Vascular Ultrasound  Protocol guides

Expanding your Clinical Experience
<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Classification of ICA Stenosis</td>
</tr>
<tr>
<td>4</td>
<td>Classification of Lower Extremity Artery Disease</td>
</tr>
<tr>
<td>3</td>
<td>Classification of Renal Artery Stenosis</td>
</tr>
<tr>
<td>8</td>
<td>Infrainguinal Vein Bypass Graft Assessment</td>
</tr>
<tr>
<td>10</td>
<td>Venous Imaging Techniques</td>
</tr>
<tr>
<td>12</td>
<td>Criteria for Intraoperative Color Duplex Diagnosis</td>
</tr>
<tr>
<td>14</td>
<td>Normal Techniques and Criteria for Transcranial Doppler</td>
</tr>
<tr>
<td>18</td>
<td>Techniques and Criteria for the Diagnosis of Vasculogenic Impotence</td>
</tr>
<tr>
<td>20</td>
<td>Color Duplex Ultrasonography of Renal Artery Stents</td>
</tr>
<tr>
<td>22</td>
<td>Transcranial Doppler in the Evaluation of Pediatric Patients with Sickle Cell Anemia: The STOP Protocol</td>
</tr>
<tr>
<td>24</td>
<td>Aortic Endovascular Stent Graft Assessment</td>
</tr>
</tbody>
</table>
Classification of ICA Stenosis

Gathering Spectral Waveforms for Classification of ICA Disease

- Gather all signals at an angle of 60 degrees to the vessel axis for both frequency and velocity measurements. In tortuous vessels where obtaining a 60-degree angle may be difficult, take the most favorable angle close to 60 degrees and always document it for future reference. Never take spectral waveforms at angles above 60 degrees.

- Keep the sample volume as small as possible to obtain the most discrete spectral information. In the case of an occlusion or a very tight lesion, the sample volume may be increased to help locate the flow channel.

- Use the area of the maximum velocity increase or the most flow disturbance to classify disease.

- Place the sample volume in the center of the vessel or the flow channel.

- Adjust the Doppler gain to a threshold level just below the level at which background noise and/or mirror imaging begins to appear for each spectral waveform that is generated.

- Document boundary layer separation existing in the area of the normal carotid bulb. Take spectral waveforms across the bulb to show the unidirectional flow pattern near the flow divider and the reversal of flow at the outer wall. Include a B-mode image showing the sites of interrogation.

- Always identify the ICA and the ECA by comparing the characteristic Doppler waveforms: low resistance in the ICA and high resistance in the ECA. Do not rely on the image alone to identify these two vessels; find both vessels before taking spectral waveforms.

- Never take “spot” recordings. Survey the entire length of the vessels to ensure detection of very focal lesions that may not be easily visualized and above which the flow may normalize.

- Be very cautious about sample volume placement and Doppler angle measurements in vessels that are not easily visualized, i.e., the distal ICA or tortuous vessels. If there is diagnostic uncertainty, make a note in the patient’s record and on the spectral waveform so as not to over or underestimate the disease state.

- Always look at the entire extracranial carotid system and compare side to side. Observe hemodynamic changes that may occur due to very proximal or very distal lesions and contralateral disease.
### Criteria for ICA Stenosis based on NASCET
t

<table>
<thead>
<tr>
<th>Class</th>
<th>Diameter Reduction</th>
<th>Peak Systole</th>
<th>Diameter Reduction</th>
<th>End Diastole</th>
<th>Flow Characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0%</td>
<td>&lt;4 kHz</td>
<td>0%</td>
<td>*</td>
<td>Minimal or no spectral broadening during the deceleration phase of systole. Boundary layer separation within the carotid bulb is usually present. No plaque visualized.</td>
</tr>
<tr>
<td>B</td>
<td>1 - 15%</td>
<td>&lt;4 kHz</td>
<td>1 - 15%</td>
<td>*</td>
<td>Minimal spectral broadening during the deceleration phase of systole. Plaque visualized in long and short axis views.</td>
</tr>
<tr>
<td>C</td>
<td>16 - 49%</td>
<td>&lt;4 kHz</td>
<td>16 - 49%</td>
<td>*</td>
<td>Increased spectral broadening during systole until the entire systolic window is filled. Plaque visualized in long and short axis views.</td>
</tr>
<tr>
<td>D</td>
<td>50 - 79%</td>
<td>&gt;4 kHz</td>
<td>50 - 79%</td>
<td>*</td>
<td>Marked spectral broadening is usually associated.</td>
</tr>
<tr>
<td>D+</td>
<td>80 - 99%</td>
<td>*</td>
<td>80 - 99%</td>
<td>&gt;4.5 kHz</td>
<td>Marked spectral broadening.</td>
</tr>
<tr>
<td>E</td>
<td>Total Occlusion</td>
<td>N/A</td>
<td>Total Occlusion</td>
<td>N/A</td>
<td>No flow signal in an adequately visualized ICA (especially distal) with characteristic low or reversed diastolic component in the CCA. A characteristic “thump” may be noted at the stump, or origin of the occlusion.</td>
</tr>
</tbody>
</table>

Note 1: All signals taken at 60° angle to vessel axis.

Note 2: This classification is only accurate for predicting the amount of diameter reduction in the first 3 cm of the ICA. It is not reliable for accurately predicting disease in the ECA or the CCA (or the very distal portion of the ICA, above 3 cm from the origin).

Note 3: All frequency and velocity values are based on using a 5 MHz pulsed Doppler carrier frequency with a 1.5 mm cubed sample volume at a 60 degree angle to axis of vessel.

Note 4: Diameter reductions are calculated using the bulb as the reference vessel.

* End-diastolic frequency and velocity values are used only as stenosis classification criteria for 80-99% diameter reduction lesions.

---

**REFERENCES**


Gathering Waveforms for Classification of Lower Extremity Arterial Disease

- Duplex scanning should not be used as a screening test for diagnosing peripheral vascular disease (PVD). It is most helpful as a guide to localizing and grading the severity in patients with known PVD. Duplex scanning can aid in determining the appropriate interventional procedure and should be used in conjunction with SLP/PVR/Doppler analog waveforms. The exam may take two hours to complete. However, a much shorter exam time is required if examining selected areas only.

- Study each vessel along its entire length. Minimally, velocity waveforms should be recorded from the distal aorta, CIA, EIA, CFA, PFA, SFA proximal, mid and distal, (special attention to Hunter’s canal), and the popliteal artery.

- Use the smallest sample volume (SV) possible. At the point of an occlusion or stenosis, you may want to increase the SV. Place the SV in the center of the vessel or flow stream.

- Gather all velocities at or near 60 degrees to the vessel axis or flow stream (not to exceed 70 degrees).

- Keep Doppler gain just below the threshold of noise. Use a low wall filter (50 Hz).

- Utilize the “heel/toe” technique with the transducer to optimize angles and minimize steering in different directions.

- Externally rotate patient’s leg to image SFA and PFA. To visualize popliteal artery, turn patient prone and elevate legs 20 degrees. Use a high frequency transducer for best visualization at this level.
Loss of reverse component beyond stenosis waveform is monophasic and has a reduced systolic velocity.

Monophasic, preocclusive “thump” is heard proximal to the occlusion; velocities are diminished and waveforms are monophasic beyond the occlusion.

**Tips for Interrogating Aorta and Iliac Arteries**

- On the evening preceding the exam, the patient should take nothing by mouth after dinner except clear liquids and any required medications, and remain NPO after midnight.

- Use 2 - 5 MHz transducers.

- Whenever a triphasic waveform with a clear window (no spectral broadening) is documented at any level, it is unlikely that there is any severe disease proximal.

- There is no need to subdivide 50 - 99% stenosis. Once the lesion exceeds 50% diameter reduction (75% area), it is a critical stenosis and will induce intermittent claudication. In our experience, monitoring the EDV has been inconsistent and unreliable in predicting >80% stenosis (in contrast to the ICA criteria).

**Color Doppler Hints**

- High frame rate and low color velocity range will give the best visualization of triphasic color flow.

- Use low color wall filter and limit the use of persistence so you are seeing true flow dynamics.

- Remember color Doppler requires good Doppler or beam-to-vessel angle to obtain optimal color shift (filling).

- Use color aliasing pattern to locate stenosis. Adjust color gain to help in low flow states, small vessels or technically limited angles.

- Color will help identify reversal of flow and reconstitution of occluded vessels.

**Classification of lower extremity arterial stenosis**

<table>
<thead>
<tr>
<th>Diameter Reduction</th>
<th>Peak Systolic Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 19%</td>
<td>Less than double that of the closest proximal normal segment</td>
</tr>
<tr>
<td>20 - 49%</td>
<td>Less than double that of the closest proximal normal segment</td>
</tr>
<tr>
<td>50 - 99%</td>
<td>Double the proximal adjacent segment or PSV &gt;200 cm/sec</td>
</tr>
<tr>
<td>Occlusion</td>
<td>No flow in the imaged artery</td>
</tr>
</tbody>
</table>

**CLINICAL SOURCE:**
Marka M. Neumyer, BS, RVT, Milton S. Hershey Medical Center, Department of Surgery, Hershey, PA

**REFERENCES:**
Color Duplex Scanning for Evaluation of Renal Arteries and Renal Parenchymal Flow

• The patient should fast for at least six hours prior to evaluation.

• The examination may be performed with the patient in either the supine or lateral decubitus position for optimal interrogation of the renal arteries and kidneys.

• With the patient in the supine position, the Doppler velocity signal is recorded from the center stream of the abdominal aorta at the juxtarenal position using a long-axis view and maintaining a 60-degree angle of insonation. The peak systolic velocity is retained for calculation of the renal-aortic ratio.

• Using a transverse view, the left renal vein is located as it passes anterior to the aorta and continues postero-laterally to the left kidney. The right renal artery follows the course of the right renal vein moving posterior to the IVC to enter the kidney. Color Doppler imaging may facilitate localization of the renal vessels.

• Using the smallest sample volume possible, ask the patient to suspend breathing for short periods to collect satisfactory velocity signals. If vessel occlusion or tight stenosis is suspected, try increasing the sample volume size and color flow sensitivity to help locate the flow channel.

• The Doppler velocity signal is first collected from the origin of the renal artery as it arises from the postero-lateral wall of the aorta. It is then swept slowly throughout the course of the proximal, mid and distal renal artery with continuous documentation of velocity signals.

• Angle correction over a narrow range of angles may be used to accurately determine renal artery velocity. Multiple planes of view and patient positions may be required to visualize the renal arteries. The classification of disease is frequently based on the recorded Doppler signal.

• If flow-reducing stenosis (>60% diameter reduction) is present, a high velocity signal is demonstrated by pulsed and color Doppler and post-stenotic turbulence can be demonstrated. Renal artery stenosis will most likely be found at the origin of the vessel or in the proximal segment; however, disease may be located in any segment of the artery.

• Using the highest peak systolic renal artery velocity, calculate the renal-aortic velocity ratio for each renal artery:
  \[
  \text{Peak Systolic Renal Artery Velocity} = \frac{\text{Renal}}{\text{Peak Systolic Aortic Velocity}} \]
  \[
  \text{Aortic Ratio}
  \]

• Using a lateral decubitus approach, measure the pole-to-pole length of the kidney and record the Doppler velocity signals from the medulla and cortex of the organ. As discrete parenchymal vessels are not always seen, the sample volume size may be increased. The signals with the highest amplitude and velocity are used to calculate the end-diastolic to peak systolic ratio to determine parenchymal renovascular resistance. An end-diastolic to peak systolic ratio <0.2 indicates intrinsic renal parenchymal disease. The calculation is performed on at least four waveforms.

  \[
  \text{End-diastolic Velocity} = \frac{\text{Parenchymal Peak Systolic Velocity}}{\text{Resistance}}
  \]

• Doppler velocity signals may also be recorded from the renal hilum and acceleration time and index calculated to complement the determination of significant renal artery stenosis. An acceleration time >100 milliseconds and an acceleration index <3.78 kHz/sec indicates significant renal artery stenosis. The acceleration time period is between the onset of acceleration and the initial systolic peak. The acceleration index is calculated using the following formula:

  \[
  \text{Systolic Upslope} = \frac{\text{Acceleration Index}}{\text{Carrier Frequency}}
  \]

  \[
  \text{Systolic Upslope} = \frac{\text{Systolic Frequency}}{\text{Sec}}
  \]

• In the presence of renal artery occlusion, no Doppler signal will be obtained from any segment of the renal artery. If the kidney is vascularized through collateral channels, low amplitude, low velocity signals may be demonstrated throughout the renal parenchyma, using color Doppler imaging or pulsed Doppler. The pole-to-pole length of the kidney may measure less than 8 cm.

• Accessory and multiple renal arteries may not be identified with duplex technology. The presence of higher amplitude signals in one pole of the organ than in the other, and collection of signals of varying velocities in the same scan plane may suggest multiple or accessory vessels. Color Doppler imaging may facilitate positive identification.
Figure 1: Cross-sectional image of aorta (Ao), left renal vein (LRV), inferior vena cava (IVC) and renal arteries (RA). Normal velocity spectra from renal artery and renal parenchyma.

Figure 2: Cross-sectional image as in Figure 1. Velocity spectra from left renal artery demonstrating flow-reducing stenosis with normal parenchymal signal. Right renal artery is occluded. Note: dampened velocity signal in right kidney consistent with collateral flow.

Classification of renal artery stenosis

<table>
<thead>
<tr>
<th>Classification</th>
<th>Renal Aortic Ratio</th>
<th>Peak Systolic Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal or &lt;60%</td>
<td>&lt;3.5</td>
<td>&lt;180 cm/sec</td>
</tr>
<tr>
<td>Diameter Reduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 - 99%</td>
<td>&gt;3.5</td>
<td>&gt;180 cm/sec</td>
</tr>
<tr>
<td>Diameter Reduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occluded</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

REFERENCES


CLINICAL SOURCE

Marsha M. Neumyer, BS, RVT, Milton S. Hershey Medical Center, Department of Surgery, Hershey, PA
Infrainguinal Vein Bypass Graft Assessment

Example of Bypass: Native in Situ

**Diagnostic criteria**

<table>
<thead>
<tr>
<th>% Stenosis</th>
<th>PSV</th>
<th>EDV</th>
<th>VR</th>
<th>Spectral Broadening</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20%</td>
<td>&lt;150</td>
<td>NA</td>
<td>&lt;1.5</td>
<td>Mild</td>
</tr>
<tr>
<td>20 - 50%</td>
<td>&lt;150</td>
<td>NA</td>
<td>1.5-2.5</td>
<td>Moderate</td>
</tr>
<tr>
<td>50 - 75%</td>
<td>&gt;150</td>
<td>&lt;100</td>
<td>&gt;2.5</td>
<td>Complete cardiac cycle with turbulence</td>
</tr>
<tr>
<td>&gt;75%</td>
<td>&gt;300</td>
<td>&gt;100</td>
<td>&gt;3.5</td>
<td>Complete cardiac cycle with turbulence</td>
</tr>
<tr>
<td>Occluded</td>
<td></td>
<td></td>
<td></td>
<td>No detectable Doppler flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B-mode image – visualization of vessel with no flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flow in collateral vessels or native circulation</td>
</tr>
</tbody>
</table>

**Correlating factors to diagnostic criteria**

- Waveform configuration
- Status of ABI
- B-mode image
- Maximum graft PSV from smallest normal segment of graft
- Serial exam changes – >0.15 decrease in ABI or a >30cm/sec decrease in graft PSV
- Degree of spectral broadening

**Goals**

- Identification of correctable lesions before graft thrombosis
- Determine baseline hemodynamics post revascularization
- Provide objective clinical information to aid in decision making regarding treatment alternatives

**Indications for Color Duplex Doppler**

- Routine surveillance of infrainguinal bypass grafts
- Assess clinical changes
  - >0.15 drop in ABIs
  - Evaluation of new bruits or masses
  - Onset of symptoms
  - Change in peripheral pulses
  - Nonhealing wounds

**Pertinent Patient History**

- Type of graft – in situ, reversed, nonreversed vein, composite
- Graft location and placement – peri-anastomotic sites
- Length of time post-op
- Any revisions or interventions
Scanning Protocol

• Routine scanning includes ankle brachial indices (ABIs) with color duplex scan of the entire length of the graft and related inflow and outflow vessels.

• Image acquisition — transverse and longitudinal views. Transverse views are used to add additional information to the B-mode image and identify anastomoses. Longitudinal views are used for the major portion of the exam to obtain Doppler information.

• Doppler parameters are obtained using a longitudinal view with a small sample volume placed center stream or center to flow jet. Doppler angles of insonation are kept constant at angles of less than 60 degrees. On repeat exams it is helpful to use the same angles of insonation to avoid a discrepancy in velocity measurements from the patient’s previous exam.

• Doppler parameters calculated
  - Peak systolic velocity — PSV
  - End diastolic velocity — EDV
  - Velocity ratio
    \[ VR = \frac{\text{PSV increase across stenosis}}{\text{proximal PSV}} \]

Technical Considerations

• Normal variations in flow patterns may occur at anastomotic sites, valve cusp areas, naturally occurring diameter changes and in the early post-operative period (hyperemia). The magnitude and configuration of the waveform is affected by the recording site, length of time post op and the outflow resistance. It is important to identify and decipher the difference between normal variations and pathology.

• Bypass Graft Complications
  - <30 days technical, hypercoagulable state, or inadequate outflow
  - 1-6 months residual lesion
  - 6-24 months myointimal hyperplasia
  - >24 months progression of atherosclerosis

• Technical complications usually occur within the first 30 days post-op and include retained valve leaflets, arteriovenous fistula (in situ grafts only), anastomotic stenoses, inadequate outflow, graft entrapment and intimal flaps.

• Reported statistics
  - Overall accuracy - 90%
  - Sensitivity - >95%
  - Specificity - 87%
Preparation

• Tilt bed 20 degrees with patient supine.

• Patient’s knees should be bent with hips externally rotated.

• Doppler: CFV, SFV, popliteal vein, PT veins. Listen for:
  - Spontaneous Signal = Venous signal heard without augmentation.
  - Phasic Signal = Signal waxes and wanes with respiration.
  - Augmentation = Velocity increases with distal augmentation.
  - Competency = Flow stops with Valsalva maneuver.

• Scan legs in transverse.

KEY
A Common Femoral Vein (FRV)
B Greater Saphenous Veins (GSF)
C Deep Femoral Vein (Profinda)
D Superficial Femoral Vein (SVF)
E Adductor Canal
F Popliteal Vein
G Gastrocnemius Muscular Veins
H Posterior Tibial Veins (PTs)
I Peroneal Veins
**Characteristics of thrombus-free veins**

- No echogenic material visualized within the vein.
- Vein collapses completely in response to probe pressure.
- Normal Doppler signals.
- Color fills the vein in response to distal compression.

**Characteristics of non-obstructive thrombus**

- Echogenic material fills part of the lumen of the vein.
- Compression of the vein is limited by the contained thrombus.
- Doppler may be normal or abnormal.
- Color flows around the thrombus.

**Characteristics of obstructive thrombus**

- Vein is dilated and filled with echogenic material (if acute).
- Vein is totally non-compressible.
- Doppler signals are absent.
- Color is absent in vein.

**Observable characteristics of thrombus**

<table>
<thead>
<tr>
<th>Old (Chronic)</th>
<th>New (Acute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightly echogenic</td>
<td>Lightly echogenic</td>
</tr>
<tr>
<td>Rigid texture</td>
<td>Spongy texture</td>
</tr>
<tr>
<td>Well attached</td>
<td>Poorly attached</td>
</tr>
<tr>
<td>Contracted vein</td>
<td>Vein dilated (if obstructed)</td>
</tr>
</tbody>
</table>
Criteria for Intraoperative Color Duplex Diagnosis

Indications
All patients having carotid endarterectomy (primary closure or vein patch angioplasty). Duplex evaluation is performed immediately after closure of the arteriotomy and restoration of flow.

Technique
- Fill surgical wound with sterile saline.
- Place high frequency transducer in sterile sheath and position directly over exposed vessels, advancing slowly cephalad.
- Perform imaging in both transverse and longitudinal orientation.
- Obtain Doppler waveforms in longitudinal view.
- Place sample volume in center of flow stream.
- Doppler beam angle must be at 60 degrees or less to vessel axis.
- Record velocity waveforms from common carotid, external carotid, and proximal and distal internal carotid arteries.
- If the artery was surgically closed with a vein patch, record the cross-sectional diameter measurement of this area as a baseline for future reference.
- It is essential to optimize B-mode image, adjust the Doppler beam angle and assure correct placement of the sample volume throughout the procedure.
- Any abrupt color changes, increased peak systolic velocity or spectral broadening must be carefully scrutinized.
- Magnify B-mode image and examine lumen for presence of residual plaque, intimal flaps, platelet aggregates, clamp injury or other abnormality that might dictate immediate revision.
- The surgeon may elect to obtain an intraoperative arteriogram before revising reconstruction if the following conditions exist:
  - severe residual stenosis indicated by Doppler, but no anatomical defect is observed
  - defect is visualized exhibiting characteristics of only a moderate flow disturbance
- If revision is required, duplex scanning should be repeated following revision to confirm normal flow characteristics and vessel wall integrity.
Interpretation
See Classifications of Flow Disturbance chart.

Algorithm for Revision/Angiography
See Algorithm chart.

Scanning Tips and Pitfalls
• Procedure requires that the surgeon and the vascular technologist both be skilled in the technique and interpretation of carotid duplex ultrasonography.

• Since the color Doppler patterns may obscure small defects, the vessel wall is observed in grayscale with the color off.

• The color Doppler image serves as a guide to areas of possible turbulent flow; however, it is not reliable for determination of degree of stenosis. Suspicious areas must be assessed by Doppler, since classification of flow disturbance and decisions regarding revision must be based on peak systolic velocity and spectral broadening.

Classifications of Flow Disturbance

<table>
<thead>
<tr>
<th>Flow Disturbance</th>
<th>Ultrasound Image</th>
<th>Recommended Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>B-Mode Normal</td>
<td>No Further Studies</td>
</tr>
<tr>
<td>Moderate</td>
<td>B-Mode Abnormal</td>
<td>Arteriogram</td>
</tr>
<tr>
<td>Severe</td>
<td>B-Mode Abnormal</td>
<td>Immediate Revision</td>
</tr>
</tbody>
</table>

Algorithm

<table>
<thead>
<tr>
<th>Flow Disturbance</th>
<th>Ultrasound Image</th>
<th>Recommended Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>None/Mild</td>
<td>B-Mode Normal</td>
<td>No Further Studies</td>
</tr>
<tr>
<td>Moderate</td>
<td>B-Mode Abnormal</td>
<td>Arteriogram</td>
</tr>
<tr>
<td>Severe</td>
<td>B-Mode Abnormal</td>
<td>Immediate Revision</td>
</tr>
</tbody>
</table>

CLINICAL SOURCE
Ruth Cato, RN, RVT

REFERENCES


Normal Techniques and Criteria for Transcranial Doppler

Overview
TCI uses a 2.0 - 2.25 MHz sector transducer. The transtemporal, transorbital, submandibular and foramen magnum windows are used to identify the basal cerebral arteries. The B-mode image yields a two dimensional depiction of the bone landmarks at the base of the skull and of the cerebral parenchyma and vascular structures. The vessels are identified by knowledge of the anatomy in relationship to these landmarks and are directly visualized by color Doppler. TCI has expanded applications, improved vessel identification and shortened the learning curve for intracranial vascular ultrasound. Non-imaging (TCD) uses a 2.0 MHz pulsed wave Doppler transducer and vessels are identified by the depth of the sample volume, direction of flow, distance over which each artery is traced, the orientation of the transducer and the spatial relationship of each vessel under investigation to a specific reference point. TCD augments the TCI exam with a higher percentage of vessel identification and for monitoring studies when the transducer is attached to the head and specific arteries are examined over time.

Examination Sites
- Transtemporal Window
  - Middle Cerebral Artery (MCA)
  - Anterior Cerebral Artery (ACA)
  - Anterior Communicating Artery (ACOA)
  - Terminal Internal Carotid Artery (TICA)
  - Posterior Cerebral Artery (PCA)
  - Posterior Communicating Artery (PCOA)
- Transorbital Window
  - Cavernous Carotid Artery (Siphon)
  - Ophthalmic Artery (OA)
- Retromandibular Window
  - Retromandibular Internal Carotid Artery (R-ICA)
- Foramen Magnum Window
  - Vertebral Artery (VA)
  - Basilar Artery (BA)
**Normal values** (time-averaged peak velocities TAPV and standard deviation SD):

<table>
<thead>
<tr>
<th>Vessel</th>
<th>TAPV</th>
<th>SD</th>
<th>Depth From Transducer</th>
<th>Flow Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCA (M1)</td>
<td>62</td>
<td>+/-</td>
<td>12 40 - 60 mm</td>
<td>Towards</td>
</tr>
<tr>
<td>ACA (A1)</td>
<td>51</td>
<td>+/-</td>
<td>13 65 - 75 mm</td>
<td>Away</td>
</tr>
<tr>
<td>TICA</td>
<td>39</td>
<td>+/-</td>
<td>8   65 mm</td>
<td>Towards/Away</td>
</tr>
<tr>
<td>PCA</td>
<td>38</td>
<td>+/-</td>
<td>11 65 - 75 mm</td>
<td>Towards</td>
</tr>
<tr>
<td>Siphon</td>
<td>44</td>
<td>+/-</td>
<td>13 60 - 80 mm</td>
<td>Towards/Away</td>
</tr>
<tr>
<td>OA</td>
<td>22</td>
<td>+/-</td>
<td>4   40 - 60 mm</td>
<td>Towards</td>
</tr>
<tr>
<td>R–ICA</td>
<td>36</td>
<td>+/-</td>
<td>8   50 - 60 mm</td>
<td>Away</td>
</tr>
<tr>
<td>Vertebral</td>
<td>36</td>
<td>+/-</td>
<td>10 60 - 85 mm</td>
<td>Away</td>
</tr>
<tr>
<td>Basilar</td>
<td>39</td>
<td>+/-</td>
<td>10 &gt;85 mm</td>
<td>Away</td>
</tr>
</tbody>
</table>
Normal Techniques and Criteria for Transcranial Doppler (continued)

Applications
- Detection of intracranial stenosis/thrombosis
- Identification of collateral vessels and steal effects secondary to stenoses proximal to the Circle of Willis
- Detection of vasospasm secondary to subarachnoid hemorrhage
- Evaluation of cerebral circulatory arrest
- Detection of microembolic signals
- Screening of children with sickle cell anemia to establish stroke risk
- Assessment of arteriovenous malformations and fistulas

Interpretation Criteria
Both TCD and TCI rely on the Doppler spectral waveforms for interpretation of normal and abnormal exams. The diagnostic features of the signals include (1) alterations in velocity; (2) deviations from laminar flow; (3) changes in pulsatility (Gosling’s) index for adults; (4) changes in the direction of flow and (5) Lindegaard ratios.

Velocity Measurements
TCD/TCI uses time averaged peak velocities (TAP), an average of the highest velocities over time, not peak systolic or other values. This value is automatically calculated in optimal signals but must be manually measured by a visually guided reading technique when the signals are sub optimal. The accuracy/advantages of angle correction are still being evaluated.

Both increases in volume flow and decreases in diameter will accelerate blood through an artery. To correct for systemic or local changes in volume flow the Lindegaard ratio is used. This ratio divides the velocity of the intracranial MCA by the velocity of the ipsilateral, extracranial ICA, taken from the submandibular approach (TAP - MCA / TAP - RICA).

Vasospasm Following Subarachnoid Hemorrhage
TCD/TCI is useful in detecting the onset, time course, severity and resolution of vasospasm following subarachnoid hemorrhage. When vasospasm occurs, the vessel lumen narrows and the velocity of the blood flow accelerates. Using TCD/TCI the location and degree of vasospasm can be determined and proper therapies given before neurological deficit or infarction occurs.
Spectral Doppler criteria for the diagnosis of vasospasm

<table>
<thead>
<tr>
<th>TAP (cm/sec)</th>
<th>Lindegaard Ratio (MCA/ICA)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;120</td>
<td>&lt;3.0</td>
<td>Normal, nonspecific elevation</td>
</tr>
<tr>
<td>&gt;120</td>
<td>3.0 – 5.9</td>
<td>MCA vasospasm mild – moderate</td>
</tr>
<tr>
<td>&gt;200</td>
<td>&gt;6.0</td>
<td>Severe MCA vasospasm</td>
</tr>
<tr>
<td>ACA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;130 (With no MCA/ICA vasospasm present)</td>
<td>Vasospasm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(In the setting of MCA/ICA vasospasm)</td>
<td>Vasospasm versus collateral flow</td>
</tr>
<tr>
<td>PCA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;130 (With no MCA/ICA vasospasm present)</td>
<td>Vasospasm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(In the setting of MCA/ICA vasospasm)</td>
<td>Vasospasm versus collateral flow</td>
</tr>
<tr>
<td>VA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;80 (With no MCA/ICA vasospasm present)</td>
<td>Vasospasm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(In the setting of MCA/ICA vasospasm)</td>
<td>Vasospasm versus collateral flow</td>
</tr>
<tr>
<td>BA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;95 (With no MCA/ICA vasospasm present)</td>
<td>Vasospasm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(In the setting of MCA/ICA vasospasm)</td>
<td>Vasospasm versus collateral flow</td>
</tr>
</tbody>
</table>

CLINICAL SOURCE:
Colleen Douville, BA, RVT, Harborview and University of Washington Medical Centers, Department of Neurological Surgery, Cerebrovascular Laboratory, Seattle, Washington

REFERENCES:
Anatomy

The corpora cavernosa forms the main part of the body of the penis. These structures are located dorso-laterally and divided by a fibrous tissue, the medium septum. Arterial supply to the penis flows from the internal iliac artery through the internal pudendal artery. After branching, the internal pudendal artery becomes the penile artery. This artery is a short segment that divides into four terminal branches:

- Dorsal artery (feeding the skin and glans)
- Urethral artery (supplying the corpus spongiosum and urethral tissue)
- Bulbar artery (feeding the urethral bulb and bulbourethral gland)
- Cavernous artery (cavernosal, supplying the erectile tissue of the corpus cavernosum)
Drainage from the corpora cavernosa is provided by the emissary or circumflex veins that empty into the deep dorsal vein. The proximal portions of the corpora cavernosa are drained by deep penile veins that join with urethral veins draining the corpus spongiosum and eventually draining into the internal pudendal vein. The superficial dorsal vein drains the skin and subcutaneous tissue.

The hemodynamic changes that occur in a normal physiologic erection result from a relaxation of the smooth muscle of the cavernous arterioles and sinusoids resulting in dilation and an increase in blood flow. The distension of the sinusoids creates a mechanical compression of the draining venules restricting venous outflow.

Penile Ultrasound to Rule Out Vasculogenic Impotence

**Indications**
- Impotence
- Decreased erectile duration

**Patient Preparation**
The patient is supine with the penis placed dorsally on the pubic area. Rolled washcloths on either side of the penis may be helpful at times for stabilization.

**Technique**
- To examine the penile arteries, begin with the appropriate equipment setup parameters. These include:
  - low wall filter
  - low color PRF
  - color map that displays slow flow
  - appropriate small parts or slow flow setups
- Begin at the base of the penis, with the penis in a flaccid state. Images should be obtained both in transverse and sagittal views.
- During the scan, the echogenicity of the corpora cavernosa should appear homogeneous throughout. Any increased echogenicity may indicate an area of fibrosis.
- While in the flaccid state, measure the diameter of each of the cavernous arteries. *Note: These arteries vary considerably and there are no absolute normal or abnormal values currently being used.*
- Obtain intimal diameter measurements in grayscale and record a pulsed Doppler signal.
- At this time, a vasoactive agent, such as Prostaglandin E-1 or Papavirine, is injected into the corpora cavernosa. The clinical response is graded as to firmness, rigidity and the ability to penetrate.
- Patient is then rescanned to assess dilatation of the cavernosal arteries in response to the drug.

**Clinical Assessment**
A normal artery should demonstrate a 75 - 100 percent increase in diameter. The spectral waveform can also offer qualitative information in evaluating arterial disease.

A normal waveform should show a peak systolic increase of 75 - 100 percent post injection. A quick acceleration phase shows a higher percentage of change in vessel diameter and a good clinical response.

Measurements taken post injection should always denote the time lapse since the drug was administered. Taking serial measurements will ensure proper documentation while the drug is demonstrating its maximum effect. During this peak period, researchers believe that if an end diastolic component is present, and if the end diastolic component is >.05 cm/s, there is sufficient venous leakage resulting in either an inadequate erection or a diminished erection duration.
Color Duplex Ultrasonography of Renal Artery Stents

Renal artery duplex scanning is used for the detection of renal artery stenosis and to follow patients post treatment. Treatment alternatives include surgical revascularization (bypass or endarterectomy) and angioplasty with or without stent placement. Renal artery stenting is a relatively new procedure and may create new challenges for the technologist when scanning the patient. Some of these challenges include the ability to visualize the stent and to determine if the present diagnostic criteria applies to patients with stents.

Goals and objectives of scanning a renal artery stent include: the definition of the location with special attention to the proximal and distal

**Indications:**
- Post stent placement/ long term follow up/ change in clinical status post stent

**Equipment:**
- Color duplex ultrasound scanner
- Low frequency transducer / select frequency appropriate to body habitus
- Warm acoustic coupling gel
- Recording device

**Patient Preparation:**
- Low fiber dinner evening prior to exam
- NPO 8-12 hours.
- Explain breath-holding techniques

**Patient Position:**
- Supine for anterior approach
- Lateral decubitus for flank approach

**Examination Procedure:**
From an anterior approach locate the SMA, left renal vein and the abdominal aorta in a transverse view. Use these landmarks to locate the renal arteries. Locate the treated renal artery. If the stent was placed for an ostial lesion the proximal portion of the stent will extend into the aorta. This provides an excellent reference point to follow the course of the stent. When the stent is identified, rotate the transducer to obtain a sagittal view of the renal artery/ stent. Examine the stent to determine the position within the artery. When using color, optimize color settings to minimize color overwrite of the stent. Obtain multiple images from multiple views for complete assessment of the stent.

The Doppler evaluation is done using a small sample with a 60-degree Doppler angle. If a 60-degree Doppler angle cannot be maintained, angles less than 60 degrees can be used using correct angle correction technique. Any variation from a 60-degree angle should be recorded so the patient can be followed using that same angle format for all follow up scans. The Doppler sample volume is swept through the vessel to determine the maximum PSV. Recordings are obtained from the proximal, mid and distal segments of the stent and proximal (if possible) and distal native renal artery. If using renal aortic ratio criteria, calculate the PSV from the abdominal aorta at the level of the SMA. This will be used as the denominator for calculating the Renal Aortic Ratio (RAR). If the aortic PSV is less than 40 or there is an abdominal aortic aneurysm present the RAR will be inaccurate and should not be used to determine degree of stenosis.

A complete exam includes both direct evaluation of the renal stent and indirect evaluation at the renal hilum and the renal parenchyma.
ends as the distal segment is related to increased incidence of restenosis, and to determine stent patency. Potential complications post stent placement include: incomplete deployment, renal artery dissection, and distal embolization to the kidney and thrombosis. The post procedure renal artery should be evaluated for these complications.

TIPS

- The distal end of the renal stent may cause angulation of the artery causing an increased Doppler shifted frequency. Correlate any increase in PSV with the B-mode image findings.
- Ultrasound characteristics of stents vary in appearance from echogenic to poorly echogenic.
- Confirm all PSV calculations from two different views. This helps to minimize errors from poor Doppler angles or improper cursor alignment.
- The renal artery stent and its effect on the PSV have not yet been determined and should be considered when interpreting the exam findings.
- The most common cause of a false negative exam, when the artery is well visualized, is missing the jet of the stenosis. If the maximum PSV is not detected, the degree of disease will be underestimated.
- The most common cause of a false positive angle is overestimation of PSV due to Doppler angle errors.

Classification of Renal Artery Stenosis

There are two widely accepted sets of criteria for classification of renal artery stenosis. One set is based upon the renal aortic ratio while the second utilizes absolute velocity criteria and post-stenotic turbulence. Each set of criteria has advantages and disadvantages, therefore it is important to determine which criteria yields the best results for the user, and employ those criteria.

University of Washington Criteria

<table>
<thead>
<tr>
<th>Classification</th>
<th>Renal Aortic Ratio (RAR)</th>
<th>Peak Systolic Velocity (PSV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 60% Diameter Reduction</td>
<td>&lt;3.5</td>
<td>&lt;180 cm/sec</td>
</tr>
<tr>
<td>60 - 99% Diameter Reduction</td>
<td>&gt;3.5</td>
<td>&gt;180 cm/sec</td>
</tr>
<tr>
<td>Occluded</td>
<td>No detectable Doppler signal</td>
<td>0</td>
</tr>
</tbody>
</table>

Dean RH, Hansen KJ, Bowman Gray Criteria

<table>
<thead>
<tr>
<th>Classification</th>
<th>Renal Aortic Ratio (RAR)</th>
<th>Peak Systolic Velocity (PSV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 60% Diameter Reduction</td>
<td>&lt;200 cm/sec</td>
<td>No PST</td>
</tr>
<tr>
<td>60 - 99% Diameter Reduction</td>
<td>&gt;200 cm/sec</td>
<td>PST present</td>
</tr>
<tr>
<td>Occluded</td>
<td>No detectable Doppler signal</td>
<td>None</td>
</tr>
</tbody>
</table>

CLINICAL SOURCE
Gail Sandager, RN, RVT
Michael R Jaff, DO
The Heart and Vascular Institute, Morristown, NJ

REFERENCES
Introduction
Sickle cell anemia is an inherited blood disorder that alters the genetic coding of hemoglobin, resulting in deformation of the red blood cells and disruption of oxygen delivery to the body's organs. The shape of the red blood cells changes from the normal doughnut shape to a sickle shape, causing the red blood cells (RBCs) to become rigid, clump together, and block normal flow pathways. Patients with sickle cell anemia are more susceptible to ischemic episodes, including stroke or thrombotic pain crisis as well as infection, kidney infection and other symptoms. Ischemic stroke occurs in about 11% of patients with sickle cell anemia; the most vulnerable children are those between the ages of 2 and 16. The Stroke Prevention Trial in Sickle Cell Anemia (STOP) demonstrated that transcranial Doppler could reliably identify those at highest risk for stroke because the sites of intracranial stenosis, primarily the intracranial internal carotid artery (ICA) bifurcation and proximal middle cerebral artery (MCA), are assessable by TCD. As demonstrated in the STOP study, children with time averaged mean of the maximum (TAMM) flow velocities >200cm/sec have a significantly increased risk of stroke. The time averaged peak (TAP) maximum flow velocity, calculated by the ultrasound system, tracks the envelope of the waveform and calculates velocities that are equal to the TAMM data, if the calculations are derived from optimized waveforms.

Background
The protocol for TCD and TCDI in children with sickle cell anemia is very specific, and is based on the results of the Stroke Prevention Trial in Sickle Cell Anemia (STOP). The STOP protocol was designed to insure correct arterial segment identification based on depth of sampling, direction of flow, and the spatial relationship between arterial segments. Although TCDI has the advantage of visualizing intracranial structures, these parameters are still used in vessel identification. Prior to initiating the study, the child's bi-temporal diameter (BTD) is measured using calipers, so that the midline (BTD/2) and expected depths of intracranial structures can be calculated. The STOP data found that the ICA bifurcation was usually about 10 mm from the midline. During or after measuring the BTD, the procedure should be explained to the patient, emphasizing the need to remain awake but cooperative throughout the exam. If the patient becomes sleepy, the CO2 levels rise, artifically elevating the mean flow velocities; this could result in a false positive result.

Protocol
- After measuring the BTD and explaining the procedure to the patient, position the child comfortably on their back, and place a rolled towel under the neck for support and stability; it is advised that the TCD sonographer sit at the head of the bed to assure access to the patient and instrumentation.
- Document proper instrumentation settings; suggested to use a 4-6 mm sample volume size, spectral display set to at least 250 cm/sec (PSV), focal depth and grayscale display should be adjusted to approximately 8 cm to assure visualization of patient's midline.
- Place the transducer over the right temporal “window” (see illustration on next page); optimize the best MCA spectral display, with the depth of the sample volume set at 50 mm. After locating the strongest MCA signal, decrease the depth to 38 mm and record the first MCA signal at a depth of 36 - 38 mm. (This waveform is labeled “M-1” according to the STOP protocol, first or shallowest MCA recording.) Flow direction in the MCA will be “forward” or toward skull (transducer).
- Trace the entire course of the MCA by increasing the depth of the sample volume, optimizing the signal and recording the spectral waveform at 2 mm increments. Flow in the MCA usually produces the strongest and highest velocity signal. (see waveform illustration on next page).
- Track the course of the MCA to the bifurcation (BIF), where the intracranial ICA terminates and forms the MCA and ACA; this landmark is identified by a bi-directional signal; optimize and record. The BIF is a reference point for all other measurements (see illustration on next page).
- Trace the ACA (flow away from transducer, toward midline) 4 mm deeper than the BIF, optimize and record.
- After identifying the ACA, decrease the depth of the sample volume to BIF, angle the transducer inferiorly, as if you were focusing the beam toward the floor of the skull, and increase the sample volume by 4 mm to assure insonation of the dICA; optimize signal, record. The ICA signal is frequently turbulent and harsh, due to flow dynamics and angle of insonation.
• After identifying the dICA, return sample volume to the BIF, and angle posteriorly/inferiorly to locate the PCA (forward flow in P1 segment). The PCA can be traced from depths of 50 - 58 in most pediatric patients.

• Track PCA to the midline, where both PCAs originate from the BA. Record the bi-directional signal documenting the ipsilateral (flow toward) and contralateral (flow away) PCAs; this signal is identified as the top of the basilar (TOB) signal in the STOP protocol.

• Repeat entire protocol on left side.

• After completing both temporal studies, turn the patient to one side, chin to chest, and place the transducer at the base of the skull. Angle the transducer so that the ultrasound beam is directed toward the bridge of the nose; the sample volume should be set to default at a depth of 74 mm. Flow in the BA is toward the transducer. Record 3 to 4 waveforms at 2 mm increments.

• The protocol must be followed precisely to assure accuracy.

Children with two confirmed abnormal studies might be candidates for transfusion therapy, as determined by local policy.

Comments

Children with sickle cell anemia are often anemic, resulting in higher mean flow velocities than usually encountered in children with normal hematocrits. Therefore, the TAP in all intracranial vessels may normally exceed 100 - 140 cm/sec. Children with a focal increase in velocity should be carefully evaluated. If the lesion occurs in the distal ICA or proximal MCA, the severity of disease is determined by the mean flow velocity (TAP). The STOP classification, listed below, applies to the intracranial ICA and MCA:

- Normal: <170 cm/sec
- Conditional: 170 - 199 cm/sec
- Abnormal: >200 cm/sec

Basic: normal findings (140 - 169 cm/sec); follow up annually.

Conditional (170-199 cm/sec): varies with age; young children should be reevaluated every 6 months to verify their Doppler results have not converted to abnormal.

According to the STOP protocol, children with abnormal findings should be reevaluated within 2-4 weeks to reconfirm abnormal findings. This prevents false positives and unnecessary treatments.

Children with a “conditional” TCD exam should be re-evaluated in 6 months to determine if there has been progression. All studies must be bilateral and complete, as defined by the STOP protocol.
Aortic Endovascular Stent Graft Assessment

The treatment of abdominal aortic aneurysms (AAA) with endovascular stent graft techniques has gained popularity since Parodi first introduced it in 1991. These devices are placed transluminally through small femoral incisions and then deployed remotely. There are different types of endografts. Some are completely externally supported while others are only supported at the attachment or fixation sites. Some are modular in design while others are single body construction. There are several forms of devices including bifurcated, tube and aorto-uni-iliac configurations.

Diagram of Type I (Attachment/Fixation endoleak) and Type II (Branch vessel endoleak)
Scanning Protocol
The purpose of the duplex ultrasound evaluation is to aid in the assessment of complications such as endoleak, limb dysfunction, stenosis, enlarging aneurysmal size or other anatomical or hemodynamic impairment that might adversely affect endograft function.

- Routine post-placement ultrasound includes high resolution B-mode assessment of the entire endograft, attachment sites and entire residual aneurysm sac.
- Color and spectral Doppler are used routinely to identify and confirm endoleaks, source of endoleak, limb dysfunction, graft patency and outflow vessels.
- Image acquisition – transverse views, measuring maximum transverse diameter of the residual aneurysm size, document color and spectral evidence of endoleak, incomplete deployment of the device. Longitudinal views to document location and patency of the endograft, color and spectral evidence of endoleak, limb dysfunction, incomplete deployment and attachment sites.
- Doppler parameters are obtained in the longitudinal view to assess the flow through the entire endograft, native aorta and outflow iliac vessels as well as assessment of the entire residual aneurysm sac. Using a small sample volume, place the cursor center stream and parallel to the flow at less than 60 degrees. All suspected endoleaks should be confirmed with spectral Doppler. It may be helpful to characterize the spectral flow pattern.

Technical considerations
- Patients should be fasting to minimize the amount of bowel gas. A bowel prep is usually not needed.
- It is important to know the details of the procedure prior to performing the duplex ultrasound. This will assist in understanding structural details of what has been placed, what normal anatomy may have been altered and what complications may be associated with the particular device placed.
- Careful assessment using B-mode, color and spectral Doppler is necessary. Optimize B-mode and color settings so as to be sensitive enough to identify small endoleaks but without excessive artifact. Color artifact can be pulsatile and appear to be true endoleak and must be confirmed using spectral Doppler. True leaks will have reproducible waveforms that usually differ from those in the endograft. The endoleak should have a different characteristic waveform from that of the endograft.
- Power Doppler may be helpful in identifying endoleak.
- Look for potential sites of endoleak: attachment sites, branch endoleak (IMA & lumbar), transgraft and modular disconnect leaks.
- Look for limb dysfunction: twisting, telescoping, crimping, kinking or other deformity that could lead to limb stenosis or thrombosis. The same criteria for infrainguinal graft stenosis may be used to define stenosis in the graft limbs.
- Identify flow characteristics in the native outflow iliac arteries and document patency of the hypogastric arteries.

CLINICAL SOURCE
Kathy Carter, BSN, RN, RVT.
Technical Director, Norfolk Surgical Group, Norfolk, VA
Philips Medical Systems is part of Royal Philips Electronics

Interested?
Would you like to know more about our imaginative products? Please do not hesitate to contact us. We would be glad to hear from you.

On the web
www.medical.philips.com/ultrasound

Via email
medical@philips.com

By fax
+31 40 27 64 887

By postal service
Philips Medical Systems
Global Information Center
P.O. Box 1168
5602 BD Eindhoven
The Netherlands

Asia
Tel: +852 2821 5888

Europe, Middle East, Africa
Tel: +31 40 27 62092

Latin America
Tel: +954 835 2600

North America
Tel: +800 285 5585

© Koninklijke Philips Electronics N.V. 2005
All rights are reserved. Reproduction in whole or in part is prohibited without the prior written consent of the copyright holder.

Philips Medical Systems Nederland B.V. reserves the right to make changes in specifications and/or to discontinue any product at any time without notice or obligation and will not be liable for any consequences resulting from the use of this publication.

Printed in The Netherlands.
4522 981 97921/795 - FEB 2005