Non-invasive examination

Segmental pressure and Ankle-Brachial Index (ABI)

The segmental blood pressure (SBP) examination is a simple, noninvasive method for diagnosing and localizing arterial disease. This method was first introduced by Winsor in 1950[14] and still remains a very sensitive indicator of arterial disease. Typically, pressure cuffs are placed around the patient's ankles, below the knee (BK), above the knee (AK) and at one or more locations in the thigh. The SBP may be obtained using standard pneumatic cuffs with a hand-held aneroid manometer. However, considering the time involved for multiple measurements, in some clinical settings where multiple cuffs are used, is may be advisable to use an automated, computerized system. In addition to multiple pressure measurements, a full SBP examination also includes obtaining and evaluating Doppler waveforms at various levels in the leg usually in the pedal, popliteal, superficial femoral and common femoral arteries. SBPs are not a routine part of the protocol presented in this paper. Instead, clinical symptomatology and pulse palpation direct the examiner's attention to the most likely segment, or level, of disease in the arterial tree.

Ankle Brachial Index (ABI) Calculation	
$\frac{\text{Ankle systolic pressure}}{\text{Brachial systolic pressure}}$	= ABI

The ankle-brachial index (ABI) is a simple, reliable index that is essentially free of technical artifacts and that defines the severity of arterial disease in the lower extremities quickly, inexpensively and relatively easily. It is simply the ratio between the systolic pressure in a pedal artery (dorsalis pedis (DP), posterior tibial (PT), lateral malleolar (LM)) to the systolic pressure in the arm (brachial artery). The ratio equation is shown in the accompanying text box. Each ankle systolic pressure is divided by the highest brachial systolic pressure to obtain this ratio. The normal ABI value is one or slightly greater ($\geq$ 1.0); an abnormal value is anything less than one ($<$1.0).[15]

The brachial systolic pressure is used as the reference standard and is used to calculate the ABI. Systolic pressure recordings should be obtained from both arms, and the higher value becomes the standard. A pneumatic cuff is placed on the upper arm, and a continuous wave (CW) Doppler probe is placed over the brachial or radial artery. The pneumatic cuff is inflated above the systolic pressure, at which time the Doppler signal disappears. The cuff is then allowed to slowly deflate until the Doppler signal re-appears. When the Doppler signal re-appears, the systolic pressure is recorded.

Both right and left brachial systolic pressures should be obtained in all patients when possible. There should be no more than 10 mmHg difference in the brachial systolic pressures. If the difference exceeds 10 mmHg, the side with lower pressure indicates a possible stenosis or occlusion of the ipsilateral innominate, subclavian, axillary, or proximal brachial artery. In this situation, a carotid ultrasound examination, which includes duplex evaluation of the subclavian and vertebral arteries, is required to look for occlusion, stenosis or vertebral steal patterns.[16]

After the brachial systolic pressures are taken, the lower extremity systolic pressures are obtained in a similar manner. The cuff is placed around each ankle about 3 fingers-breadth above the inferior margin on the lateral malleolus. CW Doppler is used to locate the strongest signal in the ankle (DP or PT) and, the pressure is taken as described above.

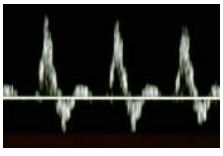
There are two divisions in the abnormal ranges, classified according to patient symptoms and abnormal ABI values as follows:

- ***Claudication (ABI 0.6 to 0.9).*** Claudication is seen in moderate stenosis and occlusive states. Claudication presents as intermittent pain associated with exercise. This condition is due to the inability of the collateral circulation to meet the needs of the exercising muscle. Thus, all patients whose ABI ranges from 0.6 to 0.9 should have systolic pressure measurements taken after exercise. Stress or exercise testing is also indicated in those patients who are symptomatic but in whom pressure measurements are borderline or normal under resting conditions. The ABI in these patients usually ranges from 0.9 to normal at rest.
- ***Severe occlusive states (ABI <0.5).*** If the ABI is 0.5 or less, there is no need for exercise testing. Doppler waveform analysis is performed to complete the examination and to correlate with the segmental pressures. The ABI defines the severity of the disease, whereas the segmental pressures localize the area of involvement.[17]

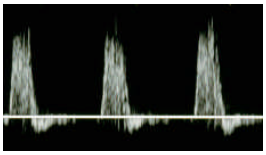
Doppler waveforms

Doppler waveforms obtained from normal peripheral arteries are ***triphasic*** in nature and represent three distinct flow components: an initial, rapid upsweep to peak systolic velocity (PSV); a small flow reversal in early diastole; and a final forward flow in late diastole. Triphasic waveforms are normally obtained from the common and superficial femoral, popliteal, posterior tibial, and dorsalis pedis arteries in the normal non-vasoconstricted lower extremity at rest.

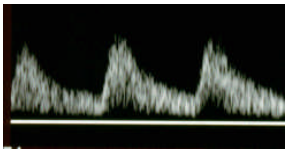
As the atherosclerotic disease process begins to diminish the elasticity and compliance of the arterial wall, the Doppler waveform becomes ***biphasic*** with a loss of the flow reversal in early diastole. Late diastolic forward flow is maintained. As the disease progresses, blood flow becomes ***monophasic*** with both the early and late diastolic phases absent and only the systolic forward component present. These waveform changes are summarized along with other duplex criteria for grading arterial stenosis in Table VII below.



Triphasic



Biphasic



Monophasic

Exercise testing

Exercise testing (sometimes referred to as stress testing) should be performed in all patients when the ABI is consistent with claudication. It is especially beneficial in patients with borderline pressure values at rest but who present with symptoms strongly suggestive of claudication. Patients with mild to moderate atherosclerotic disease typically have sufficient collateralization and dilatation of the arteries so that the ABIs may measure slightly low to normal (0.8 – 1.0). However, with exercise, the increased perfusional demands of the calf muscle and the increased resistance of the distal extremity vessels will exceed the supply capability of arterial flow, resulting in a significant decrease in the pressure value.

Exercise testing can be performed by having the patient walk or use a treadmill with a 12° grade moving at 2 miles per hour. The patient walks for 5 minutes or until the pain or familiar leg symptoms occur. It is recommended that electrocardiogram monitoring be performed if treadmill testing is used and, therefore, this method of stress testing may not be suitable in many ultrasound laboratories. A simple and effective alternative exercise that induces claudication in most patients with peripheral arterial disease, and does not require cardiovascular monitoring, is “toe-ups” or “toe-raises”. The patient is instructed to stand on the floor, bracing him/herself against a chair or counter and raising up and down briskly on his/her toes. The time it takes for symptoms to first appear is recorded and, in the author’s experience, typically occurs well before 5 minutes of this type of exercise.

Immediately following the exercise period, ABIs are repeated. It is important to re-measure the arm with the highest brachial pressure as it may raise several mmHg after exercise. In the normal response to exercise, there is usually no significant drop in the ABI. There may even be elevation in the pressure measurement. The abnormal response to exercise testing is a noticeable decrease in the ABI (<0.8). Such a drop in pressure is an indicator of the presence of PAD and helps confirm or refute the patient’s complaints of claudication.

Time-sequential ankle pressures taken after exercise add a further dimension in the assessment of the severity of peripheral arterial disease. They are obtained, initially at 30-second intervals for the first 4 minutes and then every minute until the pressure measurement returns to normal or to the pre-exercise level. Two ankle pressure cuffs are extremely useful in obtaining sequential ABIs. In cases of severe occlusive disease, it may take 30 minutes or longer for pressures to return to normal; however, 10 to 15 minutes is sufficient recording time to evaluate vascular status. Any drop in pressure is an indicator of significant disease, and the degree of impairment will be reflected in the time it takes for the pressure to return to normal. Usually, when a single level of disease is present, the pressure will return to normal values within 2 to 6 minutes. With multiple levels of disease, it takes up to 12 minutes for pressures to return to normal. In a patient with a severe occlusive state, it may take up to 30 minutes or longer for pressures to return to normal.[18] See Table VI.

Triplex Imaging

Color Doppler Imaging (CDI) has become an integral part of the non-invasive diagnosis and evaluation of peripheral vascular disease. In addition to providing two-dimensional gray scale images of the gross morphology of the arterial tree, CDI permits easy and accurate evaluation of flow patterns and hemodynamic status within selected segments of vascular structures in the lower extremity. This makes CDI, as an adjunct to well-established physiologic and Doppler examination techniques, an important component in increasing the sensitivity of ultrasound examination of the lower extremity and in reducing examination time and complexity.[19 20]

Duplex arterial testing has been proven to be a highly sensitive, specific and accurate method of assessing the patient with peripheral arterial disease (PAD) and in many cases can be obviate the need for angiography in patient's considering interventional or surgical treatment. [21 22 23] Duplex ultrasound is a reliable method of helping in the selection of treatment modalities for patients with infrainguinal PAD and is also an effective method of post-operative infrainguinal graft surveillance and in the detection of pseudoaneurysms. [24]

The primary utility of duplex imaging in patients with PAD is to:

- Distinguish between a stenosis and a complete occlusion in a vessel;
- Establish the length of the disease segment in an artery;
- Assess patency of the distal vessels for use as possible target sites for distal graft anastomosis;
- Evaluate the results of intervention (angioplasty, stent placement);
- Diagnose aneurysms and post-operative pseudoaneurysms;
- Monitor a patient's postoperative course with regular interval bypass graft surveillance.

Method

The technique of lower extremity duplex imaging has been described in detail by many authors and is beyond the scope of this paper to repeat in full.[25 26] However, there are several important points that must be considered when incorporating duplex into a patient evaluation algorithm:

- The examination is begun in a longitudinal plane of section in the groin over the common femoral artery (CFA) and proceeds caudad through the superficial femoral, popliteal, tibio-peroneal trunk, and anterior and posterior tibial arteries to the foot.
- When CDI indicates an area of unusual flow dynamics, such as turbulence, color bruit, or high velocity jets, spectral Doppler interrogation should be performed and peak systolic velocities (PSV) should be obtained:
    a. Cephalad (upstream) to the flow disturbance
    b. At the flow disturbance, in the area of maximum flow velocity
    c. Distal to the flow disturbance, assessing degree of post-stenotic turbulence

- Spectral waveforms are obtained from a longitudinal plane of section employing careful angle correction technique and are used to estimate the degree of stenosis in all arterial and graft segments and . Diagnostic criteria are presented in Table VII.[27 28] Cross-sectional or longitudinal residual diameter measurements with or without the use of CDI are notoriously inaccurate and do not correlate well with contrast angiographic findings.
- In patients with a significant SFA stenosis or occlusion, flow into the popliteal artery should be examined with CDI to determine degree and integrity of flow reconstitution. This helps the surgeon determine whether an infrainguinal bypass graft may be anastomosed as a fem-pop bypass or whether a fem-distal technique is required for limb salvage.
- Presence or absence of collateral flow should be noted. Common sites where collateral vessels may be identified are in the groin and hip area in patients with inflow disease) aortoiliac) or around the knee in patients with outflow (femoral artery) disease. This frequently requires CDI system sensitivity to be set for detection of low flow states. (Low baseline, low velocity detection level (threshold), low amplitude enhancement)
- Duplex examination of an infrainguinal bypass graft (femoral-popliteal, femoral-tibial, etc.) is similar to that of native vessels. The graft is scanned longitudinally in its entirety from proximal to distal anastomosis. CDI is used to identify areas of significant flow disturbance and spectral waveforms are obtained as noted in item 3 above.

Table VII
Duplex criteria for grading arterial stenoses

	Peak systolic velocity (PSV)	**Spectral waveform**
Normal	70-100 cm/sec	Triphasic
<50% stenosis	30-100% increase over proximal segment	Triphasic
>50% stenosis	>100% increase over proximal segment	Monophasic Turbulent
>75% stenosis	PSV >400cm/sec Pre-stenotic:stenotic ratio; >4:1	Monophasic High velocity Bruit may be heard
Occlusion	Absent flow Collaterals may be seen adjacent	Dampened proximal to occlusion
Aortoiliac disease	PSV in CFA $\leq$ 45cm/sec[29]	Monophasic