CAROTID ARTERY EVALUATION

Traditional Duplex and Emerging Ultrasound Approaches

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Lecture Outline

- Background
- Role of US in management of carotid disease
- Traditional triplex US approach
- Plaque morphology assessment
- Contrast-enhanced US
- Quantitative plaque elasticity
Background

- Strokes (CVAs) in USA >795,000/year
- ~25% have had previous CVAs
- ~87% are ischemic strokes (vs. hemorrhagic)
- ~15% result from ASVD emboli from carotid bifurcation
- Risk is closely associated with degree of ICA stenosis
Risk Statistics

- Asymptomatic patients
  - <1% risk; <75% stenosis
  - 2-5% risk, >75% stenosis
- Symptomatic patients (TIA, RIND, CVA)
  - 10% risk in 1st year; >50% stenosis
  - 30-35% risk next 5 years; >50% stenosis
Stroke Prevention - Symptomatic

- NASCET and ESCT studies show:
  - Benefits of early intervention
  - 5 year risk reduction
  - 16% (70%-near occlusion)
  - 4.6% (50-69%)
  - Risk outweighs benefit (<50%)
Role of US in Carotid Disease

- Identify and quantify arterial stenosis and plaque burden
- Identify occlusions
- Identify dissections
- Assess collateral flow patterns
- Identify subclavian steal syndrome
- Assess recanalization or reocclusion s/p thrombolysis
Role of US in Carotid Disease

- Identify and quantify arterial stenosis and plaque burden
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Traditional US Approach: B-mode

- Carotid morphology
- Arterial wall changes
  - Fatty streak
  - Intimal medial thickness (IMT) ≥1 mm
  - Dissection
- Plaque morphology
- Associated pathology
  - Chemodectoma (carotid body tumor)
  - Carotid thrombosis
Role of US in Carotid Disease

- Identify and quantify arterial stenosis and plaque burden
  - Normal
  - <50%
  - 50-69%
  - 70% - near occlusion
  - Near occlusion
  - Occlusion
Arterial Wall Changes

Normal

Fatty streak

IMT measurement

Frank plaque
Dissection

- Delamination of intima from media arterial layers
- Blood enters IM space via tear in intima
- Etiologies include:
  - Trauma - MVA, cervical chiropractic, sports-related
  - Spontaneous - FMD, connective system disorders
  - Iatrogenic - post interventional procedure
- Left side associated with Horner syndrome
- US sensitive method: 95% detection rate*

*Strutzenegger, 1995
Dissection
Dissection - US Findings

- Intimal flap in carotid artery
- Abnormal Doppler waveforms
- High-resistance, pulsatile signal proximal to significant stenosis
- Two arterial waveforms identified in true and false lumens
Dissection
Dissection
Dissection
Dissection
Plaque Morphology

- Identify vulnerable, unstable plaques
- Increased risk of thromboembolic events
- Histologic characteristics
  - Lipid-rich, necrotic core
  - Thin fibrous cap
  - Inflammatory infiltrate
  - Neovascularization
  - Intra-plaque hemorrhage
Plaque Morphology
Plaque Morphology

Unstable
Plaque Morphology

Ulcerated
Plaque Morphology

- Usually a subjective evaluation
- US assessment not reliable
- Computer assisted B-mode evaluation may be used but no consensus on objective parameters
- Emerging “advanced B-mode tissue differentiation” methods offer promise
- CEUS detects neovascularization and better delineation of surface disruptions
Plaque Morphology

Soft

Fibrotic

Calcified

Complex
Chemodectoma (Carotid Body Tumor)

- Paraganglioma in neck
  - Neuroendocrine tumor arising from paraganlia
- Usually diagnosed in 4th-5th decade of life
- Bilateral in 10% of cases
- Patient present with slowly growing neck mass
- Malignant transformation in 2-36% of cases*

*Lee, AJR, 2006
Chemodectoma
Carotid Thrombosis

• High morbidity and mortality (40-69%)*
• Found in presence or absence of carotid stenosis
• Absent ASVD, etiology usually hyper coagulable state
• May be intra- or extracranial in extent (or both)

*Berthert, Ann Vasc Surg, 1995
Carotid Thrombosis - US Signs

- Flow signal void over hypo- or anechoic area in vessel
- “Crescent moon” appears with CDI/PDI of residual lumen
- High velocity ECA signal or contralateral vessels

*Berthert, Ann Vasc Surg, 1995*
Carotid Thrombosis
Carotid Thrombosis
Traditional US Approach: Spectral Doppler

PW signals obtained in:

- CCA (prox, mid, distal)
- ICA (bulb, prox, mid, distal, in areas of stenosis)
- ECA (flow direction)
- Vertebral (flow direction)
- Subclavian (flow direction, patency)
Traditional US Approach: Spectral Doppler

PW values measured:

- Peak systolic velocity
- End diastolic velocity
- IC:CC ratio
- Others (A:B ratio, PI)
## Criteria for Carotid Stenosis

<table>
<thead>
<tr>
<th>% Stenosis</th>
<th>ICA PSV</th>
<th>ICA EDV</th>
<th>IC:CC Ratio</th>
<th>Plaque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt;125 cm/sec</td>
<td>&lt;40 cm/sec</td>
<td>&lt;2.0</td>
<td>None</td>
</tr>
<tr>
<td>&lt;50%</td>
<td>&lt;125 cm/sec</td>
<td>&lt;40 cm/sec</td>
<td>&lt;2.0</td>
<td>&lt;50% diameter reduction</td>
</tr>
<tr>
<td>50-69%</td>
<td>125-230 cm/sec</td>
<td>40-100 cm/sec</td>
<td>2.4-4.0</td>
<td>≥ 50%</td>
</tr>
<tr>
<td>70% - near occlusion</td>
<td>&gt;230 cm/sec</td>
<td>&gt;100 cm/sec</td>
<td>&gt;4.0</td>
<td>≥ 50%</td>
</tr>
<tr>
<td>Near occlusion</td>
<td>Low or undetectable</td>
<td>Variable</td>
<td>Variable</td>
<td>Extensive, detectable lumen</td>
</tr>
<tr>
<td>Occlusion</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>No detectable lumen</td>
</tr>
</tbody>
</table>

Society of Radiologists in Ultrasound 2002
Carotid Occlusion - US Signs

- Absent flow in distal ICA
- “Stump” flow proximal to occlusion
- Internalization of ECA
- Decreased arterial wall pulsation c/w contralateral side
- Absence of structural lesion in cervical ICA, suspect distal occlusion
Carotid Occlusion - US Signs

- Occluded CCA
- Bifurcation
- ECA
- Temporal Tap
Carotid Occlusion - US Signs
Emerging Ultrasound Approaches

- Advanced B-mode tissue differentiation
- Contrast enhanced US
- Quantitative plaque elasticity
- Vector flow imaging
Advanced B-mode Tissue Differentiation

• Advanced image processing technology

• Creates B-mode image within ROI based on acoustic characteristics of different types of tissue

• Increased spatial and contrast resolution

• NOT a B-mode post processing method
Advanced B-mode Tissue Differentiation
Advanced B-mode Tissue Differentiation
Advanced B-mode Tissue Differentiation
Contrast-enhanced Ultrasound

• New, noninvasive methods of imaging ASVD lesions
• Better delineation of wall irregularities
• Identification of plaque neovascularization
• Readily available at bedside or in US suite
• FDA approval of agents in cardiology, liver lesions
• Carotid imaging - off-label use
Contrast-enhanced Ultrasound

*Ultrasound contrast agents (UCA):*

- Inert gas micro bubble encased in a stabilizing shell
- FDA approval for use in adult and peds liver - 2014
- Intravenous injection
- “Blood pool” agents which remain intravascular - do not permeate into tissue parenchyma
- As such are ideal for displaying and assessing perfusion patterns (macro and micro)
Contrast-enhanced Ultrasound

*Ultrasound contrast agents (UCA):*
Contrast-enhanced Ultrasound

*Ultrasound contrast agents (UCA):*

- Rarely, if ever, associated with contrast related reaction or complications
- CT, MR agents carry potentially significant post-injection sequelae
  - Iodinated media: anaphylactic shock, nephrotoxicity
  - Gadolinium: nephrogenic systemic fibrosis, Gd body storage
Contrast-enhanced Ultrasound

*Physical interactions:*

- Significant impedance mismatch = linear reflection
- Bubble size (3-4 µm, < λ) = nonlinear backscatter
- Bubble oscillations = harmonic frequencies (2nd)
- All three energies used to create CEUS images
- Proportion of each related to incident MI
Contrast-enhanced Ultrasound

Physical interactions:
Contrast-enhanced Ultrasound

CCA
Contrast-enhanced Ultrasound

Plaque ulceration
Contrast-enhanced Ultrasound

*Plaque neovascularization*
Contrast-enhanced Ultrasound

Plaque neovascularization
Quantitative Plaque Elasticity

- Mechanical characteristics of a ASVD plaques determine biomechanical environment
- “Softer” plaques associated with greater risk of rupture
- Histology/MRI correlates elasticity with neovascularization and lipid content
- Elasticity measure in KPa
- Good results in early studies*

*Zhang, Ultrasonics, 2015
*Nieustadt, Med Eng Phys 2015
Vector Flow

- Non-Doppler display of complex hemodynamic states
- Quantitative color coded vector arrow display
- Each arrow represents flow characteristics in a microstream
- Extremely high back-end frame rate required (>300 fps)
- Non-angle dependent
Vector Flow
Vector Flow
Traditional Duplex and Emerging Ultrasound Approaches

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