Therapy

- **Patients with DM and extracranial carotid or vertebral artery atherosclerosis.**
  - Diet, exercise, and glucose-lowering drugs
  - Stroke prevention benefit of intensive glucose lowering therapy to a glycosylated hemoglobin A1c level less than 7.0% has not been established.

- **Antiplatelet therapy with aspirin (75 to 325 mg daily) is recommended for prevention of MI and other ischemic cardiovascular events**
  - Patients with ischemic stroke or TIA
    - aspirin alone (75 to 325 mg daily)
    - Clopidogrel alone (75 mg daily)
    - Aspirin plus extended-release dipyridamole (25 and 200 mg twice daily, respectively)
  - Antiplatelet agents are recommended rather than oral anticoagulation for patients with or without ischemic symptoms

### Best Medical Therapy

- Hypertension
- Hyperlipidemia,
- Smoking Cessation
- Antiplatelet

*Image provided courtesy of Blair Vermilion, MD*
Is Carotid Intervention Still Needed?

Asymptomatic Carotid Artery Stenosis

- North American Symptomatic Carotid Endarterectomy Trial (NASCET)
  - Followed the asymptomatic contralateral carotid artery for 5 years
  - 2,377 patients
    - 216 (9%) had a stenosis >60%
    - 113 (4.7%) had a stenosis of 75-99%
  - The 5-year risk of ipsilateral stroke (not TIA) in the 75-99% asymptomatic stenosis cohort was 18.5% (3.7%/yr)
  - 60%-99% cohort such that the annual stroke rate was reported as 3.2%.

The Asymptomatic Carotid Stenosis and Risk of Ipsilateral Hemispheric Ischemic Events Study (ACSRS) - 1,115 patients with asymptomatic carotid stenosis >50% by duplex scanning for 6-84 months (mean 37.1)
- Annual stroke rate in high-risk patients was 4.3% (vs 0.7% in low-risk patients).
- 453 patients with 70%-99% stenosis by NASCET
  • Raw stroke rate of 5.7%
  • 5-year ipsilateral event rate of about 18%.
- If patients with 50-69% were added, the raw stroke rate decreased to 1.3%.
Severity of asymptomatic carotid stenosis and risk of ipsilateral hemispheric ischaemic events: results from the ACSRS study.

The Asymptomatic Stenosis Embolus Detection (ASED)
- Prospective trial, transcranial Doppler embolic signal detection would identify increased risk of ipsilateral neurologic events
- 240 arteries studied, 115 (48%) had a stenosis of 70%-99%
  • Average ipsilateral carotid event rate was 3.1%/yr with a 1% stroke/yr.
Embolic signals and prediction of ipsilateral stroke or transient ischemic attack in asymptomatic carotid stenosis: a multicenter prospective cohort study.

Randomized prospective trials such as the asymptomatic carotid artery stenosis (ACAS), and Asymptomatic carotid surgery trial (ACST)
- Similar annual stroke risk of 2% for patients treated with medical therapy
- 10-year follow-up data in the ACST trial demonstrated a sustained benefit for endarterectomy over optimal medical therapy.
- Nearly 80% of patients were on optimal medical therapy (aspirin plus statin agents) in the later years of the trial.
- 10-year data showed protective effect of endarterectomy was higher in non statin group (5.8% in patients taking a statin and 6.2% in those who were not)
- BUT protective effect of endarterectomy over optimal medical therapy was statistically significant (P=0.002).

Asymptomatic Carotid Artery Stenosis

Asymptomatic Carotid Artery Stenosis

Symptomatic Disease

- 70 – 99%
- NASCET 2 year follow up
  - 26% stroke risk in medical arm
  - 9% stroke risk in surgical arm
Symptomatic Disease

- 50 – 69%
- NASCET 5 year follow up
  - 22.7% stroke risk in medical arm
  - 15.7% stroke risk in surgical arm

Symptomatic Disease

- Symptoms within 120 days
- Increased risk reduction with greater degrees of stenosis
- Especially benefits males > 75
- There is benefit for women, but not as dramatic

Carotid Artery Stenting Outcomes

- Randomized trials plagued by
  - bias
  - operator inexperience
  - aberrant CEA outcomes
  - angioplasty without stent

Stenting Outcomes

<table>
<thead>
<tr>
<th>Trial</th>
<th>CEA stroke/death</th>
<th>CAS stroke/death</th>
<th>CEA restenosis</th>
<th>CAS restenosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAVATAS 2001</td>
<td>9.9%</td>
<td>10%</td>
<td>10.5%</td>
<td>30.7%</td>
</tr>
<tr>
<td>SAPPHIRE 2004</td>
<td>20.1%</td>
<td>12.2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVA-3S 2006</td>
<td>3.9%</td>
<td>9.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPACE 2006</td>
<td>6.3%</td>
<td>6.8%</td>
<td>4.6%</td>
<td>10.7%</td>
</tr>
</tbody>
</table>
CREST

- The most rigorous credentialing effort of any clinical trial (2,502 lead-in patients)
- Operators screened based on pre-trial outcomes and experience
- Then proctored
- Then subject to review after up to 20 cases performed during the lead-in phase

CREST Lead-In

- CAS
  - 4.4% stroke/death
  - 13.2% stroke/death > 80
  - 13% restenosis

CREST

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>CAS</th>
<th>CEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke/MI/death</td>
<td>6.8%</td>
<td>6.8%</td>
</tr>
<tr>
<td>Stroke</td>
<td>2.3%</td>
<td>2.3%</td>
</tr>
<tr>
<td>MI</td>
<td>1.1%</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

CREST

- Better outcomes with CAS < 70
- Better outcomes with CEA > 70
- Symptomatic patients have lower stroke/death rates with CEA
- Stroke had greater QoL impact than MI
**Recommendation Asymptomatic Disease**

1. Patients with stenosis <60%
   - Optimal medical therapy
2. CEA is preferred to CAS for reduction of all-cause stroke and periprocedural death
   - CREST suggest that patients aged <70 years may be better treated by CAS, but these data need further confirmation.
3. >60% diameter stenosis
   - Considered CEA for reduction of long-term risk of stroke
   - 3- to 5-year life expectancy
   - Perioperative stroke/death rates can be <3%

**Recommendation Asymptomatic Disease**

4. CEA is preferred over CAS in patients aged >70 years of age
   - with long (>15-mm) lesions
   - preocclusive stenosis
   - lipid-rich plaques that can be completely removed safely
5. Patients deemed “high risk” for CEA >3% perioperative morbidity / mortality
6. Insufficient data to recommend CAS as primary therapy for 70% to 99% diameter stenosis
   - CREST showed CAS is equivalent to CEA in the hands of experienced interventionalists.

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**Recommendation Symptomatic Disease**

1. Patients with stenosis <50%
   - Optimal medical therapy
2. CEA is preferred to CAS for reduction of all-cause stroke and periprocedural death
3. CAS is preferred over CEA with >50% stenosis and
   - tracheal stoma
   - local tissues are scarred and fibrotic
   - prior cranial nerve injury
   - lesions that extend proximal to the clavicle or distal to the C2

**Recommendation Symptomatic Disease**

4. CAS is preferred over CEA with >50% stenosis and
   - severe uncorrectable CAD
   - congestive heart failure
   - chronic obstructive pulmonary disease
   - May be potential increased role of optimal medical management as primary therapy in this high-risk group.