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Ultrasound of peripheral arteries

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Peripheral arterial disease

Ultrasound has long been established in the investigation of arterial disease of the limbs. The use of continuous wave (CW) Doppler ultrasound and pressure measurements is a non-imaging cost-effective and reliable method of detecting the presence and severity of occlusive peripheral arterial disease in the lower limbs. For those with identified disease, duplex ultrasound scanning is used to identify specific sites of stenosis and occlusion as an aid to surgical or endovascular intervention [(1, 2)]. Ultrasound imaging is competitive and complementary to angiography, CT angiography (CTA) and magnetic resonance angiography (MRA) for many arterial investigations, even in very low flow conditions.

Clinical background

The onset of symptomatic peripheral arterial disease (PAD) affecting the leg arteries may take the form of a gradual deterioration due to either the slow build-up of plaque or a or sudden, acute thrombotic event. The most common presentation is chronic pain on exercise: intermittent claudication. In these patients, 75% will stabilise with the aid of medical treatment and exercise. Only 5% of these will proceed to reconstructive surgery or endovascular therapy. Acute limb ischemia may require medical therapy, surgery, or even amputation.

PAD is found at all levels of the arterial tree but atheroma has an apparent predilection for certain sites, particularly at bifurcations and bends in the artery. In the lower limb the most common site is the superficial femoral artery at adductor canal level and the second most common is the aortoiliac segment. Diabetic patients tend to present with distal disease in the tibial and peroneal arteries. Proximal occlusions often have greater clinical effect than distal disease. There are limited collateral vessels present to bypass an iliac artery occlusion, the profunda femoris and geniculate branches provide a good collateral route around a superficial femoral artery occlusion and cross branches between the three arteries in the lower half of the calf and foot are extensive.

Other pathological conditions, some related to atherosclerosis, may affect arterial flow and distal perfusion. These include local thrombosis, embolization and downstream occlusion. Aneurysms can leak or rupture or may lead to mural thrombus that may cause local occlusion or distal embolization. Abdominal aortic aneurysms are often clinically silent yet are readily diagnosed with B-mode ultrasound. Popliteal artery aneurysm is a common site of thrombus formation and sudden occlusion of the arterial supply at this level causes acute limb threatening ischaemia. Common indications for ultrasound investigation of peripheral arteries are presented in table 1.

Table 1 Common indications for ultrasound investigation of limb arteries.

- Disabling intermittent claudication,
- Rest pain
- Gangrene, non -healing ulcer
- Trauma
- Popliteal artery aneurysm
- Femoral artery aneurysm
- Acute limb ischaemia
- Post procedure bruits, masses
- Raynaud's disease
- Haemodialysis access preparation, assessment and dysfunction
- Thoracic outlet syndrome
- Vasculitis
- Surveillance and investigation of failure of arterial interventions

Equipment

Continuous wave ultrasound

CW Doppler ultrasound devices range from inexpensive hand-held devices to those with spectral sonogram displays of the Doppler output with flow waveform analysis [Figure 1]. Typical transducer frequencies are:

- 8–10 MHz: digital, ulnar, radial, brachial arteries; tibial arteries at ankle level, dorsalis pedis artery, and pedal arch.
- 3–6 MHz: subclavian, axillary arteries; popliteal, superficial and common femoral arteries.

High-end ultrasound scanners

High-end ultrasound scanners are desirable for investigation of PAD with good B-mode imaging across a range of depths and good sensitivity to flow in both colour flow and spectral Doppler modes. A large range of transducers are ideal but should include:

- High frequency (around 8–15 MHz) linear array (for tibial/pedal arteries and arm arteries). High frequency small footprint arrays are also used for imaging of temporal arteries.
- Lower frequency linear array (approximately 4–9 MHz) for subclavian, femoral and popliteal arteries, curvilinear array (1–4 MHz) for iliac arteries, aorta and femoral arteries in larger patients. In addition, the following are desirable.
- A phased array (1–4 MHz) is also useful for abdominal branches to complement the curvilinear probe where access is limited.
- A high frequency (4–9 MHz) tightly curved array or phased array is useful for subclavian and innominate arteries.

Figure 1 Continuous Wave Doppler equipment with two probes and spectral analysis.

Continuous wave Doppler ultrasound of PAD

Ankle brachial pressure index

The use of ankle-brachial pressure index (ABPI) without or with exercise should be the initial test to establish the presence of disease. Duplex scanning is comparatively expensive and time-consuming and should be reserved for those patients with identified disease in whom treatment is planned or contemplated.

First described by Yao [(3)], the ABPI is defined as ankle systolic pressure: brachial systolic pressure. The use of a pressure index rather than the absolute pressure allows serial comparison of results from the same, and comparison between, individuals. The technique is straightforward but must be performed correctly [(4)] with the patient supine and using cuffs of the appropriate width.

An ABPI value of less than 1.0 is used to diagnose the presence of PAD. ABPI falls with worsening disease. There is an overlap in pressure index between those with and without disease [(5)] and lower thresholds e.g. 0.9 [(6)] have been applied. Typically a pressure index of <0.8 is found in patients with mild intermittent claudication and this level of index would contraindicate venous compression bandaging [(4)]. An index of 0.5 or less is associated with severe claudication and indices of 0.3 or less are associated with ischaemic rest pain, ulceration and gangrene [(7)].

Medial artery wall calcification is a source of error that results in the overestimation of ankle pressure [(8)]. ABPI index of greater than 1.3-1.4 generally indicates nondiagnostic calcified arteries. It is commonly found in patients with chronic renal failure and diabetes [(5)]. The artery wall is stiffened and so the pressure measured is no longer just a measure of blood pressure but also of the strength of the arterial wall. In arteries that are totally incompressible at cuff pressures of 300 mmHg the error is obvious but there is a risk of misinterpretation of ABPI in patients in whom a partial increase in stiffness of the artery wall results in a plausible but falsely raised reading. Since digital arteries are less affected by calcification, careful comparison of ABPI with pedal artery waveform shape and pressure is prudent. For patients with non-compressible tibial arteries, distal arterial blood pressure drop can be measured by the laser Doppler toe/brachial pressure ratio since these arteries are generally not affected by calcification. Normal toe pressures are greater than 50 mmHg. The use of the toe /brachial index for patients with calcified arteries is recommended by TASC guidelines [(2)].]

Stress or exercise testing may be used in conjunction with ABPI measurements. With exercise the increased demand through a stenosis leads to a corresponding increase in pressure loss [(9)] across it. Exercise provides further information on the functional and haemodynamic consequences of PAD. The most common exercise is walking on a treadmill. Standardised exercise protocols have been suggested [(10)] but methods vary and patients can typically be tested with no incline or on a slope of up to 12%, at speeds of between 2–4 kph for a duration of 1–5 min or until limited by symptoms.

Velocity waveform analysis

The shape of the arterial velocity waveform has specific characteristics in different vascular circulations [Figure 2]. The velocity flow waveform shape is representative of physiological function and disease. Changes in the arterial waveform can be assessed qualitatively by eye [(11)]. In PAD proximal to the site of insonation, proximal occlusion or severe stenosis leads to a reduced pressure pulse resulting in a slower systolic upstroke and reduced pulsatility of the arterial waveform [Figure 3].

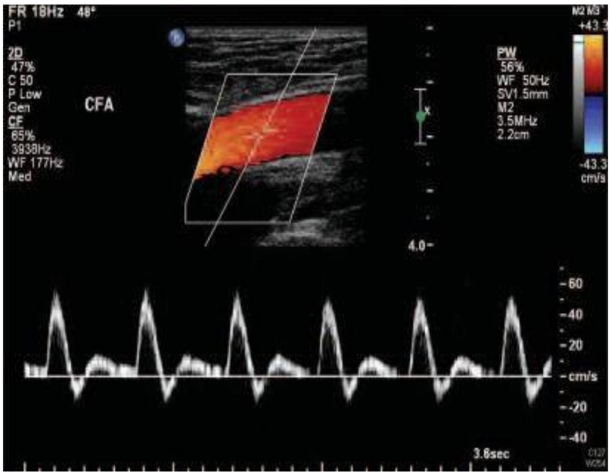
Quantitative changes such as the pulsatility index have been used to assess the presence and severity of proximal stenosis. However, the increased availability and use of duplex scanning has allowed more direct imaging of stenoses and the use of the pulsatility index for this application has receded. Visual waveform inspection at the common femoral artery is useful when aortoiliac scanning is precluded by poor quality images [(11, 12)].

Doppler (triplex, duplex) ultrasound of PAD

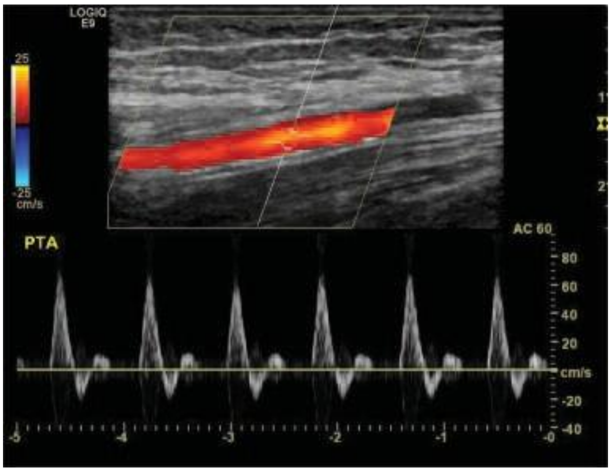
Duplex ultrasound is used to identify the level and severity of occlusive disease in the lower limbs, to identify run-off arteries suitable for bypass surgery and to monitor therapy such as bypass grafts or stents. Because of its ability to determine and measure occlusions, it can be instrumental in planning endotherapy or surgery [(13-16)].

Figure 2 **Normal flow waveforms from: a) a femoral artery patient resting, b) posterior tibial artery patient resting, c) common carotid artery.**

a



b

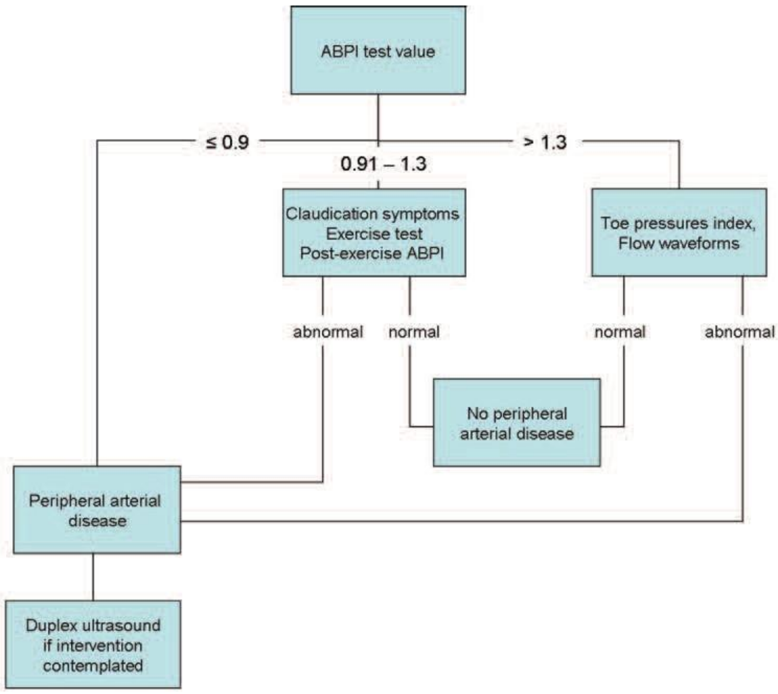


c

Figure 3 Common femoral artery flow waveform distal to an aortoiliac occlusion.

Duplex ultrasound complements and competes with intra-arterial contrast angiography, (usually regarded as the gold reference standard against which other modalities are compared), and contrast and non contrast-enhanced MRA and CTA. Local practice is dependent on the resources and expertise available and the implementation of diagnostic pathways. Duplex ultrasound requires time and skilled practice to investigate PAD. The examination of the lower limb arteries is time-consuming, commonly requiring 30–60 min for investigation of the major arteries from aorta to tibial arteries. For this reason it should be limited to those patients for whom intervention is contemplated [Figure 4].

Figure 4 A diagnostic pathway for leg arterial disease



Scanning technique

Scanning is mostly undertaken longitudinally. Angle correction is required to measure velocities because stenoses are described in terms of their peak velocity and the ratio of peak velocities to those in adjacent non-diseased segments. In the aortoiliac segment, fasting is recommended to reduce the problems caused by gas. The aorta and proximal iliac vessels are usually scanned with a curvilinear or phased array transducer [Figure 5 and 6] In the thigh and calf; linear arrays are used [Figures 7] although high frequency curvilinear arrays produce a greater field of view.

Figure 5 **Aorta occlusion. There is flow to the celiac axis and SMA before the aorta occludes. The occluding material is as hypoechoic as the overlying liver.**

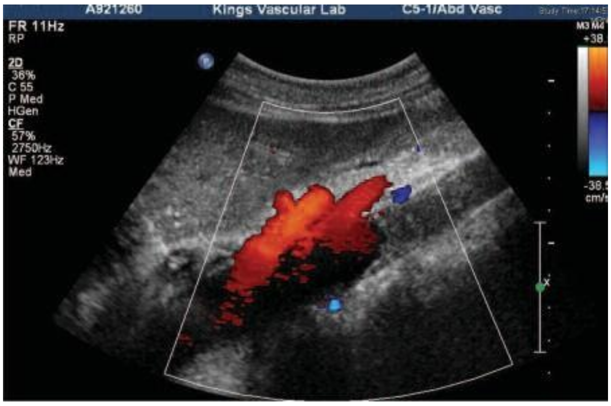
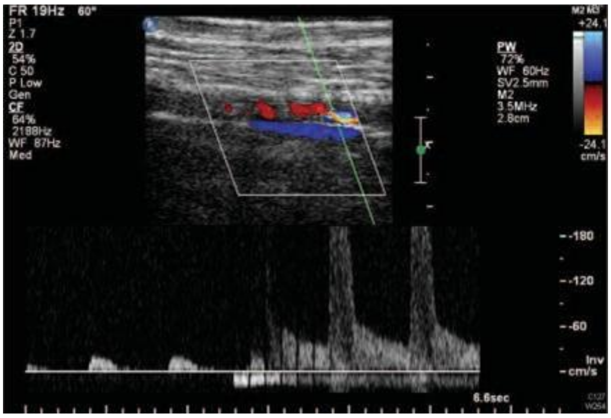


Figure 6 **External iliac artery origin stenosis. High velocities (> 3 m/s) indicating a severe narrowing.**

Figure 7 **Superficial femoral artery stenosis. Colour flow shows a short length of aliasing indicating a velocity change. Moving the Doppler sample volume from the proximal artery shows very low velocities pre-stenosis with a > 8-fold velocity increase at the site of a tight stenosis. Profiling the stenosis by "walking" the**

sample volume through it can be documented by one image (as in this case) or as a series of images before, in, and after the stenosis.



Atherosclerotic changes are difficult to quantify by B-mode but gives a general idea of the amount of plaque that is present. The colour flow image is used to identify the course of the artery. Voids in flow indicate occlusion or stenosis [Figure 5 and 8] and regions of velocity increases [Figures 6, 7 and 9] at stenoses. Areas of interest are then tested using spectral Doppler. The highest PSV is recorded and used for quantification.