CAROTID DUPLEX ULTRASOUND EXAMINATION

POLICY: Carotid duplex ultrasound examination will be performed with an order from a physician or other qualified clinical practitioner. The examination will be supervised and interpreted by a radiologist or other licensed practitioner who is qualified by reason of training to understand the normal anatomy and pathophysiology of the extracranial carotid, vertebral and subclavian arteries, and integration of ultrasound with other imaging techniques to optimize the probability of detecting disease.

PURPOSE: To assess the extracranial carotid, vertebral and subclavian arteries for arterial disease using duplex ultrasound imaging. Duplex is combined B-mode and Doppler (color/spectral) sonography. Duplex scanning permits localization of disease in these vessels. Spectral analysis of velocity waveforms permits accurate classification of disease in the internal carotid artery based on the extent of diameter reduction.

INDICATIONS: Carotid duplex ultrasound examination is indicated for patients with signs and/or symptoms of carotid arterial disease. Such indications include, but are not limited to: cerebrovascular accident (CVA), transient ischemic attacks (TIA), cervical bruit and pulsatile mass in either the carotid or subclavian region. Other non-lateralizing, less specific indications include: dizziness, headaches and vertigo (insofar as they are associated with an overall loss of cerebral blood flow, either form extensive carotid disease or because of disease in the vertebrobasilar system). Carotid duplex ultrasound can be used to monitor known carotid arterial disease. It is also used as a screening evaluation in candidates for cardiac or vascular surgery and in postoperative patients following revascularization operations (e.g. endarterectomy, stenting, carotid to subclavian bypass).

PATIENT PREPARATION: There is no special preparation for this examination.

PROCEDURE/TECHNIQUE: Carotid duplex ultrasound will be performed with the patient in a supine position. The patient’s head may be elevated, and a rolled towel can be placed under the patient’s neck for support. The patient’s head should be slightly hyperextended and turned toward the contralateral side. Changes in position should be made as needed to optimize the scanning window. Patients with thick, muscular necks can be a challenge; asking the patient to reach for his/her hip may help to take the shoulder down and out of the way. If necessary, the patient may be scanned in an upright position. Recent neck surgery, such as endarterectomy, may result in discomfort from transducer pressure. Providing extra gel to float the transducer footprint may alleviate the pressure and allow the examination to be performed. The highest frequency transducer(s) that will allow adequate penetration should be used in order to optimally visualize arterial anatomy. Using duplex ultrasound imaging, the accessible portions of the common and internal carotid arteries should be imaged in their entirety, and a basic assessment of the external carotid, vertebral and subclavian
arteries should be performed. A bilateral examination should always be performed, beginning with the right.

The single most reliable parameter for differentiating internal and external carotid arteries is the presence of branches associated with the external carotid artery. A “temporal tap” may also be employed. Temporal tapping is performed by tapping on the temporal artery (located 1-2cm anterior to the top of the ear) while simultaneously observing corresponding reverberations seen on the spectral waveform of the ECA. A normal ICA will have a lower resistance waveform than a normal ECA.

Minimal required images satisfy the ACR-AIUM-SPR-SRU Practice Parameter for the Performance of an Ultrasound Examination of the Extracranial Cerebrovascular System (Revised 2014). The order of imaging will be as follows (minimal number of images in parenthesis):

**B-MODE**

- Common Carotid Artery (CCA) (4 images on each side)
- CCA Bifurcation (2 images on each side)
- External Carotid Artery (ECA) (1 image on each side)
- Internal Carotid Artery (ICA) (1 image on each side)

**COLOR/SPECTRAL DOPPLER**

- Common Carotid Artery (CCA) (2 color / 2 spectral images on each side)
- Carotid Bulb/Sinus (1 color / 3 spectral image on each side)
- Internal Carotid Artery (ICA) (3 images / 3 spectral on each side)
- External Carotid Artery (ECA) (1 color / 1 spectral image on each side)
- Vertebral (1 color / 1 spectral image on each side)
- Subclavian (1 color / 1 spectral image on each side)

**B-MODE:** The extracranial carotid arteries should be evaluated in longitudinal and transverse planes. If atherosclerotic plaques are present, their extent, location and characteristics should be documented with B-mode imaging. Additional images may be required to fully document the findings.

- Minimal stored images should include:
  - One longitudinal image of the proximal CCA, labeled *Rt or Lt Long CCA Prox*
  - One transverse image of the proximal CCA, labeled *Rt or Lt Trans CCA Prox*
  - One longitudinal image of the distal CCA, labeled *Rt or Lt Long CCA Dist*
  - One transverse image of the distal CCA, labeled *Rt or Lt Trans CCA Dist*
  - One transverse image of the carotid bulb/sinus at the CCA bifurcation, labeled *Rt or Lt Trans Bifur*
  - One transverse image of the ICA and ECA immediately distal to the dilated proximal ICA, labeled *Rt or Lt Trans Bifur*
  - One longitudinal image of the proximal ICA at the CCA bifurcation, labeled *Rt or Lt Long ICA Prox*
  - One longitudinal image of the proximal ECA, labeled *Rt or Lt Long ECA Prox*
COLOR/SPECTRAL DOPPLER: Color/spectral Doppler settings (e.g. gain, PRF/scale, frequency, wall filter, steer/angle correction) should be optimized appropriately for each image. Color images should be obtained to demonstrate filling of the lumen and potential flow disturbances associated with stenoses. When obtaining spectral Doppler images, an attempt should be made to adjust settings so that the waveform fills at least 2/3 of the image and there are approximately 3-4 cardiac cycles. Each spectral Doppler sample should include calculated velocities as specified below. Waveforms should be obtained according to the protocol described in this document, as well as in areas of suspected stenosis; associated flow disturbances distal to the stenosis should also be demonstrated.

All flow velocities obtained from a spectral waveform must be angle corrected. A consistent and reproducible Doppler angle should be used and should never exceed 60 degrees. The classifications for disease used in this protocol were validated using a consistent Doppler angle between 45-60 degrees. For follow-up studies, the same Doppler beam-steering direction and Doppler angle used on the prior study should be reproduced for consistent and reproducible data. The sample volume (gate) size should be kept as small as possible to detect discrete changes within the blood flow. Very densely calcified vessels may not allow penetration by the ultrasound beam, yielding limited to no Doppler signal or imaging data in to affected segment; however, useful Doppler information may still be obtained in unaffected segments. Additional images may be required to fully document the findings; see “Pathologic Conditions” section for further information regarding these requirements.

- Minimal stored images should include:
  - One longitudinal color Doppler image of the most proximal, straight segment of the CCA, labeled Rt or Lt Long CCA Prox
  - One longitudinal spectral Doppler waveform with calculated PSV and EDV, obtained in the most proximal, straight segment of the CCA, labeled Rt or Lt Long CCA Prox
  - One longitudinal color Doppler image of the distal CCA, about 2-3cm below the bifurcation, labeled Rt or Lt Long CCA Dist
  - One longitudinal spectral Doppler waveform with calculated PSV and EDV, obtained in the distal CCA, about 2-3cm below the bifurcation, labeled Rt or Lt Long CCA Dist
  - One longitudinal color Doppler image of the carotid bulb/sinus at the base of the ICA, labeled Rt or Lt Long ICA prox
  - One longitudinal color Doppler image of the proximal ICA, immediately distal to the carotid bulb/sinus (where the vessel is no longer dilated), labeled Rt or Lt Long ICA prox
  - One longitudinal spectral Doppler waveform with calculated PSV and EDV, of the proximal ICA, immediately distal to the carotid bulb/sinus (where the vessel is no longer dilated), labeled Rt or Lt Long ICA prox
• One longitudinal color Doppler image of the mid-segment of the ICA, labeled Rt or Lt Long ICA mid
• One longitudinal spectral Doppler waveform with calculated PSV and EDV, of the mid-segment of the ICA, labeled Rt or Lt Long ICA mid
• One longitudinal color Doppler image of the distal ICA, at least 3 cm above the bifurcation, labeled Rt or Lt Long ICA dist
• One longitudinal spectral Doppler waveform with calculated PSV and EDV, of the distal ICA, at least 3 cm above the bifurcation, labeled Rt or Lt Long ICA dist
• One longitudinal color Doppler image of the ECA, labeled Rt or Lt Long ECA
• One longitudinal spectral Doppler waveform with calculated PSV and EDV, of the ECA, labeled Rt or Lt Long ECA
• One longitudinal color Doppler image of the vertebral artery, labeled Rt or Lt Long Vert A
• One longitudinal spectral Doppler waveform with calculated PSV and EDV, of the vertebral artery, labeled Rt or Lt Long Vert A
• One longitudinal color Doppler image of the subclavian artery, labeled Rt or Lt Long Subclav A
• One longitudinal spectral Doppler waveform with calculated PSV, of the subclavian artery, labeled Rt or Lt Long Subclav A

*ICA/CCA ratio: calculated using a normal CCA PSV and the highest ICA PSV

Normal Spectral Doppler Waveform Findings

*CCA: end-diastolic velocity of the CCA should be above zero and similar to the end-diastolic velocity of the contralateral CCA taken at approximately the same level
*Bulb: unidirectional flow along the flow divider of the bifurcation; transient reversal of flow at peak systole near center stream and at the outer wall opposite the flow divider; velocities at the outer wall may drop to zero in end diastole
*ICA: low-resistance vessel, having continuous flow throughout the cardiac cycle; velocities remain well above zero in end-diastole; normal flow disturbances of the carotid bulb may extend into the proximal ICA
*ECA: sharp upstroke to systole, followed by a prominent dicrotic wave, which may reverse at end-systole/early diastole; velocities approach or reach zero in end-diastole; peak velocity normally higher than the ICA
*Vertebral: low-resistance vessel; similar to, but more resistive than, the ICA; antegrade flow direction
*Subclavian: high-resistance (triphasic) vessel, having forward systolic, reversal late systole/early diastole, and forward late diastolic components; waveform should be taken as close to the origin as possible
**PATHOLOGIC CONDITIONS:** When pathologic processes are detected during the course of the examination, extra images and/or cine clips are necessary to characterize the abnormality. Particularly, further investigation and documentation for a proximal stenosis is required if there are post-stenotic spectral Doppler findings discovered in any vessel during the examination (e.g. tardus parvus suggesting proximal stenosis; retrograde vertebral artery suggesting subclavian or innominate stenosis/occlusion). The following is a description of commonly encountered abnormalities, or conditions that should be considered during the examination and the minimum additional stored images expected for each circumstance. The list is not intended to be comprehensive, and sonographers are expected to apply their knowledge of pathophysiology to provide clear images of the abnormalities they encounter.

**Plaque:** Atherosclerosis is a disease in which plaque builds up within arterial walls. Plaque is a substance made up of cholesterol, fatty substances, cellular waste products, calcium and fibrin. On an ultrasound image, plaque can be homogeneous or heterogeneous. Homogeneous plaques may be fibrous (soft) or calcified (hard). They have a uniform internal structure.

**Stenosis:** Arterial stenosis is a hemodynamically significant narrowing of the internal lumen of a vessel, typically caused by atherosclerotic changes. Ultrasound findings of carotid artery stenosis include plaque visible by B-mode imaging and focal changes in velocity that meet the criteria for stenosis by spectral Doppler imaging. Color imaging is helpful in identifying higher velocity areas of interest, but should not be solely relied on to pinpoint the site of highest velocity; the area of suspected stenosis should be surveyed by moving the sample volume through the site, and the highest velocity documented.

**Pitfalls/Considerations:**
- Very densely calcified vessels may not allow penetration by the ultrasound beam, yielding limited to no Doppler signal or imaging data in the affected segment. Angling the transducer through a different scanning window may produce results. If this proves unsuccessful, then the calcified segment should be measured and effort should be taken to produce a signal distal to the segment. If the shadowing segment is <1cm and no turbulent flow is demonstrated beyond the plaque, there is unlikely to be a significant stenosis (>50%) within the shadowing segment. If a damped or turbulent waveform is demonstrated beyond the shadowing segment, then a more severe stenosis should be suspected. If the shadowing segment measures >2cm in length, then the degree of stenosis is indeterminate. Both scenarios warrant confirmation with another imaging modality.
- It is important to differentiate a true stenosis from a non-stenotic increase in the velocity, as is seen in the sharp curve of a tortuous vessel. Therefore, in the absence of plaque, Doppler samples within sharp curves should be avoided to limit potential false positive results.
• Additional disease present proximal or distal to a given stenosis may cause a decrease in the velocity due to decreased inflow or increased resistance. As a result, the degree of stenosis may be underestimated.

• Disease may also be underestimated in the presence of decreased cardiac output. An overall decrease in velocity would be present, bilaterally.

• For a given stenosis, the presence additional disease on the contralateral side may cause a compensatory increase in flow on the ipsilateral side and lead to an overestimation of disease state.

• In the presence of “trickle flow” in a nearly occluded artery, blood flow velocities may be slower than the typical color velocity scale thresholds, resulting in a false positive diagnosis of complete occlusion. Therefore, it is important to sufficiently lower the scale and increase the gain in order to detect “trickle flow” when differentiating near versus total occlusion.

• A moderate increase in velocity is often expected after endarterectomy, generally throughout the length of the endarterectomized segment (probably as a result of stiffening and post-surgical changes of the arterial wall).

Given all of the variables that can affect velocity, it is important to demonstrate secondary findings to confirm a true stenosis. A stenosis profile will help identify a true stenosis:

*Stenosis Profile:

  • Pre-stenotic: waveform may or may not demonstrate flow disturbance, depending on the shape of the lesion; may also be dampened
  • Stenotic: waveform at the point of maximum velocity or most disturbed flow; at least x3 individual Doppler waveforms (using the same Doppler angle) should be obtained and the highest reproducible velocities should be used to classify the severity of disease
  • Post-stenotic: waveform reflects the chaotic nature of turbulence

CCA STENOSIS/OCCLUSION

*It is important to compare the spectral Doppler waveforms from both proximal CCA’s, with particular attention paid to the shape and end-diastolic component. The end-diastolic velocity of the CCA should be above zero and similar to the end-diastolic velocity of the contralateral CCA taken at approximately the same level. In the case of a high-grade stenosis or total occlusion of the ICA, the CCA will sometimes take on the characteristics of the ECA with end-diastolic flow at or very close to zero. Oppositely, the contralateral CCA may have an increase in end-diastolic flow in order to compensate for ipsilaterally reduced flow to the brain. In the presence of a proximal stenosis (e.g. origin of CCA, brachiocephalic), the ipsilateral CCA waveform may be dampened with low velocity and a slower upstroke compared with the contralateral CCA. The ipsilateral CCA waveform may also appear post-stenotic in character (tardus parvus). An occluded CCA may appear smaller in diameter than the contralateral CCA. The vessel will be filled with immobile, echogenic material. The occlusion may involve the ICA and proximal ECA (to its first branch). The distal ECA may remain patent due to reversed flow in the branches. Another possible scenario in CCA occlusion is
patency of both the ECA and ICA, with reversed flow in the ECA supplying the lower resistance ICA.

*The strict velocity criteria used for classifying disease in the ICA are not accurate in the CCA. Disease states in the CCA can be classified as <50% diameter reduction or >50% diameter reduction. Severe stenosis (>50%) findings may include: focally increased velocity (CCA PSV >230cm/s; CCA EDV >100cm/s) and post-stenotic turbulence.

*In the presence of a stenosis, the CCA/CCA(prox) ratio should be calculated using the CCA PSV at the stenosis and the CCA PSV of a proximal non-stenotic segment.

*Velocity differences between left and right CCA’s of >20cm/s indicates asymmetric flow.

ICA STENOSIS/OCLUSION

Atherosclerosis in the ICA will usually develop in the first 2 cm of the bifurcation and rarely will be seen isolated in the distal ICA. As visualization becomes difficult and a vessel becomes tortuous, as is often the case in the mid to distal ICA, caution should be taken to prevent inappropriate and inaccurate Doppler angles when obtaining spectral waveforms. These will result in overestimated measurements that can lead to a misdiagnosis of stenosis.

In the case of a high-grade stenosis or total occlusion of the ICA, the blood flow will be shunted through the ECA. As a result, the ipsilateral CCA will sometimes take on the characteristics of the ECA with end-diastolic flow at or very close to zero, and the contralateral CCA will have an increase in flow as a compensatory reaction (chronic cases may demonstrate a return to normal contralateral flow because the development of collaterals reduce the distal resistance). Another hemodynamic change that occurs as a result of ICA occlusion is an overall increase in ECA velocity. A thumping sound may be heard at the origin of the ICA occlusion. This thumping is often visible as an area of transient flow reversal as blood strikes against the occlusion and then reverses. The mere cessation of color is not a reliable means of identifying an occluded vessel.

*ICA Stenosis Interpretive Criteria: The following criteria have been shown to be accurate for the interpretation of stenosis of the ICA (proximal 3cm). Their accuracy has not been documented for the external carotid or the common carotid arteries.

- **Normal/Mild (0-49% Diameter Reduction):**
  - Normal: absence of visible plaque & PSV<125cm/s;
  - 0-15% Diameter Reduction: PSV<125cm/s with minimal flow disturbance;
  - 1-49% Diameter Reduction: PSV<130cm/s & ICA/CCA <1.6

- **Moderate (50-69% Diameter Reduction):**
  - PSV=130-229cm/s, EDV=70-99cm/s, ICA/CCA=1.6-3.1

- **Moderate/Severe (70-79% Diameter Reduction):**
  - PSV>229cm/s, EDV=100-139cm/s, ICA/CCA=3.2-4.0

- **Severe (80-99% Diameter Reduction):**
  - PSV>229cm/s, EDV>139cm/s, ICA/CCA>4.0

- **Occlusion (100% Diameter Reduction):**
  - No detectable blood flow
ECA STENOSIS
The ECA may take on the appearance of the ICA in end-diastole (velocities above zero) as the resistance in the face and scalp decrease with warming or in the presence of disease.

*The strict velocity criteria used for classifying disease in the ICA are not accurate in the ECA. Disease states in the ECA can be classified as <50% diameter reduction or >50% diameter reduction (locally increased velocity followed by post-stenotic turbulence).

VERTEBRAL ARTERY STENOSIS
The most common site of disease in the vertebral arteries is at its origin with the subclavian artery. This location is caudal in the neck under the clavicle and may be difficult to visualize (often more difficult on the left). If reversed flow is present, the diagnosis of ipsilateral subclavian/innominate stenosis/occlusion is critical for completeness of a steal (see next section).

*The strict velocity criteria used for classifying disease in the ICA are not accurate in the vertebral artery. Disease states in the vertebral artery can be classified as <50% diameter reduction or >50% diameter reduction (locally increased velocity followed by post-stenotic turbulence).

SUBCLAVIAN AND INNOMINATE ARTERY STENOSIS/OCLUSION (Subclavian Steal)
Stenosis of the subclavian and innominate (brachiocephalic) arteries most commonly occurs proximally. This location is caudal in the neck under the clavicle and may be difficult to visualize. An increase in velocity, the loss of the reversal component in the spectral waveform, and post-stenotic flow changes identifies a significant stenosis. These post-stenotic flow changes may also be present within the vertebral and CCA’s. Subclavian or CCA origin stenosis may both result in low systolic, high diastolic flow in the post-stenotic CCA.

Another possible presentation of subclavian disease is reversed flow within the vertebral arteries. Flow direction of the vertebral arteries can be antegrade, retrograde or bidirectional. Subclavian or innominate stenosis/occlusion may result in reversed flow of the ipsilateral vertebral artery in order to supply the arm (subclavian steal).

The severity of the steal can be assessed by directional changes:

- occult (minimal hemodynamic changes) – antegrade flow with midsystolic deceleration or reversed late systolic flow
- partial (moderate hemodynamic changes) – bidirectional flow
- complete – constant retrograde flow

If a subclavian steal is present, further evaluation in an attempt to localize subclavian stenosis or occlusion is necessary. Such pathology is typically located within the segment of subclavian artery between the CCA and vertebral branches. Bidirectional flow occurs when there is an equal decrease in pressure in both the distal bed supplied by the vertebral and the subclavian artery. Reactive hyperemia testing
with a blood pressure cuff inflated to suprasystolic pressure at the brachial level for 2 minutes can then be performed. While continuing to record the spectral waveform from the vertebral artery, the cuff is released. Retrograde flow in the direction of the arm on release of the cuff indicates a steal.

*The strict velocity criteria used for classifying disease in the ICA are not accurate in the subclavian or innominate artery. Focally increased velocity, loss of the reversal component in the spectral waveform, and post-stenotic turbulence identifies a significant stenosis in the subclavian artery. In addition, the identification of a difference in blood pressures of 15mmHg and PSV>180cm/s indicates a significant stenosis in the subclavian artery.

CAROTID DISSECTION
Findings include: visualization of an intimal flap at grayscale imaging, reversed flow in the true channel and antegrade flow in the false channel at color Doppler imaging, a damped high resistive spectral Doppler flow pattern proximal to the dissection.

CAROTID BODY TUMOR
Carotid body tumors are located between the proximal ICA & ECA. A carotid body tumor may cause splaying of the carotid vessels, and extrinsic compression caused by mass effect of the tumor may result in significant narrowing of the vessels.
# Inland Imaging

## Extracranial Carotid Ultrasound Stenosis Criteria

<table>
<thead>
<tr>
<th>Diameter Reduction</th>
<th>Peak Systolic Velocity</th>
<th>End Diastolic Velocity</th>
<th>ICA/CCA Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal/Mild 1-49%</td>
<td>&lt;130 cm/sec</td>
<td>NA</td>
<td>&lt; 1.6</td>
</tr>
<tr>
<td>Moderate 50-69%</td>
<td>130 - 229 cm/sec</td>
<td>70 - 99 cm/sec</td>
<td>1.6 - 3.1</td>
</tr>
<tr>
<td>Moderate/Severe 70-79%</td>
<td>≥230 cm/sec</td>
<td>100 - 139 cm/sec</td>
<td>3.2 - 4.0</td>
</tr>
<tr>
<td>Severe 80-99%</td>
<td>≥230 cm/sec</td>
<td>≥140 cm/sec</td>
<td>≥ 4.1</td>
</tr>
<tr>
<td>Occluded 100%</td>
<td>NO FLOW</td>
<td>NO FLOW</td>
<td>NA</td>
</tr>
</tbody>
</table>
The protocol outlined in this document was developed for Inland Imaging’s general ultrasound department and was modeled after the following Inland Imaging Vascular Services written protocol:


**References:**


Grant EG, Duerinckx AJ. Noninvasive Diagnosis of Carotid Stenosis: Technique, Normal Anatomy, and New Observations in Light of the NASCET Study. *RSNA Categorical Course in Vascular Imaging* 1998; pp 211-221

**Additional References:**

ACR-AIUM-SPR-SRU Practice Parameter for the Performance of an Ultrasound Examination of the Extracranial Cerebrovascular System (Revised 2014)

Available from: http://www.acr.org/~/media/5d63a45f7a54417c93cd58f109f0fdd2.pdf


http://www.slideshare.net/shaffar75/doppler-ultrasound-of-carotid-arteries