EXTREMITY ARTERIAL PHYSIOLOGIC TESTING

Indications and Contraindications:

<table>
<thead>
<tr>
<th>Claudication</th>
<th>Unspecified limb pain</th>
<th>Vasospastic disease</th>
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<tbody>
<tr>
<td>Digital embolization</td>
<td>Digital occlusive disease</td>
<td>Limb trauma</td>
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</table>

Limitations:

1. Presence of open wounds, fresh incisions or skin staples, casts or devices that limit access to limb segments.
2. Patient factors (ability to cooperate or body habitus)

Instrumentation: (Items 1-6 may be contained in a commercial modular system)

1. Appropriately-sized blood pressure cuffs (the width of the blood pressure cuff bladder should exceed 20% of the diameter of the limb segment that it will encompass).
2. Sphygmomanometer
3. Bi-directional Continuous-wave Doppler velocimeter (5 MHz, 8 MHz)
4. Strip chart recorder (zero crossing recorder)
5. Air plethysmography
6. Photoplethysmography
7. Treadmill

Patient Preparation and Positioning:

1. Patient position may be supine, prone, or lateral decubitus to allow access to limb arterial segments.
2. Patient’s head may be slightly elevated on a pillow for comfort.
3. Patient’s heels should be slightly elevated on rolled towel or pillow to allow air to fill blood pressure cuffs.

Technical Components:

Ankle-Brachial Index (ABI)

a. Apply appropriately-sized blood pressure cuffs to both ankles and both upper arms.
b. Using a continuous-wave (CW) Doppler, obtain arterial signal over the right brachial artery.
c. Inflate the blood pressure cuff to supra-systolic pressure to occlude the brachial artery.
d. Using slow (2-3 mmHg/sec) deflation rate, note the pressure at which the arterial signal is again heard. Record the brachial systolic pressure.
e. Repeat the procedure for the left arm.
f. Using the CW Doppler, obtain the anterial signal for the right dorsalis pedis (DP) artery. Record the Doppler waveform from the DP artery and retain.

g. Inflate the blood pressure cuff to supra-systolic pressure to occlude the dorsalis pedis artery.

h. Using slow (2-3 mmHg/sec) deflation rate, note the pressure at which the arterial signal is again heard. Record the DP systolic pressure.

i. Repeat the procedure for the posterior tibial (PT) artery.

j. Repeat the procedure for the left DP and PT arteries.

k. Calculate the ankle-brachial index.

**Segmental Systolic Pressure Measurements**

a. Apply appropriately-sized blood pressure cuffs to the high thigh (HT), above knee (AK), and below knee (BK) segments of the lower limb.

b. Using either the DP or PT artery, obtain segmental limb pressures at HT, AK, BK and ankle level, beginning at the ankle, in a manner identical to that used for obtaining ankle pressures for the ABI.

c. Record pressures for each segment.

d. Repeat the procedure for the contralateral limb.

**Pulse Volume Recording (PVR)**

a. Apply appropriately-sized cuffs to the thigh, proximal calf and ankle segments of the lower limb.

b. Following manufacturer’s instructions, inflate the cuffs to a pressure exceeding 65 mmHg and note that they are balanced. Also determine that the volume of air in the cuff bladder is balanced (within 15%) side-to-side.

c. Simultaneously, record the pulse volume waveforms from both lower extremities taking care that the Gain is set at the same level for all limb segments.

**Photoplethysmography (Toe-Brachial Index)**

a. Apply photoplethysmographic (PPG) sensors to the great toe using clear double-stick tape. Alternatively, the sensors can be held adjacent to the skin of the toe with commercially-obtained clips. Be certain that the clip allows the sensor to be housed within the clip and not one that compresses the clip.

b. Adjust the system gain so that arterial waveforms are distinct and that system noise is minimized.

c. Record PPG arterial waveforms from the tissues of the great toes.

d. Apply an appropriately-sized digital blood pressure cuff to the base of both great toes.

e. Inflate the cuff to suprasystolic pressures to occlude the digital arteries.

f. Deflate the cuffs slowly to obtain return of digital waveforms. Record digital pressures.
**Constant-load Treadmill Exercise Study**

a. Apply appropriately-sized blood pressure cuffs to the ankles.
b. Instruct the patient on how to walk on the treadmill
c. The test is generally performed at a speed of 2 mph and 12% elevation but may be adjusted to a slightly lower speed and elevation for a given patient.
d. The patient walks until lower extremity symptoms occur but no longer than 5 minutes.
e. Post-exercise ankle pressures are obtained immediately post-exercise and at 3-minute intervals using the tibial artery (DP or PT) with the highest pre-exercise pressure until the baseline pressure value is achieved.
f. Record: post-exercise pressures, duration of exercise, length of time required for pressures to return to baseline values and location of limb pain (buttocks, thigh, calf, ankle, foot).

**Diagnostic Criteria:**

**Ankle-Brachial Index (ABI)**

<table>
<thead>
<tr>
<th>Disease Type</th>
<th>ABI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1.0 - 1.4</td>
</tr>
<tr>
<td>Minimal disease</td>
<td>0.9 - 1.0</td>
</tr>
<tr>
<td>Moderate disease</td>
<td>0.5 – 0.9</td>
</tr>
<tr>
<td>Severe disease</td>
<td>0.3 – 0.5</td>
</tr>
<tr>
<td>Critical ischemia</td>
<td>&lt; 0.2 – 0.3</td>
</tr>
</tbody>
</table>

**Toe-Brachial Index (TBI)**

<table>
<thead>
<tr>
<th>Condition</th>
<th>TBI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&gt; 0.8</td>
</tr>
<tr>
<td>Claudication</td>
<td>0.2 – 0.5</td>
</tr>
<tr>
<td>Rest Pain</td>
<td>&lt; 0.2</td>
</tr>
</tbody>
</table>

**Segmental Systolic Pressure Measurements**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Systolic Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt; 20 mmHg</td>
</tr>
</tbody>
</table>

Ankle pressure is normally greater than brachial pressure (See ABI Interpretation)

Critical ischemia is suspected when absolute ankle pressure is less than 40 mmHg in non-diabetic patients.
High thigh pressure is normally 30-40 mmHg higher than brachial pressure.

High thigh (HT) to above knee (AK), above knee to below knee (BK), and below knee to ankle pressure gradients are normally less than 20-30 mmHg.

Toe pressure is normally 80% of systemic (brachial) pressure.

**Pulse Volume Recording (PVR)**

Normal PVR waveform components have

- Rapid systolic upstroke
- Dicrotic notch (reflected wave) on the deceleration slope
- Rapid diastolic run-off

Proximal flow-limiting lesion –

- delayed systolic upstroke
- rounding of systolic peak
- loss of dicrotic notch
- reduced amplitude
- delayed run-off

Distal flow-limiting lesion –

- rapid systolic upstroke
- loss of dicrotic notch
- delayed run-off

Multi-segmental flow-limiting disease –

- dampening of the waveform
- loss of amplitude
- delayed systolic upstroke
- delayed diastolic run-off

**Constant-load Treadmill Exercise Testing**

- Normal – No significant decrease in ankle pressure compared to the baseline pressure. Normally, there is a slight increase in ankle pressure post-exercise.

- Return to baseline pressure within 3-5 minutes = Single-segment flow-limiting disease.
• Multi-segmental disease = Inaudible arterial signals or ankle pressures; less than 60 mmHg for up to 10 minutes.

UPPER EXTREMITY ARTERIAL PHYSIOLOGIC STUDIES

Segmental Systolic Pressure Measurements

a. Most often, a four-cuff procedure (upper arm, forearm, wrist, and digit)
b. Normal pressure gradients between adjacent cuffs is < 20 mmHg
c. Significant arterial lesion is suspected when the pressure gradients exceeds 30 mmHg.
d. Low brachial pressure suggests an innominate, subclavian, axillary or proximal brachial lesion. (Note: Consider possibility of subclavian steal on the side with the lower brachial pressure).

Pulse Volume Recording

a. Used to detect arterial occlusive disease in the arm and digits
b. Most commonly a four-cuff technique as used for segmental systolic pressure measurements.
c. Interpretation of PVR waveforms is subjective, as noted above.

Photoplethysmography

a. Most commonly used for detection of palmar arch and digital disease.
b. A finger-brachial index (FBI) > 0.8 is considered normal. (Note: Calculate the FBI using the ipsilateral brachial pressure, not the highest brachial pressure.)
c. Ischemia is suggested by wrist to digit pressure gradients equal to 30 mmHg or greater and digit-to-digit pressure gradients exceeding 15 mmHg.

NOTE: There are a number of upper extremity arterial specialty examinations which employ the techniques described above. To exclude the possibility of an inflow arterial lesion (innominate, subclavian, axillary, brachial), it is important to obtain segmental pressures and PVRs prior to performing any of the digital examinations.

Testing for Vasospasm –

• Digital arterial spasm attributed to Raynaud’s disease (primary Raynaud’s; digital cold sensitivity) and Raynaud’s phenomenon (secondary Raynaud’s; vasospasm with fixed arterial obstruction).
• Plethysmographic waveforms demonstrate a “peaked pulse” morphology. An anacrotic notch (apparent on the systolic upstroke), and the dicrotic notch (apparent on the deceleration slope) are clustered near the systolic peak.
• Testing is performed at ambient room temperature and following 20 second immersion of the digits in an ice water bath.
Pressure measurements, pulse volume recording and digital thermometry are noninvasive procedures of choice.

**Palmar Arch Patency Analysis (Allen Test)** –

- Commonly performed prior to radial artery harvesting, dialysis access placement, or when occlusion of the arteries distal to the wrist is suspected.
- Arterial flow is sensed at digital level. Sensors of choice include photoplethysmography (PPG), pulse volume recording and CW Doppler.
- Digital waveforms are recorded using a chart recorder speed of 2 – 5 mm/sec. when using PPG sensors.
- Place PPG sensors on the thumb and little finger. Record baseline waveforms with the hand and digits relaxed.
- Simultaneously compress the radial and ulnar arteries – the waveform should become non-pulsatile, i.e., flatline.
- Release compression of the radial artery – the waveform should return to pre-compression morphology.
- Simultaneously compress the radial and ulnar arteries as before. Note loss of arterial pulsatility.
- Release compression of the ulnar artery. Note waveform morphology as before.
- Complete palmar arch – Return to baseline morphology with release of either the radial or ulnar artery.
- Incomplete palmar arch with radial artery dominance is suggested when PPG pulsatility is reduced by more than 50% of the baseline amplitude or the waveform becomes non-pulsatile when compression of the ulnar artery is released.
- An incomplete arch with ulnar artery dominance is suggested when PPG pulsatility is reduced by more than 50% of the baseline amplitude or the waveform becomes non-pulsatile when compression of the radial artery is released.

**Thoracic Outlet Syndrome (TOS) Analysis**

- Used to diagnose compression of the subclavian artery in the thoracic outlet. The artery may be compressed by the clavicle, cervical rib, or scalenus muscle.
- Compression of the artery is documented by reduction in arterial pressure or dampening of arterial waveforms distal to the thoracic outlet. Commonly the test is performed using PPG sensors to document arterial flow at digital level.
- The study is performed with the head and shoulders in a neutral position and during provocative maneuvers (Adson, Costoclavicular, Hyperabduction, Symptomatic position).
• Using PPG sensors attached to a digit and a chart recorder speed of 2 – 5 mm/sec, record digital waveform with the patient maintaining a neutral position of the head, arms, and hands.
• In turn, record the PPG waveforms while the patient performs the following maneuvers: Adson (both right and left), costoclavicular, 180 degree arm hyperabduction, 90 degree arm hyperabduction, and while the arm is held in the position which causes symptoms.
• Normal response – No change or an increase in waveform amplitude
• Abnormal – loss of waveform amplitude exceeding 50% compared to baseline amplitude or flatline suggests subclavian artery compression and TOS.
• NOTE: Approximately 25% false positive studies have been documented.

References:

