Vascular Laboratory Fundamentals

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Duke University Medical Center
5/2/08
Goals of Lecture

- Understand basic ultrasound principles
- Understand normal and abnormal arterial hemodynamics and waveforms
- Understand the goals of the Carotid Examination
- Understand the various tests for evaluation of peripheral arterial disease
700 am QUIZ
Which healthy artery exhibits this waveform?

- a) SMA-post prandial
- b) Celiac Artery
- c) SFA
- d) ICA
Which Normal artery is this?

- a) Middle Cerebral Artery
- b) SMA
- c) ICA
- d) Renal Artery
What is going on?
ECA or ICA?
What is the diagnosis?

- a) normal CCA
- b) ipsilateral ICA occlusion
- c) ipsilateral ECA stenosis
- contralateral occluded ICA
What can you infer?

- a) bilateral SFA disease
- b) severe Aortic stenosis
- c) Aortic aneurysm
- d) severe aorto-iliac disease
For a AAA US study, what frequency probe is best suited?

- a) Linear 4 MgHz
- b) Linear 8 MgHz
- c) Curvilinear 8 MgHz
- d) Curvilinear 2 MgHz
Is the Vertebral artery flowing retrograde or antegrade?
Ultrasound Principles

- Ultrasound transducer generates sound waves in discrete pulses
- Reflected waves are received by the transducer at various times and allow for positioning of the tissue interface
- The strength and timing of the returning waves allow for the formation of a grayscale (B mode) image
Ultrasound frequency and penetration

Low frequency—better tissue penetration but poor resolution

Higher frequency—better tissue resolution but poor penetration
For a AAA US study, what frequency probe is best suited?

- a) Linear 4 MgHz
- b) Linear 8 MgHz
- c) Curvilinear 8 MgHz
- d) Curvilinear 2 MgHz
Duplex Imaging

- Gray scale image utilized to facilitate placement of Doppler sample volume
- Transducer generally perpendicular to the vessel
- Doppler assessment made with angle between insonation beam and vessel wall adjusted to 45 to 60 degrees
Doppler Shift is Used to Determine Velocity of Blood

- Blood flow is detected by processing echo signals scattered from RBC.
- RBCs are moving: SHIFT HAPPENS
- Doppler equation:

\[ f_{\text{received}} - f_{\text{sent}} = 2f_{\text{sent}} v_{\text{flow}} \cos \theta / c \]
Each pixel corresponds to a specific f shift/velocity at specific time

Pixel’s brightness: number of RBCs causing that f shift

Ø: Doppler angle

X axis: time in s

f shift=velocity

Flow direction: above/below baseline relative to transducer
Angle of Insonation

60°

FLOW

DOPPLER BEAM
Angle of Insonation

Correct angle and cursor

Incorrect angle and cursor

\[ f_{\text{received}} - f_{\text{sent}} = 2f_{\text{sent}}v_{\text{flow}}\cos\theta/c \]
Impact of Insonation Angle on Velocity Assessment

- Strength of signal diminishes at shallow angles
- Error up to 20% occurs with angles greater than 70 degrees
- Angle of 60 degrees is standard and practical
Waveform Analysis

- Turbulence: assessed by spectral broadening and color aliasing/mosaic
- Stenosis: determined by elevated velocities
- Post stenosis: suggested by dampened upstroke and diminished velocities
Doppler Waveform

- Low resistance
- Acceleration
- Flow disturbance
Low Resistance Waveform
High Resistance Waveform
Flow reversal: Pressure in peripheral vessels > aortic pressure

Peripheral arteries
- ECA
- ICA, MCA, Celiac Artery
- Renals, SMA (post prandial) and diseased vessels
Atherosclerosis leads to PAD
Turbulence and Stenosis

LT PROX ICA
PS 458.5 cm/s
ED 268.0 cm/s

TIS=0.7 MI=1.1 AO=69%
What causes turbulence and spectral broadening?
Which healthy artery exhibits this waveform?

- a) SMA-post prandial
- b) Celiac Artery
- c) SFA
- d) ICA
Which Normal artery is this?

- a) Middle Cerebral Artery
- b) SMA
- c) ICA
- d) Renal Artery
Aortic Stenosis

Main feature is delay in arterial upstroke.

Examine arterial ratios.
Peak systolic velocity alone may underestimate stenosis.
High Cardiac Output

Peak systolic velocity alone may overestimate stenosis.

High cardiac output
Sickle cell anemia
Normal
Carotid Imaging: Anatomy, Scanning and Use in Practice
Essential Principles

Details of the wall are best seen with the beam perpendicular to the wall

Insonation angle should be 60 degrees with respect to the wall (flow jet)

Pay attention to the shape of the waveform
Carotid Imaging

- ANATOMY
- CRITERIA FOR DETERMINING STENOSIS
- PLAQUE MORPHOLGY
- INTIMAL MEDIAL THICKNESS
Carotid Ultrasound Imaging

• Provides detail of the vessels in the neck, and can indicate proximal and distal disease.
• Performed in the setting of bruit, TIA, post procedure and potentially risk assessment.
• Accessible, noninvasive evaluation.
Carotid Exam Performance

- Optimize gray scale image
- Pay attention to spectral waveform
- Use consistent Doppler angle/ 5 MHZ
- Use color Doppler as a guide
- Compare right and left sides
- Institution specific diagnostic criteria
- Pay attention to the clinical context
Everything you need to know about carotids in one slide

Table 1 Duplex evidence of arterial stenosis
- Elevated velocities: diagnostic criteria use peak systolic velocity (eg, >125 cm/s), ratios of distal to proximal sequential peak systolic velocities (eg, 2:1), and elevated end-diastolic velocity, supportive criteria include aliasing of color Doppler signal
- Diameter reduction: transverse or longitudinal measurements indicating reduction in luminal diameter are supportive, not diagnostic
- Spectral broadening or color mosaic pattern: the presence of turbulent flow is supportive, not diagnostic; it is most prominent just distal to significant stenosis
- Color bruit, color persistence: color bruit, providing evidence of vibration in the tissue surrounding arterial narrowing, is supportive, not diagnostic; continuous forward flow, or persistence, is supportive evidence of arterial stenosis

Table 2 Indications for carotid artery ultrasound
- Cervical bruits
- Amaurosis fugax
- Hemispheric stroke
- Focal cerebral or ocular transient ischemic attacks (which demonstrate localizing symptoms, such as weakness of one side of the face, slurred speech, weakness of a limb, retinal or hemispheric visual field deficits)
- Drop attacks or syncope (rare indications primarily seen in vertebrovascular insufficiency or bilateral carotid artery disease)
- Vasculitis involving extracranial arteries
- Pulsatile mass in the neck
- Trauma to neck
- Follow-up of carotid artery atherosclerosis not requiring revascularization
- Follow-up surveillance after carotid revascularization, a baseline ultrasound is recommended within 30 days after carotid stenting
Anatomy of Carotid Imaging

- Extracranial (cervical) arteries
- Common carotid artery
- Internal carotid artery
- External carotid artery
- Vertebral artery
- Brachiocephalic/ proximal subclavian artery
Cerebral Circulation

Figure 1.

- Internal Carotid
- External Carotid
- Vertebral
- Common Carotid
- Subclavian

Ascending Pharyngeal
Superior Thyroid

Thyrocerical Trunk

Internal Mammary
(Inominate)
Components of Carotid Ultrasound Spectral Analysis

- B-mode image and color Doppler are used to locate arteries and facilitate placement of pulsed Doppler sample volume.
- Severity of disease is determined by spectral analysis of the pulsed Doppler signal.
Carotid Bifurcation

The bulb extends from the CCA into the ICA.
Carotid Bifurcation
CCA Waveform:
Combination of ICA and ECA waveform
# Velocity Criteria to Grade ICA Stenosis

<table>
<thead>
<tr>
<th>Stenosis</th>
<th>ICA PSV (cm.sec)</th>
<th>Lumen Narrowing</th>
<th>ICA EDV cm/sec</th>
<th>ICA/CCA PSV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&lt;125</td>
<td>-</td>
<td>&lt;40</td>
<td>&lt;2</td>
</tr>
<tr>
<td>1-49</td>
<td>&lt;125</td>
<td>+</td>
<td>&lt;40</td>
<td>&lt;2</td>
</tr>
<tr>
<td>50-69</td>
<td>&gt;125</td>
<td>+</td>
<td>40-100</td>
<td>2-4</td>
</tr>
<tr>
<td>&gt;70</td>
<td>&gt;230</td>
<td>+</td>
<td>&gt;100</td>
<td>&gt;4</td>
</tr>
<tr>
<td>Subtotal Occlusion</td>
<td>Widely variable</td>
<td>++</td>
<td>Widely variable</td>
<td>Widely variable</td>
</tr>
<tr>
<td>Total Occlusion</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Society of Radiologists Consensus Panel 2002
## NASCET Doppler Criteria for Stenosis

<table>
<thead>
<tr>
<th>Diameter Reduction</th>
<th>PSV</th>
<th>EDV</th>
<th>ICA PSV/CCA PSV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-29</td>
<td>&lt;100</td>
<td>&lt;40</td>
<td>&lt;3.2</td>
</tr>
<tr>
<td>30-49</td>
<td>100-130</td>
<td>&lt;40</td>
<td>&lt;3.2</td>
</tr>
<tr>
<td>50-59</td>
<td>&gt;130</td>
<td>&lt;40</td>
<td>&lt;3.2</td>
</tr>
<tr>
<td>60-69</td>
<td>&gt;230</td>
<td>40-110</td>
<td>3.2-4.0</td>
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<tr>
<td>70-79</td>
<td>&gt;230</td>
<td>110-140</td>
<td>&gt;4.0</td>
</tr>
<tr>
<td>80-95</td>
<td>&gt;230</td>
<td>&gt;140</td>
<td>&gt;4.0</td>
</tr>
<tr>
<td>96-99</td>
<td>string flow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>no flow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ICA Stenosis
Temporal Tap: Distinguishing ICA and ECA
ECA or ICA?
Calcification: Detection of ICA stenosis
Distal ICA Occlusion
What is the diagnosis?

- a) normal CCA
- b) ipsilateral ICA occlusion
- c) ipsilateral ECA stenosis
- contralateral occluded ICA
Proximal ICA Occlusion
Proximal ICA Occlusion
Proximal ICA Occlusion

In case of abnormal flow patterns you must use ICA/CCA
Subtotal Occlusion
## Velocity Criteria to Grade ICA Stenosis

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<td>Widely variable</td>
</tr>
<tr>
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<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
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</table>
Low Cardiac Output

Sharp upstroke, diminished amplitude.
Peak systolic velocity alone may underestimate stenosis.
Plaque characteristics on ultrasound

- Echogenicity: Hypoechoic similar to blood, hyperechoic similar to adventitia
- Calcification
- Surface characteristics: Smooth, irregular, ulcerated
- Correlations with systemic and local risk
Irregular Surface
Ulcerated Plaque
Echolucent Plaque

Potentially vulnerable plaque
Pitfalls of Carotid Duplex Imaging

- Misidentification of a pulsatile vein for the internal carotid artery
- Tortuous vessels
- Near total occlusion
- Calcification
- Spot Doppler assessment
- Misidentification of external carotid artery with significant lesion as ICA
Vertebral Artery
Vertebral Artery Stenosis
Vertebral Artery Occlusion
Lower Extremity Evaluation

- ABI
- SDP’s
- Arterial Duplex
Lower Extremity Arterial Anatomy

Aortoiliac

Femoro-Popliteal

Infra-popliteal

Common Iliac
External Iliac
Internal Iliac
Aorta

Superficial Femoral (SFA)
Profunda Trunk
Descending Profunda

Popliteal

Anterior Tibial
Posterior Tibial
Peroneal

Dorsalis Pedis

Arterial Circulation

Right
Left
How to Perform and Calculate the ABI

PARTNERS Program ABI Interpretation

Above 0.90 — Normal
0.71-0.90 — Mild Obstruction
0.41-0.70 — Moderate Obstruction
0.00-0.40 — Severe Obstruction

Right ABI
\[
\text{Higher Right Ankle Pressure} = \text{mm Hg} \quad \text{Higher Arm Pressure} = \text{mm Hg}
\]

Left ABI
\[
\text{Higher Left Ankle Pressure} = \text{mm Hg} \quad \text{Higher Arm Pressure} = \text{mm Hg}
\]

Example
\[
\text{Higher Ankle Pressure} = \frac{92}{164} \quad \text{Higher Brachial Pressure} = \text{mm Hg} = 0.56
\]

See ABI Chart
Exercise ABI

- Confirms the PAD diagnosis
- Assesses the functional severity of claudication
- May “unmask” PAD when resting the ABI is normal
ABI: Limitations

- Possible false negatives in patients with noncompressible arteries, such as elderly and diabetic individuals
- Insensitive to very mild occlusive disease or iliac occlusive disease
- Poor correlation with functional status in patients with claudication, therefore should be used in conjunction with standardized patient questionnaires to assess PAD severity
SDP/PVR to Detect and Localize Disease

- Sensitivity 73%/ Specificity 80% for SFA stenoses

- Sensitivity 85%/ Specificity 53% for SFA plus popliteal stenoses

  - Sensitivity 59%/ Specificity 86% for iliac or CFA stenoses

Moneta, J Vasc Surg, 1993
Diabetic with Non-Compressible Vessels

Duke University  
6304 Herndon Road  
Durham, NC 27713

**Lower Arterial**

<table>
<thead>
<tr>
<th>Column</th>
<th>Value</th>
<th>Patient ID:</th>
<th>Date / Time:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case No:</td>
<td>N Durham</td>
<td>T45337</td>
<td>04/13/2005 11:43</td>
</tr>
<tr>
<td>Gender</td>
<td>Female</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age:</td>
<td>67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Referred by</td>
<td>Karen Alexander, MD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Examined by</td>
<td>Stephanie Semler, MS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read by:</td>
<td>David Kandzari, MD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**History**

- **Smoker:** Previous
- **Hypertension:** Yes
- **Previous Vasc Surg:** Yes
- **Previous Angioplasty:** No
- **Diabetic:** Yes
- **Vascular Ulcers:** None
- **Hyperlipidemia:** Yes
- **Skin Color Chg:** None
- **Rest Pain:** None
- **Claudication:** Both
- **Gangrene:** None

**CABG**

Patient complains of bilateral leg discomfort in the calves while walking that is relieved with rest. She reports that she can walk a block or less than a block before she would need to stop and rest.

**Segmental BP**

<table>
<thead>
<tr>
<th>Segment</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachial</td>
<td>141</td>
<td>133</td>
</tr>
<tr>
<td>High Thigh</td>
<td>n/c</td>
<td>197</td>
</tr>
<tr>
<td>Low Thigh</td>
<td>n/c</td>
<td>172</td>
</tr>
<tr>
<td>calf</td>
<td>135</td>
<td>157</td>
</tr>
<tr>
<td>ankle (PT)</td>
<td>103</td>
<td>151</td>
</tr>
<tr>
<td>ankle (DP)</td>
<td>98</td>
<td>1.07</td>
</tr>
<tr>
<td>Digit</td>
<td>101</td>
<td>98</td>
</tr>
</tbody>
</table>

Must get TBI
Essential Components of the Study

Doppler signal is essential
Essential Components of the Study
## Interpretation of PVR

Pulse volume plethysmography: Pulse volume recording contour with increasing vascular disease severity

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
</table>
| Normal            | - Sharp upstroke
                   - Scooped or flat interval between peaks
                   - Possible diastolic notch                                                | ![Normal Example](image) |
| Mildly abnormal   | - Sharp upstroke
                   - No flat period or scooping between peaks
                   - No diastolic notch                                                     | ![Mildly Abnormal Example](image) |
| Moderately abnormal | - Flat peak
                       - Equal upslope and downslope time
                       - No diastolic notch                                                     | ![Moderately Abnormal Example](image) |
| Severely abnormal | - Flat peak
                   - Equal upslope and downslope time
                   - No diastolic notch
                   - Low amplitude                                                          | ![Severely Abnormal Example](image) |
Arterial Duplex-Indications

1. Claudication
2. Leg pain
3. Abnormal Physiologic study
4. Ulcers
5. Revascularization follow-up
# Arterial Duplex Interpretation

<table>
<thead>
<tr>
<th>Diameter reduction</th>
<th>Waveform</th>
<th>Spectral broadening</th>
<th>PSV distal/PSV proximal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0</td>
<td>Triphasic</td>
<td>Absent</td>
</tr>
<tr>
<td>Mild</td>
<td>1%-19%</td>
<td>Triphasic</td>
<td>Present</td>
</tr>
<tr>
<td>Moderate</td>
<td>20%-49%</td>
<td>Biphasic</td>
<td>Present</td>
</tr>
<tr>
<td>Severe</td>
<td>50%-99%</td>
<td>Monophasic</td>
<td>Present</td>
</tr>
</tbody>
</table>

**PSV**, Peak systolic velocity.

*->4:1 Suggests >75% stenosis, >7:1 suggests > 90% stenosis.
Lower Extremity Arterial Duplex

1. SFA-normal tri-phasic waveform

2. Turbulent Flow becomes evident at tri-furcation (tibioperoneal trunk)

3. PTA exhibits monophasic waveform tripling of velocities-->75% stenosis

4. Occlusion is confirmed-no flow is evident in the PTA
What are we looking at? What causes this type of wave form?
Common Femoral Artery Pseudoaneurysm - F Type

A

LONGITUDINAL
RT GROIN

B

TRANSVERSE

C

PSEUDOANEURYSM NECK
The End

Remember, think like a physiologist and you will rarely be wrong