Recommendations. PVRs are ideal for evaluating segmental disease and are not affected by calcification. They should be considered as part of a complete noninvasive examination.

Continuous-Wave Doppler Waveforms

Doppler waveform analysis should be performed at multiple segments, including the common femoral artery, popliteal artery, at the ankle over any of the trifurcation vessels, and over the dorsum of the foot. It is most important to perform this over the common femoral artery, and this should be considered a necessary part of the noninvasive examination. The common femoral Doppler waveform analysis is often performed in conjunction with PVRs. Because upper thigh PVRs cannot distinguish proximal superficial artery disease from common femoral artery or iliac inflow disease, the common femoral Doppler waveform plays a critical role in localizing disease. An abnormal upper-thigh PVR waveform with a normal triphasic common femoral Doppler waveform indicates proximal superficial femoral artery disease, whereas an abnormal upper-thigh PVR waveform with an abnormal common femoral Doppler waveform indicates aortoiliac disease. Errors in interpretation can occasionally occur as a result of the variability in location of the common femoral artery in relation to the groin; Doppler US is the most precise modality to evaluate the common femoral artery.

A normal arterial Doppler waveform in the lower extremity has a high resistance pattern and is triphasic. The dip below baseline reflects the high resistance characteristic that distinguishes this waveform from the classic low-resistance waveform that may be seen in the internal carotid artery. The triphasic components consist of a sharp systolic upslope, a reversal of flow below baseline, and then a short forward flow component in late diastole. With mild disease, the waveform becomes biphasic with loss of the late diastolic forward flow component of the waveform. With more severe disease, the waveform becomes monophasic with loss of the flow reversal. The waveform will flatten and become rounded, with a slower upstroke and downstroke creating the classic postobstructive tardus parvus signal.

Doppler waveforms have limitations that include difficulty in reproducibility based on the angle of insonation. The angle of insonation can alter the waveform morphology and can lead to discordant information. Another limitation of Doppler waveform analysis occurs when disease is present in a proximal segment and the waveform becomes abnormal, as in tandem stenoses or occlusions. In such cases, the test is not as reliable for detecting disease distally. For this reason, Doppler waveform analysis is a poor test to detect multilevel disease. This component of the noninvasive examination is therefore less valuable than PVRs, and, in many laboratories, Doppler waveforms are obtained only at the common femoral artery.

Recommendations. Continuous-wave Doppler analysis should be performed at multiple segments when assessing the lower extremities for PAD. Continuous-wave Doppler analysis should be available as part of a complete noninvasive examination.

Exercise Testing

Exercise testing is a necessary requirement for noninvasive testing in patients with claudication. Testing can be performed on a treadmill with a standardized protocol. If a treadmill is unavailable, walking tests may be performed (even though treadmill testing is the best way to ensure reproducibility and accuracy).

The purpose of exercise testing is twofold. First, it confirms that the patient's symptoms are the result of vascular occlusive disease. Second, it can unmask disease not detectable at rest. It is common to see patients who have normal ABIs at rest and have significant decompensation after exercise. Therefore, the ABI should be measured at rest and after exercise if resting ABI is normal. Many vascular laboratories repeat the ABI and ankle PVR after exercise. The postexercise ankle ABI and the postexercise PVR are important components of the noninvasive examination.

The Gardner protocol is the most common exercise protocol for noninvasive testing. It uses a constant speed and constant grade on a treadmill. Patients walk for 5 minutes on the treadmill or until symptoms limit ambulation. This is performed on a 12° incline at 2 mph.

Recommendations. Exercise testing is useful to assist in the diagnosis of PAD in patients with claudication, and should be available as a component of the evaluation because it unmasks PAD not evident at rest. Exercise testing is mandatory in all patients with normal resting examinations who have exertional symptoms. Exercise testing can also be used as a part of surveillance testing in posttherapeutic PAD patients.

SUMMARY OF STANDARD TESTING MODALITIES

There are a number of modalities that can be used to assist in the diagnosis of PAD. Each modality has inherent advantages and disadvantages. The practitioner must be aware of the limitations of each and understand their respective strengths and weaknesses for various clinical subscenarios of PAD presentation. These modalities can also be used in posttherapeutic surveillance of the lower extremities. A complete noninvasive examination includes an ABI as well as PVRs at all levels. At a minimum, Doppler waveform analysis of the common femoral artery should be performed. Exercise testing should be available as part of the noninvasive examination when indicated. Segmental pressures and segmental Doppler waveforms may be added to provide additional information.

ANCILLARY NONINVASIVE TESTS

Reflection Photoplethysmography

Reflection photoplethysmography uses peripheral blood volume pulsation by temporally detecting skin-backscattered optical radiation. Contact probes can be placed at various anatomic positions, including fingertips, earlobes, forearms, and toes. The arterial compliance is measured by using the heartbeat pulse-wave transit time. A pulse-wave transit time average delay in the range of 23 ms $\pm$ 9 can be used as the diagnostic threshold for lower-extremity arterial stenosis, with high reliability at more than 32 ms (19). It has also been suggested that photoplethysmography has greater sensitivity in assessing patients with diabetes and chronic renal failure for PAD compared with Doppler ABI testing (20).

Recommendations. Reflection photoplethysmography has utility in patients PAD and should be considered in the diabetic and chronic renal failure PAD subgroups.

Oxygen Tension

Oxygen plays a central role in wound healing. Tissue hypoxia has been shown in wounds that do not heal adequately (21–23). Transcutaneous oximetry estimates the partial pressure of oxygen on the skin surface by using noninvasive heated electrodes. This diagnostic tool assesses the approximate oxygenation of tissues in skin flaps, wounds, and ulcerations, and consequently has beneficial value for patients with PAD. Clark first developed the prototype electrode measurement, which was later miniaturized by Silver (24). Transcutaneous oximetry is the only noninvasive method to quantify tissue oxygenation. Its advantages are that it does not disrupt tissue around the wound and that it eliminates the risk of infection as a result of its noninvasive origins. A limitation of oxygen tension is that it does not directly measure the oxygen tension within the wound. It instead measures the oxygen tension in the tissues adjacent to the wound, which is an important distinction, as the wound oxygenation will be lower than that of the surrounding tissues. Oxygen-deprived tissues surrounding the wounds would have typical oxygen tension values less than 20 mm Hg, compared with control/normal values of 30–50 mm Hg (23). The average oxygen tension in the