Peripheral Arterial Disease: Color Doppler Evaluation:

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Overview

Objectives

1. To understand the normal color and spectral Doppler appearance of the peripheral arteries, and their underlying physiology.
2. To recognize the abnormal color and spectral Doppler patterns in peripheral arterial evaluation and their clinical significance.
3. To understand the Doppler criteria for evaluation of the peripheral arteries.

The authors have nothing to disclose.

Upper Extremity Anatomy and Pearls

Borders

Pearls

Major Arteries

- Subclavian artery
- Axillary artery
- Brachial artery
- Ulnar artery
- Radial artery

Focal subclavian stenosis is usually well-compensated via collateral circulation around the shoulder.

Duplicated for all or part of its course in 20% of the population.

May give rise to the persistent medial artery of the forearm (10% of population), which passes through the carpal tunnel.

Lower Extremity Anatomy and Pearls

Borders

Pearls

Major Arteries

- Common femoral artery
- Femoral artery
- Popliteal artery
- Peroneal artery
- Anterior tibial artery
- Posterior tibial artery
- Peroneal artery

Most common site of aneurysm.

May be small or hypoplastic (2%).

Most common site of aneurysm.
Normal diameter of LLE arteries

- Sub-diaphragmatic aorta: 21 – 24 mm
- Infra-diaphragmatic aorta: 17 – 20 mm
- Common iliac artery: 10 – 12 mm
- External iliac artery: 8 – 10 mm
- Common femoral artery: 7 – 9 mm
- Superficial femoral artery: 6 – 8 mm
- Popliteal artery: 4 – 6 mm

Ultrasound Modes

- Grayscale
- Color Doppler
- Spectral Doppler
  - Duplex or Triplex Doppler
- Power Doppler
- B-flow

Used to assess anatomy and to evaluate plaque, wall abnormality, or vascular narrowing.

Simultaneous display of moving blood superimposed on a grayscale image.

Used to assess vascular flow and directionality.

Displays blood flow velocity over time as a waveform.

Duplex and Triplex Doppler refer to the simultaneous display of a vascular waveform on a grayscale image (Duplex), or with the addition of color Doppler (Triplex).

Ultrasound Settings and Technique

- Frame Rate
- Frequency
- Gain
- Doppler Angle
- Pulse Repetition Frequency (PRF)

Power Doppler

- Summation of all Doppler signals caused by moving blood.

Advantages:
- No aliasing
- Detects slow flow
- Less angle dependent

Disadvantages:
- No directional info
- Very motion sensitive

Grayscale Imaging

- Different gray intensities according to the blood speed and dynamics.

Advantages:
- Higher frame rate and spatial resolution than Color Doppler
- No vessel wall overlap

Disadvantages:
- No directional info

Waveform Characteristics

The waveform is a graphic representation of how the blood cells are moving through the vessel.

- PSV: Peak Systolic Velocity
- EDV: End Diastolic Velocity
- SRT: Systolic Rise Time

The normal triphasic waveform has a high velocity systolic flow component during systole, followed by a brief reversal of flow during early diastole due to peripheral resistance, and a final low-velocity forward flow phase in late diastole due to elastic recoil of the vessel wall.
Spectral Doppler Sampling

High-velocity flow at the vessel center and reversed flow at the periphery of the vessel are included in the larger sample volume.

Characteris4c “shoulder” or “knee” on systolic downstroke due to pulse wave reflection from distal obstruction.

Increased spectral width due to turbulent flow within the post-stenotic jet compared to laminar inflow. The maximal flow disturbance occurs within 1 cm beyond the stenosis.

Phase

<table>
<thead>
<tr>
<th>Initial</th>
<th>Biphasic</th>
<th>Monophasic</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV</td>
<td>Normal/Decreased</td>
<td>Normal/Decreased</td>
</tr>
<tr>
<td>Systolic Rise Time</td>
<td>Normal (60-90 ms)</td>
<td>Normal</td>
</tr>
<tr>
<td>Severity</td>
<td>Moderate (&lt; 50%)</td>
<td>Severe (&gt; 50%)</td>
</tr>
</tbody>
</table>
| Notes | Increased resistance reduces forward flow in late diastole | Further increased resistance reduces both early and late diastolic flow. Can be seen in severe acute obstruction. In chronic obstruction, collateral vessels develop that restore diastolic flow. SRT is delayed before PSV drops. Open capillary beds distal to the obstruction allow diastolic flow. The longer the SRT and the lower the PSV, the more severe the obstruction.

“tardus et parvus” “damped”

Waveforms in Obstruction

Pre-obstructive, waveforms show a sharp upstroke, while distally, the upstroke is reduced, or “damped.”

Phase

<table>
<thead>
<tr>
<th>Initial</th>
<th>Biphasic</th>
<th>Monophasic</th>
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</thead>
<tbody>
<tr>
<td>Pre-Obstructive</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Post-Obstructive</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Systolic Rise Time</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Severity</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
</tbody>
</table>
| Notes | Normal PSV and SRT with increased diastolic flow secondary to open capillary beds. Can be seen in exercise, fever, or distal infection. Reciprocal, “to-and-fro” waveform. Velocity and acceleration of antegrade and retrograde components can vary widely. Color Doppler flow will show a pattern of increased and decreased velocity in a “ying-yang” sign. High velocity, low resistance, turbulent waveform. “hyperemic”

Waveforms Related to Cardiovascular Devices

IABP

LVAD

ECMO

Total Artificial Heart

These waveforms will be seen in all vascular beds.

Phase

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</thead>
<tbody>
<tr>
<td>UMBP</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>LUMD</td>
<td>High</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>GOMO</td>
<td>High</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Total Artificial</td>
<td>High</td>
<td>Normal</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Notes | The first peak represents unassisted systole. The second peak represents the diastolic augmentation from the IABP, and flow below the baseline is assisted end-diastolic pressure. Flaps of the IABP allow constant antegrade flow below the baseline. Flow may be entrained into the bubble column. “saw tooth” waveform. High velocity, low resistance, low beat-to-beat variation. "saw tooth" waveform. High velocity, low resistance, low beat-to-beat variation. Increased resistance causes an increase in systolic turbulence with no flow below the baseline. Less common is the non-pulsatile waveform with no systolic peak. There may be variability in systolic augmentation and no flow below the baseline. High velocity, low resistance, low beat-to-beat variation. "saw tooth" waveform. High velocity, low resistance, low beat-to-beat variation. Increased resistance causes an increase in systolic turbulence with no flow below the baseline.

IABP, LVAD, ECMO, Total Artificial Heart
Cardiomyopathy/insufficiency  
Damped waveforms  
Reduced PSV

Aortic stenosis  
Damped waveforms  
Reduced PSV

Peripheral vascular resistance  
Increased and/or decreased PSV

Vessel tortuosity/branching  
Flow disturbance/reversal  
Increased and/or decreased PSV

Ankle Brachial Index (ABI)  

ABI is the pressure measured in the ankle divided by the brachial pressure in the arm with the higher pressure. It is a cost-effective screening method for PAD.

- Normal: ABI ≥ 1.0 or slightly greater
- Mild PAD: ABI 0.6-0.9
- Moderate PAD: ABI 0.4-0.5
- Severe PAD: ABI < 0.4

Ankle Brachial Index (ABI)  

Cystic adventitial disease  

Cystic adventitial disease is a rare condition involving a localized fusiform dilatation of a superficial artery characterized by a fluid-filled space lined by vascular endothelium with or without an associated mural thrombus.
Cys4c	adven44al	disease

• uncommon vascular pathology predominant affecting peripheral vessels
• young to middle-aged individuals without evidence of atherosclerosis or other systemic vascular disease
• Males 15:1
• collection of mucinous material (mucous cysts) within adventitial wall of the affected

Causes of PAD

<table>
<thead>
<tr>
<th>Cause</th>
<th>Most common cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atherosclerosis</td>
<td></td>
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<tr>
<td>Thrombosis or embolism</td>
<td></td>
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<tr>
<td>Aneurysm</td>
<td></td>
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<tr>
<td>Intimal dissection</td>
<td></td>
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<tr>
<td>Pseudo-aneurysm</td>
<td></td>
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<tr>
<td>Arterio-venous fistula</td>
<td></td>
</tr>
<tr>
<td>Arteritis</td>
<td></td>
</tr>
<tr>
<td>Entrapment syndrome</td>
<td></td>
</tr>
<tr>
<td>Cystic adventitial disease</td>
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</tbody>
</table>

Arterial occlusive disease

Acute Proximal Obstruction

CT scan with PMH of squamous cell lung cancer who developed acute LTI- right finger pain and discoloration.

Acute embolic occlusion of the proximal LTI-subclavian artery (arrow)

Downstream there is a tibio of venous waveforms due to lack of flow.

Further downstream, in the radial artery, pulse is decreased due to no flow downstream, flow is maintained.

Waveforms remain damped.
Grading of stenosis

**SFA:**

- PSV of A: 69 cm/sec
- PSV of B: 349 cm/sec
- B/A: 349 / 69 = 5
- > 80% diameter stenosis

**Chronic Proximal Obstruction**

75 YOF with history of diabetes and advanced chronic peripheral vascular disease presents with perforated viscus and hypovolemic shock, with a cool, mottled, pulseless right lower extremity.

- Severe atherosclerotic calcification of the bilateral common iliac arteries, right greater than left (arrow).
- Tardus et parvus waveform in the right iliac artery.
- Absence of flow within the right femoral artery due to total occlusion.
- Severe tardus et parvus waveform in the right popliteal artery.
- Absence of flow within the right femoral artery due to total occlusion.

**Atherosclerotic Disease**

75 YOF presented with left leg pain with ambulation, left heel pain at rest, and left foot cyanosis.

- RLE: Monophasic waveforms with diastolic flow due to high resistance with collateral formation.
- Seen in the setting of chronic atherosclerotic disease.
- LLE: Severe tardus et parvus waveform secondary to chronic left common iliac artery occlusion.

**Acute Distal Obstruction (Arterial Dissection)**

Routine POD C renal transplant ultrasound following uncomplicated LLQ renal transplant.

- High-resistance monophasic waveform in the AR CFA.
- Progressively decreasing PSV.
- Dissection flap (arrow).

Arterial dissection produces nonspecific pre-obstruction waveforms and can only be diagnosed on US when a mobile intraluminal flap is visualized on grayscale.

- Full: monophasic waveform with diastolic flow and high resistance with collateral formation. Seen in the setting of chronic atherosclerotic disease.

**Ultrasound**

- Ultrasound: Tardus et parvus waveform secondary to chronic left common iliac artery occlusion.
Complete occlusion with steal

Acute Stent Occlusion

Bypass Graft Origin Stenosis

Abscess of Synthetic Bypass Graft

70 YOM presents with history of PVD and right femoral-popliteal bypass graft presents with acute RLE pain and swelling.

Triphasic waveform in the CFA
Monophasic waveform in SFA
Decreasing PSV in SFA
No flow within stent

Tardus et parvus waveform distal to the stent
Stent occlusion on angiography

70 YOM with history of PVD and right femoral-popliteal bypass graft presents with acute RLE pain and swelling.

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Monophasic waveform in SFA
Decreasing PSV in SFA
No flow within stent

Tardus et parvus waveform distal to the stent
Stent occlusion on angiography

Bypass Graft Origin Stenosis

74 YOM with PVD status post bilateral femoral-popliteal bypass.

Stenosis of the origin of the saphenous vein bypass graft (arrow) due to fibroinflammatory hyperplasia. Grayscale and color Doppler demonstrate approximately 50% stenosis. Grayscale and color Doppler demonstrate approximately 50% stenosis. Note that the anastomosis is artificially enlarged. This "patulous" appearance is purposeful, intended to permit ingrowth of hyperplastic tissue without necessarily causing a stenosis.

Abscess of Synthetic Bypass Graft

64 YOM with left femoral-popliteal bypass who presents with a swollen, erythematous, painful leg.

"Shaggy-walled" fluid collection with layered debris surrounding the bypass graft consistent with abscess.
Acute Arterial embolus

34 YOF with atrial fibrillation who presents with pain and numbness in right upper extremity. Progressive high-resistance flow proximally with no flow in occluded region.

Post embolectomy

Acute Arterial embolus

32 YOF with atrial fibrillation who presents with pain and numbness in right lower extremity.

Traumatic Arterial Injury

32 YOF with decreased RUE pulses status post humerus fracture.

"Kissing" or "kneeling" with the systolic downstroke reflects distal obstruction.

Traumatic injury the shoulder with no visualization of the proximal brachial artery secondary to laceration.

Tardus et parvus waveforms distal to the injury.

32 YOF with decreased RUL pulses status post humerus fracture.

Tardus et parvus waveforms distal to the injury.
Acute Arterial injury
28 YOM with MVC
Dissection - iatrogenic (ECMO explant)

Popliteal artery dissection

Popliteal artery dissection
Compartment Syndrome

A 78-year-old patient with multiple comorbidities presents with severe LUE cellulitis. The presence of distal obstruction is suggested by the characteristic "shoulder" or "knee" waveform during diastole (solid arrow). This is observed when distal flow delays appear, which is seen with arterial obstruction to the artery near to the distal site apparent in a forming or non-compressible aneurysm.

The waveform is compartment syndrome with complete diastolic retrograde flow can appear similar to the "to-and-fro" waveform of a pseudoaneurysm.

Compression Device

A 57-year-old ICU patient with LLL weakness following angiogram with LE venous compression devices in place during exam. High-resistance monophasic waveforms with declining PSV approaching the compressed right calf.

Arteriovenous fistula (AVF)

A 76-year-old patient presents with right groin swelling following electrophysiology ablation procedure via right femoral puncture 6 days ago. Femoral artery to common femoral vein AVF, with high-velocity, low-resistance waveform noted. CTA shows high attenuation within the inferior vena cava, femoral vein, and right common femoral vein, confirming femoral artery (dashed arrow) and AVF.

AVF
Popliteal Aneurysm

70 YOM with leg swelling presents for DVT study.

Fusiform popliteal aneurysm with intra-aneurysmal thrombus outlined in yellow on the first image. The patent lumen is seen as color flow.

B-flow demonstrates the patent lumen on axial imaging.

When a popliteal aneurysm is found, the abdominal aorta should also be evaluated. 40% of patients with a popliteal artery aneurysm also have a AAA.

Aneurysms

Aneurysms

Pseudoaneurysm

50 YOM status post right femoral artery reperfusion therapy for LVAD pump thrombosis.

ICA and color Doppler images show a characteristic “to-and-fro” pattern. Note the presence of a wide variation in the “to-and-fro” pattern that can be seen.
CFA pseudoaneurysm

Reduced Cardiac Output

25 YOF presented with septic shock secondary to gangrenous cholecystitis, found to have loss of pulses in the bilateral upper extremities following decrease in vasopressors.

Pulmonary edema in the setting of septic shock.

Slightly damped, primarily biphasic waveforms with decreased PSV throughout the upper extremities bilaterally, consistent with reduced cardiac output (dampening) and open capillary beds (loss of late diastolic flow).

Similar findings in multiple vascular beds suggests cardiac dysfunction.

Severe Aortic Regurgitation

20 YOF with sepsis and pericarditis found to have pulseless, cyanotic arms.

There are two systolic peaks due to maximal systolic aortic regurgitation during diastolic period. During diastole there is regurgitation flow, while in early systole aortic regurgitation flow is not seen.

Cardiovascular support devices
Intra-aortic Balloon Pump Waveforms

The IABP provides temporary left ventricular support by mechanically displacing blood within the aorta to augment early diastolic flow, thereby improving coronary perfusion.

The first peak represents unassisted systole. The second peak represents the diastolic augmentation from the IABP, and flow below the baseline is from balloon deflation (assisted end-diastole).

Intra-aortic Balloon Pump (IABP)

Two peaks of forward flow are present. The first peak is the unassisted systolic flow from the LV contraction. The second peak is diastolic augmentation secondary to inflation of the IABP balloon.

LVAD Waveforms

The Doppler waveform present in the setting of a LVAD depends on:
1. the type of LVAD (1st, 2nd, 3rd gen, pump design)
2. the patient's residual myocardial function
3. device flow settings (L/min)
4. the artery being evaluated

Monophasic waveforms seen in the setting of 2nd and 3rd generation CF-LVADS with axial pump design. These 3 waveforms were sampled from the femoral artery in patients with different degrees of residual myocardial function, accounting for the difference in pulsatility. In some cases, flow below the baseline can be seen.

Left Ventricular Assist Device (LVAD)

70 YOM presents with history of PVD and right femoral-popliteal bypass graft presents with acute RLE pain and angling.

Monophasic tardus et parvus waveforms.

The systolic peak is thought to be due to increased residual myocardial reserve pumping some of the blood. Less commonly there may be non-pulsatile flow with no systolic peak.
Nonpulsatile, monophasic waveform in a patient with the same device and less residual myocardial function.

Increased pulsatility of Heartmate III CF-LVAD with centrifugal pump design relative to Heartmate II CF-LVAD with axial pump design.

Monophasic, high-flow, low resistance waveform with rapid rise or rise and demonstrate systolic pulsatility.

High-flow, low resistance waveforms with minimal systolic pulsatility secondary to patient’s myocardial reserve.
“Saw tooth” waveforms are seen in bilateral lower extremities from artificial heart. A slight “blip” in the waveform is seen at the start of systole corresponding to the opening of the inflow valve and the opening of the outflow valve.

39 YOM with Arrhythmogenic Right Ventricular Dysplasia status post TAH implant.

Total Artificial Heart (TAH)

The SynCardia Total Artificial Heart replaces both failing ventricles and all four heart valves. It is used for biventricular circulatory support as a bridge to heart transplantation.

Comparison of Modalities

<table>
<thead>
<tr>
<th>Modality</th>
<th>No. of studies</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE MRA</td>
<td>14</td>
<td>&gt;70-90%</td>
<td>&gt;65-97%</td>
</tr>
<tr>
<td>DE TOF MRA</td>
<td>11</td>
<td>&gt;70-90%</td>
<td>&gt;65-97%</td>
</tr>
<tr>
<td>CTA</td>
<td>7</td>
<td>&gt;70-90%</td>
<td>&gt;65-97%</td>
</tr>
<tr>
<td>Doppler US (DUS)</td>
<td>28</td>
<td>&gt;70-90%</td>
<td>&gt;65-97%</td>
</tr>
</tbody>
</table>

Notes:
- Use MRA when:
  - Patient is allergic to iodinated contrast
  - To avoid ionizing radiation
  - Excessive vessel calcification, especially small vessels, subclavian Imaging of outflow vessels assist to segment many DOX
  - Occult endoleak

Use CTA or DUS when:
- Patient is claustrophobic
- Lesions are not evaluated in MRA
- Vessels are not evaluated in X-ray
- Determination of steal/leak desired

References

Thank you

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