Carotid Artery Doppler
Patient Position

- supine or semisupine
- head slightly hyper-extended
- rotated 45° away from the side being examined.
- Higher-frequency linear transducers (7 MHz)
• Vessels should be imaged as completely as possible
• Caudal angulation of the transducer in the supraclavicular region and cephalic angulation at the level of the mandible
• Assessed both in gray scale and colour doppler settings
Limitations

» short muscular neck
» a high carotid bifurcation
» tortuous vessels
» calcified shadowing plaques
Optimal Scanning Techniques and Doppler Settings
• Scan both in transverse and longitudinal plane.
• Starting from proximal most CCA, bulb, ECA and ICA.
• Distal carotid - 2 cm from the bulb
• ICA or ECA?
  Large in caliber, posterior and lateral
  low resistance wave form (not reliable)
  no branches
  no cluttering with temporal artery tapping,
‘Internal is not Internal’
Color Doppler Sampling Window

• also known as the color box
• The size is adjusted to include all regions of interest.
• Adjustment of the angle- by changing the box angles from left to center or right
• angling the transducer to ensure that the Doppler angle is less than 60° to the direction of blood flow
Proper steering
Sample Volume Gate and Angle Correction

• If the Doppler angle is small or more than 60 degree - small error in the estimated velocity.
• preferred angle of incidence is 45° ± 4.

The optimal position of the sample volume gate

• in a normal artery is in the mid lumen parallel to the vessel wall
• in a diseased vessel, parallel to the direction of blood flow
• should not be placed on the sharp curves of a tortuous artery - falsely high velocity reading

• Should not be placed too close to the vessel wall - spectral broadening.
Spectral Broadening

- Spectral broadening results from turbulence in the blood flow.

**Spurious spectral broadening**

- a large Doppler angle
- a sample volume gate located close to the vessel wall
- a high Doppler gain setting

- The size of the gate is normally - between 2 and 3 mm.
- too small (1.5 mm) - the Doppler signal may be missed
- too large >3.5 - spectral broadening
Color velocity scale

• If set below the mean velocity of blood flow, **Aliasing** throughout the vessel lumen

• Set significantly higher than the mean velocity of blood flow, aliasing may disappear resulting in a **missed stenosis**

• In a normal carotid US examination, the color velocity scale should be set between **30 and 40 cm/sec** (mean velocity).
Too much aliasing

Color scale too low (4 cm/s)

No color jet

Soft plaque

Color scale too high (115 cm/s)

The narrowest segment

Optimal color scale (39 cm/s)
Color Gain Control

• The color gain should be set so that color just reaches the intimal surface of the vessel.

• If the color gain setting is too low, trickle flow may go undetected.

• If a color gain setting is high, “bleeding” of the color into the wall and surrounding tissues limit visualization of the plaque surface.
PDI may provide increased sensitivity to visualize the continuity of blood flow in arterial stenoses.
Advantages of power doppler

• Angle independent
• No aliasing
• Very sensitive to low velocity and low amplitude flow
• Helps in differentiating critical stenosis from occlusion

Disadvantages:

motion sensitive

does not give direction and velocity of flow
Carotid plaque

- Defined as a localized protrusion from the wall into the lumen with an area 50% greater than the intima-media thickness of neighboring sites.

- low and high echogenic plaque.
- heterogeneous or homogeneous.
- regular (smooth) or irregular.
• If more than 20% of the plaque echogenicity differed from the echogenicity of the rest of the plaque by two or more echogenicity grades – is heterogenous.

• When height variations between 0.4 and 2 mm along the contour of the lesion – is irregular

• Ulcerated plaques - recesses in the contour of the lesion at least 2 mm in depth, with a well-defined back wall at the base showing flow.
• Heterogeneous plaques and ulcerated plaques are unstable or friable
• Potential for embolic TIA and cerebro-vascular accidents
Fissuring or ulceration in the plaque
Is this artifact or ulceration?

Soft plaque

What is this?
Plaque Classification

- **Class I**, homogeneous texture, uniformly hypoechoic
- **Class II**, heterogeneous texture, predominantly hypoechoic
- **Class III**, heterogeneous texture, predominantly hyperechoic
- **Class IV**, homogeneous texture, uniformly hyperechoic
- **Class V**, unclassified calcified plaques
After optimizing the setting

Measure the velocity – PSV and DV
- Proximal and distal CCA
- ICA and ECA
- Vertebral artery

Wherever stenosis present –
- at stenosis
- proximal to and
- distal to stenosis

• Compare bilateral carotid velocities – symmetric or asymmetric
Waveform Analysis
Normal Carotid Artery
CCA

- combination of ICA and ECA patterns,
- intermediate amount of continuous forward diastolic flow
- a sharp systolic upstroke and thin spectral envelope
- flow below the baseline or filling in of the spectral window normally **should not be seen**
• a low-resistance waveform pattern
• systolic peak should be sharp and the spectral envelope thin
• continuous forward diastolic flow
• the systolic peak may be slightly blunter than the systolic peak of the ECA
• the systolic upstroke is sharp
• the spectral envelope is thin.
• **reduced to no diastolic flow**
• diastolic flow should be symmetrical bilaterally
• **Transient reversal in early diastole (characteristic early diastolic notch)** - a normal finding
VERTEBRAL ARTERY

- low resistance wave pattern
- forward diastolic flow
- no systolic or diastolic notch
- similar to carotid in flow (colour)
- no reversal of wave form
Look At

- Pattern
- Systolic contour
- Diastolic pattern
- PSV
- DV
- ICA PSVs / CCA PSVs ratio
- Compare Right and Left side
Abnormal CCA

• either low or high PSVs.
• abnormally high-resistance waveform,
• an abnormally low-resistance waveform,
Abnormally low PSVs

- A normal CCA PSV should be in the range of approximately 60 – 100 Cm/s
- IF less than this, examine opposite side

  Symmetric  Asymmetric
  (near normal)

  Low cardiac output  Evaluate further

- A velocity difference of >20 cm/sec between the right and left is abnormal.
Causes for unilateral low PSVs

- Proximal stenosis (brachiocephalic)
  - Parvus - tardus waveform or normal pattern but asymmetrical PSVs.

- Distal stenosis (carotid bulb level)
  - High resistance wave form
Innominate artery occlusion
**High-resistance waveform in CCA**

- High-grade ICA stenosis or occlusion (externalization of the CCA)
- Distal waveforms should be assessed (support the diagnosis)
- **EXCEPTION IF**
  - ???
  - is bilateral and low PSVs indicates
    - Aortic stenosis
    - Severe cardiac failure
Internalisation of ECA
Focal stenosis of the CCA

- The ratio of the highest PSV at the CCA stenosis divided by the PSV 2 cm proximal to the stenosis should be calculated.

\[
\frac{\text{PSV}_{\text{cca at stenosis}}}{\text{PSV}_{\text{cca prox.}}}
\]

- If the ratio is 2 or more and less than 2.99 - stenosis of 50% or more.
- If the ratio is 3 or more - stenosis of 75% or more.
- Also used if there are tandem stenosis.
PSV\textsubscript{B} / PSV\textsubscript{A}
CCA - mildly elevated resistance

Luminal narrowing with color Aliasing

High-velocity flow 627 cm/s, turbulence

ICA- tardus-parvus waveform
Unusual finding in Case of CCA occlusion

Reversal of flow in ECA and low resistance and low PSVs in ICA as it is fed by collaterals.

This is to maintain the antegrade flow in ICA
Remember....

• If the stenosis is unilateral, there is marked asymmetry in the systolic contour of the waveforms of the right and the left CCAs.

• If the stenosis is central, such as with aortic stenosis, the waveforms are affected bilaterally.
ICA

- Normal is - low resistance with high diastolic pattern.
- Most common site is ICA origin – plaque extending from the bulb.
- High resistance pattern in the ICA- Stenosis distally.
- PSVs raises - Significant stenosis
<table>
<thead>
<tr>
<th>Stenosis Level</th>
<th>ICA PSV cm/s</th>
<th>Plaque/diameter</th>
<th>ICA/CCA ratio = ( \frac{PSV_{ICA}}{PSV_{CCA}} )</th>
<th>ICA EDV cm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt;125</td>
<td>None</td>
<td>&lt;2</td>
<td>&lt;40</td>
</tr>
<tr>
<td>&lt;50%</td>
<td>&lt;125</td>
<td>&lt;50%</td>
<td>&lt;2</td>
<td>&lt;40</td>
</tr>
<tr>
<td>50%–69%</td>
<td>125–230</td>
<td>≥50%</td>
<td>2–4</td>
<td>40–100</td>
</tr>
<tr>
<td>≥70 to near occlusion</td>
<td>&gt;230</td>
<td>≥50%</td>
<td>&gt;4</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Near occlusion</td>
<td>High, low, or undetectable</td>
<td>Visible</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td>Total occlusion</td>
<td>Undetectable</td>
<td>Visible, no detectable lumen</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Carotid Stenosis Criteria

<table>
<thead>
<tr>
<th>Stenosis</th>
<th>Peak Systolic Velocity (cm/s)</th>
<th>Peak End Diastolic Velocity (cm/s)</th>
<th>Peak Systolic Velocity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50</td>
<td>&lt;150</td>
<td>&lt;50</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>50-59</td>
<td>150-200</td>
<td>50-70</td>
<td>2.0-2.5</td>
</tr>
<tr>
<td>60-69</td>
<td>200-250</td>
<td>50-70</td>
<td>2.5-3.0</td>
</tr>
<tr>
<td>70-79</td>
<td>250-325</td>
<td>70-90</td>
<td>3.0-3.5</td>
</tr>
<tr>
<td>80-89</td>
<td>325-400</td>
<td>70-100</td>
<td>3.5-4.0</td>
</tr>
<tr>
<td>90-99</td>
<td>&gt;400</td>
<td>&gt;100</td>
<td>&gt;4.0</td>
</tr>
<tr>
<td>Occlusion</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>
String sign - Near Total Occlusion
Total Occlusion
Near Total Occlusion or Total
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Recommended Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transducer frequency</td>
<td>&lt;7 MHz</td>
</tr>
<tr>
<td>Color box</td>
<td>Steer to the center or straight position</td>
</tr>
<tr>
<td>Sample volume box</td>
<td>Steer to the center or straight position</td>
</tr>
<tr>
<td>Focal zone</td>
<td>At the level of the diseased segment</td>
</tr>
<tr>
<td>Color velocity scale</td>
<td>Decrease to &lt;15 cm/sec</td>
</tr>
<tr>
<td>PW Doppler scale</td>
<td>Decrease to &lt;15 cm/sec</td>
</tr>
<tr>
<td>Color Doppler gain</td>
<td>Increase to the point of visible background noise</td>
</tr>
<tr>
<td>PW Doppler gain</td>
<td>Increase to the point of visible background noise</td>
</tr>
<tr>
<td>Wall filter</td>
<td>Decrease to low</td>
</tr>
<tr>
<td>Color threshold</td>
<td>Increase to ≥80%</td>
</tr>
<tr>
<td>Sample volume gate</td>
<td>Increase to ≥2.5 mm</td>
</tr>
</tbody>
</table>
Normal PSVs in ICA always normal???

- As the stenotic grade increases PSVs start falling as flow through the tight stenosis reduces.
- So measure EDV - which raises.
- Measure ratio – ICA, PSVs / CCA PSVs.
- Normal to <50% stenosis ratio will be < 2.
- As the stenosis increases ratio becomes > 4 or variable, internalization of ECA, opposite ICA PSVs increases.

Pitfalls----

Tortuous artery
Plaque which is shadowing
severe stenosis
So assess ICA

- In gray scale for amount of luminal narrowing
- Assess velocities in proper settings
- Should assess PSV, EDV and ratio of PSVs in ICA and CCA
- Assessed proximally, mid and distally
- If no color flow demonstrated in a tight stenotic segment even in power doppler confirm with other modality
- Assess opposite ICA for compensatory flow
Confirm the ECA
Is there any reversal of flow
Is there any internalization
VERTEBRAL ARTERY

• LOOK AT

Normal or hypoplastic or not seen
Waveform pattern
Direction of flow
PSVs
• **Reversal of flow** – stenosis or occlusion at subclavian or brachiocephalic artery

• **Transient systolic reversal** – in lesser degree stenosis

• **High resistance wave pattern** – distal occlusion or stenosis

• **Low resistance wave pattern** – more proximal stenosis
High resistance vertebral artery

Distal vertebral stenosis
Parvus tardus

Stenosis at vertebral origin - high PSV
Pitfall--

If not seen
?
Occlusion or small or congenitally absent

Clinical correlation and other modality helps
SUBCLAVIAN STEAL SYNDROME

• Subclavian artery steno-occlusive disease proximal to the origin of the vertebral artery.

• Resulting in decreased blood pressure in the arm distal to the steno-occlusive disease.

• Causes ipsilateral vertebral artery blood flow alteration

• Severe stenoses, flow reversal occurs in the ipsilateral vertebral artery as compensatory collateral to the vascular territory beyond the subclavian steno-occlusive lesion.
Subclavian artery stenosis  
Innominate artery stenosis
Classification Based On
Vertebral Artery
Hemodynamics

• reduced antegrade vertebral flow
  (stage I)
• reversal of flow during reactive hyperemia testing of the arm
  (stage II)
• permanent retrograde vertebral flow
  (stage III).
Conversion of a presteal waveform to a complete steal following provocative maneuvers.

at rest

After inflation of a blood Pressure cuff on the left arm and rapid deflation
After inflation of a blood Pressure cuff on the left arm and rapid deflation

at rest
• The blood pressure cuff maneuver induces reactive hyperemia in the distal arm and increases blood flow across the subclavian stenosis, resulting in a complementary pressure drop and change in direction of blood flow in the ipsilateral vertebral artery towards the lower pressure subclavian origin.
Other wave patterns
Mid Systolic Retraction – Pulsus Bisferience
PULSUS BISFERIENCE

“beat twice,”

• Characterized by two systolic peaks with an interposed midsystolic retraction

• Seen in
  AR with or without concomitant AS
  Hypertrophic obstructive cardiomyopathy

• Occasionally, may be seen in healthy, athletic, young individuals or in older patients.
Alternating systolic peak - Pulsus Alternans
PULSUS ALTERNANS

- Alternating peak systolic heights on sequential beats in a regular normal sinus rhythm
- Clinical conditions
  - Intrinsic myocardial disease
  - Ischemia
  - Cardiomyopathies
  - Valvular heart disease
“water hammer pulse”

- In aortic regurgitation – reversed early diastolic flow in both CCAs with elevation of PSV and a sharp systolic upstroke

- Depending on the severity, the reversal of flow may be limited to early diastole with normalization of forward flow in end Diastole or may persist throughout diastole.
Appearance is Bilateral
Large cerebral infarct with uncal herniation
CAROTID DISSECTION
DISSECTION

• **Trauma** - seat belt injury or repetitive trauma.

• Occasionally, spontaneous and isolated to the carotid arteries in Marfan syndrome, Ehlers-Danlos syndrome, fibromuscular dysplasia, hypertension, or drug abuse

• Also - direct extension of an aortic dissection.

• Rare but, dissection of the ICA is the most common cause of stroke in young patients.

• Most ICA dissections occur at the level of the carotid bifurcation.
• Wave pattern is extremely bizarre in configuration: low PSV velocity with a highly irregular waveform contour with many spikes or fluttering with reversed or bidirectional of flow, such that it may be difficult to distinguish systole from diastole

• an intramural hematoma, causing a long-segment tapering of the ICA without a break in the intima

• The residual lumen may be narrowed markedly, creating a “string sign.”
• Thrombosis of the false lumen - mimic stenosis

• The waveform may be indistinguishable from a stenosis except that typically it extends over a much longer segment and often no plaque is visualized.
• The presence of **early diastolic flow reversal in the ipsilateral CCA**

• **Reduced peak systolic and diastolic velocities in the ipsilateral ICA**

    are non-specific, but warrant a search for a cause of increased peripheral vascular resistance.
Hematoma with dissection

Echogenic flap
So -------

What is this ???
Thank you