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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].

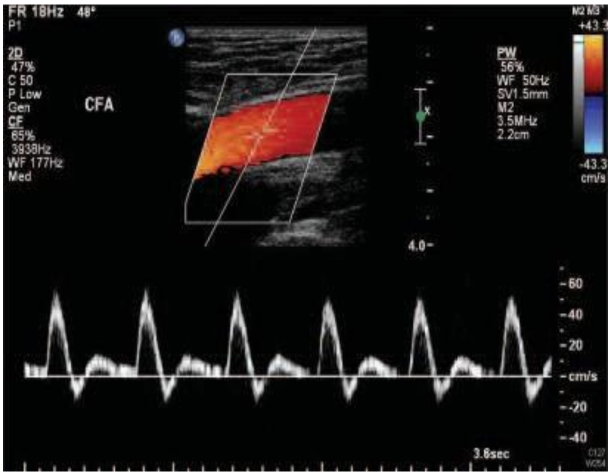
Quantitative changes such as the pulsatility index have been used to assess the presence and severity of proximal stenosis. However, the increased availability and use of duplex scanning has allowed more direct imaging of stenoses and the use of the pulsatility index for this application has receded. 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



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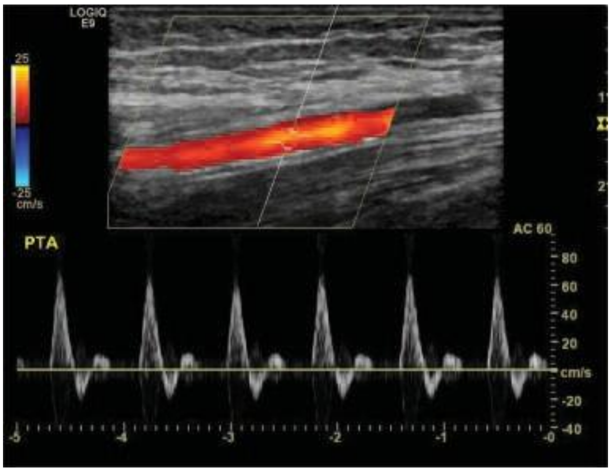
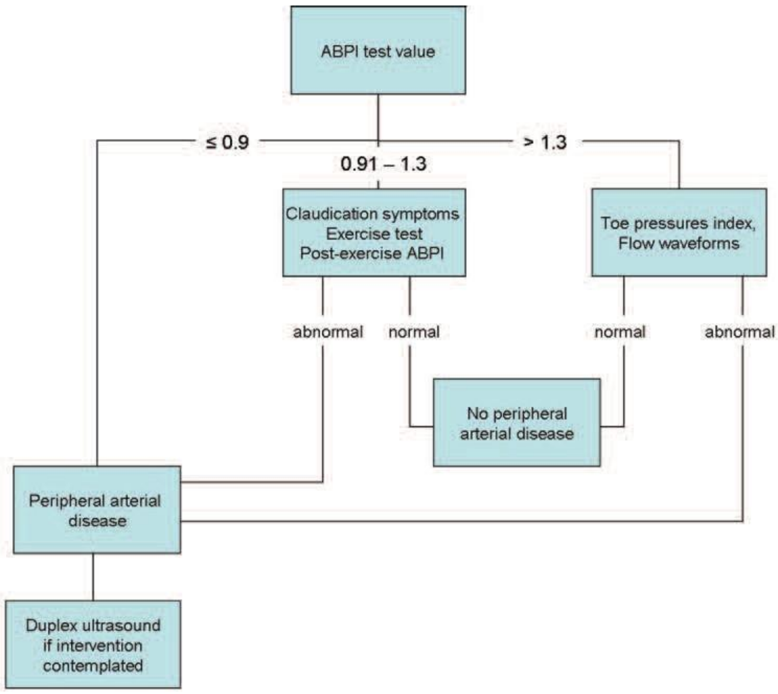


c

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.**

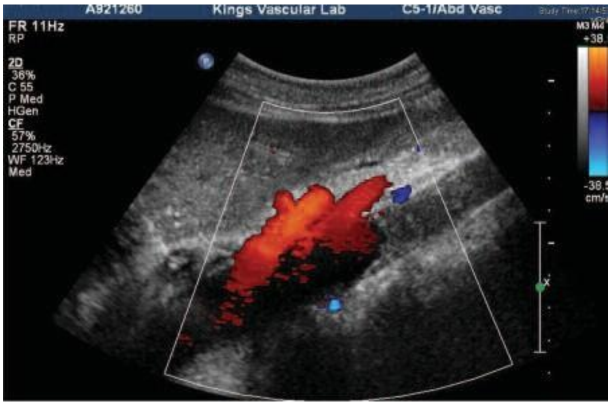
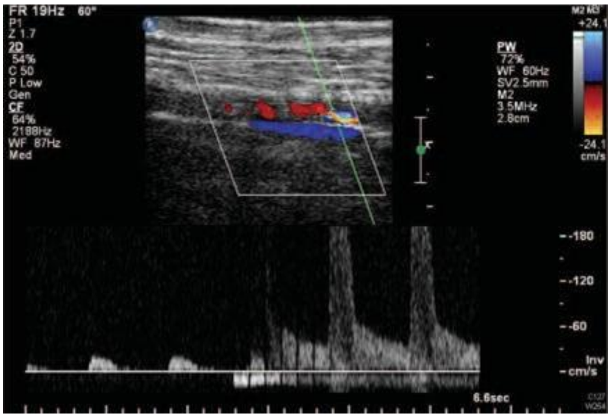


Figure 6 **External iliac artery origin stenosis. High velocities (> 3 m/s) indicating a severe narrowing.**

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.

Figure 8 **Popliteal occlusion. Colour flow shows a patent proximal popliteal artery with flow to superficial and deep collaterals and no flow in the popliteal artery distal to these. In this instance the occlusive material is nearly anechoic. The absence of echogenic material makes identification by B-mode alone difficult.**

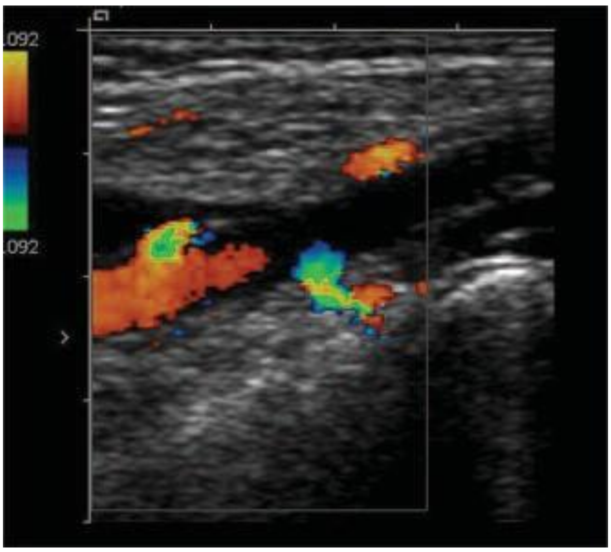


Figure 9 Tibial stenosis. A short colour flow image reveals an area of aliasing in a calcified artery. Flow velocities here are high, indicating a stenosis.

The degree of stenosis is obtained by measuring angle corrected PSV from the spectral Doppler sonogram. Doppler angles lower than 60° are preferred (a single fixed angle is not necessary). Care should be taken when using beam/flow angles greater than 60^{o} although the use of velocity ratios to assess severe stenoses at angles of up to 70^{o} is acceptable (with reservation) if scanning limitations dictate the use of high angles. When determining occlusion, low pulse repetition frequencies and power Doppler also should be used to check for patency in the vessel. Flow waveforms in healthy peripheral arteries exhibit pulsatile flow with reverse flow in late systole: triphasic or biphasic flow [Figure 2]. Changes in flow waveform shape can be an indication of proximal disease or distal occlusion [Figure 10].

Figure 10 CFA, distal stenosis. The sharp deceleration from the peak velocity and almost absent reversed flow are indicative of distal disease, probably at the point of shadowing at the femoral bifurcation.

Stenosis criteria

Stenosis severity is described by a focal increase in PSV through the stenosis. Increased severity of stenosis is reflected by an increase in the PSV ratio, the ratio reflects the anatomical change in area while the peak velocity in the stenosis is indicative of the pressure loss at that point. Most centres use a PSV ratio of >2 to indicate a >50% diameter reduction stenosis, although a range of 1.8–2.5 has been reported [(14, 17, 18)]. The range reflects differences of interpretation in ultrasound and arteriography measurements and illustrates the problems that are inherent in defining a stenosis by its diameter. A 50% reduction in diameter produces a 75% reduction in area if the stenosis is concentric and 50% reduction in area if the stenosis is semi circular. In practice, stenoses are rarely concentric or semi-circular and their irregular shape further compounds technical limitations and errors in converting flow velocity increase to stenosis diameter. A study to examine progression of femoral artery disease [(18)] observed that stenoses with velocity ratios >3.0 had a high incidence of early occlusion and that, at this level, early intervention is advised. Higher velocity ratios are indicative of more severe disease, as a guide, a PSV ratio of ≥4 is indicative of a 75– 99% stenosis.

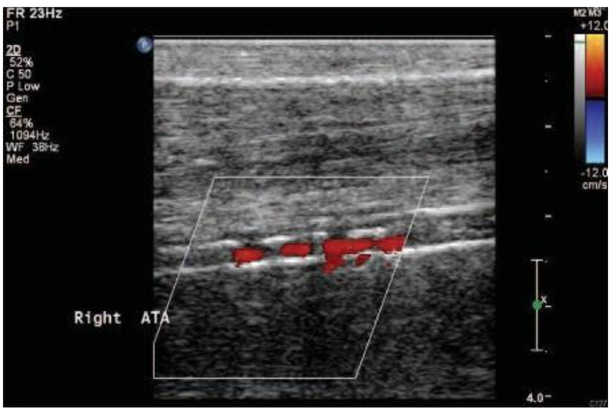
To obtain a velocity ratio, PSV is measured in the proximal artery where there is no or minimal disease and at the point of maximum velocity increase [Figures 6, 7]). Angle correction should be made in line with the direction of the artery. In practice this may under- or overestimate the PSV if the true jet is not in line with the artery, but a systematic method will lead to less operator-dependent variation. Attempts have been made to assess pressure loss from measured peak velocities using a modified Bernoulli equation with limited success [(19, 20)].

In studies comparing duplex ultrasound with angiography [(21, 22)] good agreement has been shown in the aorto-iliac and femoro-popliteal segments. There have been fewer studies reporting on the effectiveness of scanning infra-popliteal arteries. A full study of the distal arteries is time- consuming and the peroneal artery can be difficult to image in patients with large calves. Calcification in patients with diabetes or renal failure limits images of the tibial arteries [Figure 11]. Despite this, a study comparing angiography and duplex scanning assessment of vessel patency concluded that agreement between the two modalities was similar to agreement between radiologists reporting on angiograms [(23)].

Ultrasound has been shown to be effective in evaluating run-off vessels suitable for femoro-crural reconstructions [(24)]. For these examinations, flow and velocities are often very low indeed. Colour continuous through the ankle can identity an adequate target artery. The patient should be seated in a legs dependent position. High frequency transducers are required with low colour and spectral pulse repetition (scale) settings.

Because of the numerous samples and arteries evaluated, just a series of images of the leg arteries are difficult to analyse effectively. It is helpful to present ultrasound findings in diagrammatic form or map to highlight the presence and size of occlusions and aneurysms, the site and severity of stenoses and major collateral pathways identified at the scan.

Figure 11 Tibial artery calcification. Calcification can obscure flow in tibial arteries evident as highly echogenic artery walls.



Peripheral artery bypass grafts

Ultrasound is used extensively to monitor bypass grafts, which permits early intervention to prolong graft life and to enhance limb salvage rates. Grafts can fail for the following reasons:

- Inadequate inflow or outflow leading to poor graft flow and consequent thrombosis,
- Technical errors including intimal flaps, twisted or kinked grafts,
- Intimal hyperplasia (vein grafts),
- Progression of disease in native arteries leading to inadequate inflow or outflow.

In general, bypass grafts terminating at or above femoral artery level have a higher patency rate than those at the infrainguinal level. These proximal grafts tend to make more use of artificial materials that tend to fail as a result of thrombosis. Ultrasound is used to determine patency, stenosis (particularly in the proximity of anastomoses), thrombosis, technical errors, mismatches in lumen size and abnormal haemodynamics (disturbed flow, regions of low velocity) in grafts.

The most effective application of ultrasound in bypass grafts has been for infrainguinal vein grafts. In these cases, the comparatively high failure rate, clinical implications of graft failure and the gradual onset of failure from hyperplasia-induced stenoses may justify the cost of a surveillance programme.

Pre-operative vein scanning for arterial bypass

In addition to examination of proximal and run-off arteries, ultrasound is used to identify veins suitable for use in surgery. The most commonly used vein is the great saphenous vein although the small saphenous vein, cephalic vein or basilic veins may be used where necessary. Veins are examined for size, scarring, patency and evidence of varicosities. Their length and their course are mapped on the skin. The patient should be tested with their upper body raised to increase venous pressure, if the patient is supine, the veins may collapse.

Post-operative scanning: femorodistal bypass grafts

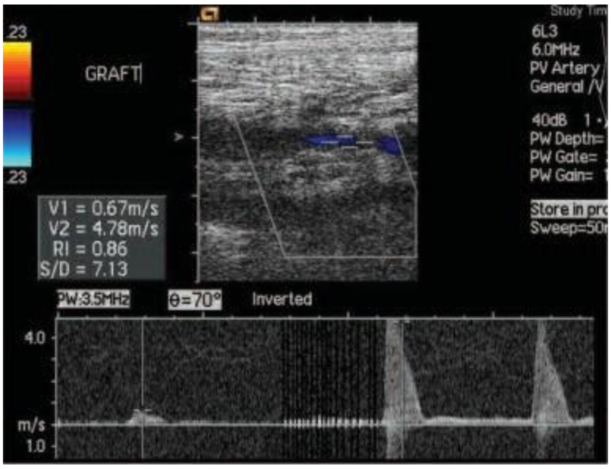
Duplex ultrasound is seen as particularly important in evaluating vein grafts because it can identify problems in the graft before they are evident from clinical indications or from ankle/brachial pressure measurements.

Failure is most common in the early post-operative period. Graft surveillance programmes using duplex ultrasound reflect the need for close monitoring over the first year after operation and routine scanning at 1, 3, 6, 9 and 12 months post-operation is typical. Continued follow-up has been advocated beyond the first year [(25)], although the low rate of late failure and low incidence of new stenoses after the first 6 months has led to suggestions that programmes should be restricted to the first six months [(26)] or 12 [(27)] months for grafts showing no evidence of deterioration.

In the immediate post-operative period, restricted access may limit detailed imaging, although graft patency can usually be quickly confirmed. In artificial grafts, small air bubbles can cause a strong reflection of ultrasound at the graft surface in the initial post-operative period. When scanning of the graft is possible, it is examined for stenoses [Figure 12], thrombosis [Figure 13], collections and any other anomalies evident on B-mode or Doppler ultrasound. Inflow and outflow is assessed in terms of flow waveform shape and PSV and can be compared with previous results. Because the graft offers a low resistance path for the circulation with little pressure loss, run-off flow at the distal anastomosis is commonly antegrade to distal vessels. Retrograde backfilling of the native vessel proximally from the bypass may be seen [Figure 14].

Figure 12 Graft stenosis. Femerodistal graft stenosis. Duplex ultrasound shows a seven-fold velocity increase (a). Angiography confirms the stenosis (b).

a



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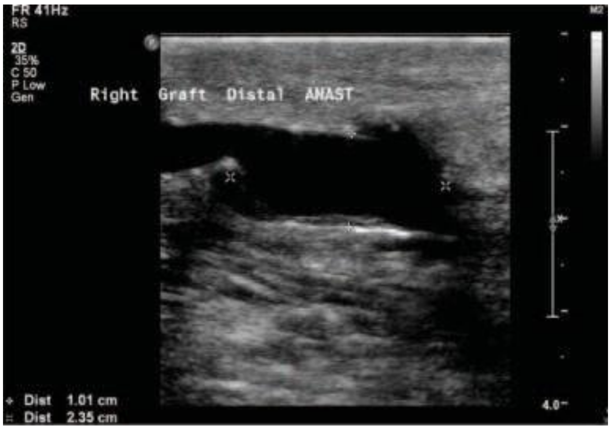
Stenosis criteria are generally divided between moderate stenoses for which continued surveillance is indicated and severe lesions that threaten the graft and need urgent intervention. PSV ratio is used to characterise the severity of stenosis. For moderate stenoses, velocity ratios of 1.5 [(26)] and 2.0 [(27)] have been proposed. For severe stenoses, velocity ratios of 3.0 [(26)] and 3.5 [(28)] are indicative of impending failure.

Severe stenosis usually decrease the ankle/brachial pressure index >0.15 from baseline. A decrease can also indicate worsening in proximal or distal disease. However, in comparison to duplex ultrasound the index is insensitive to graft stenoses.

Figure 13 Thrombus at distal anastomosis. At an early post-operative visit, a large anastomotic cuff is seen (a). At a visit a year later, there is thrombus at the area of previous flow separation (b).

a



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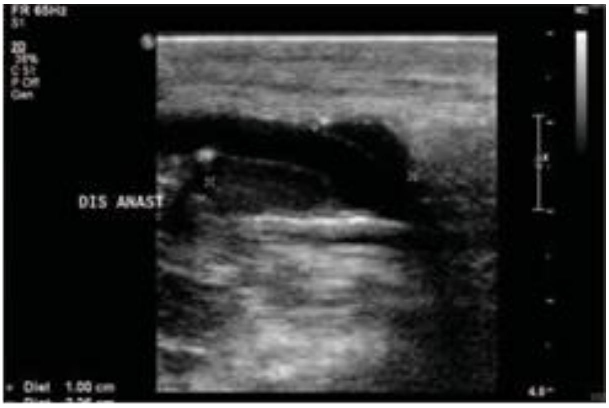
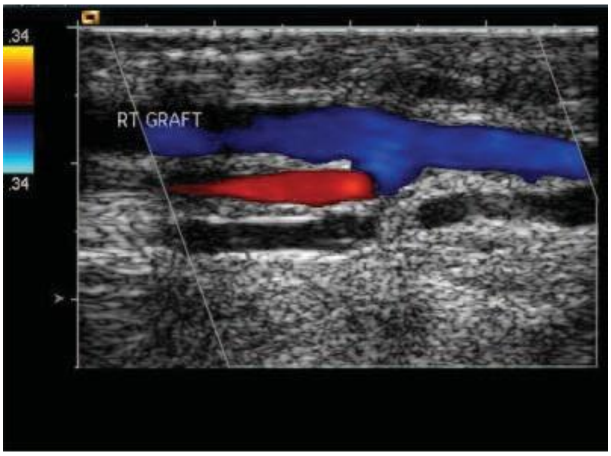


Figure 14 Distal anastomosis run-off. Flow is both antegrade to the distal tibial artery (blue run- off) and retrograde to the proximal tibial artery (red).



Low velocities in a graft are indicative of inadequate inflow or outflow and are associated with a risk for occlusion. A PSV of 45 cm/s, below which velocities should not fall, has been suggested for both vein [(28)] and polytetrafluoroethylene [(29)] grafts.

Angioplasty: stents

Duplex ultrasound is used to assess lesions suitable for angioplasty, which reduces the need for diagnostic arteriography prior to intervention. Ultrasound has also been used to guide angioplasty in femoral and iliac lesions [(30, 31)]. This permits an immediate assessment of the outcome of balloon inflation by haemodynamic parameters.

For follow-up of angioplasty, velocity ratio criteria can be used to measure relief of the constriction and shows good agreement with angiographic appearance [(32)]. The diagnostic potential of these measurements is uncertain. Velocity ratios of >2 have been used to indicate a 50% stenosis although the usefulness of this in determining long-term patency is unclear [(33, 34)].

Duplex ultrasound has been advocated as a measure of stenosis severity for SFA stents. In a retrospective study comparing ultrasound with angiography [(35)] (using PSV and the velocity ratio Vr of in-stenosis: pre-stenosis PSV) PSV ≥ 190 m/s and Vr ≥ 1.5 were most accurate for ≥ 50% stenosis and PSV ≥ 275 m/s and Vr ≥ 3.5 were optimum for a ≥ 80% stenosis.

Acute ischaemia

Acute ischaemia in limbs usually arises from two main causes:

- Acute thrombosis on an existing plaque, which is often described as acute on chronic.
- Embolism from a proximal source, usually the heart, aneurysm or upstream plaque. These commonly lodge at a bifurcation.

In both cases there is a rapid onset of ischaemia with pain and coldness in the limb and risk of tissue loss. The use of ultrasound depends on its availability and speed with which it can be used compared with angiography. Ultrasound can identify the location of the occlusion, its proximal and distal extent and the arterial access for intervention.

Popliteal entrapment

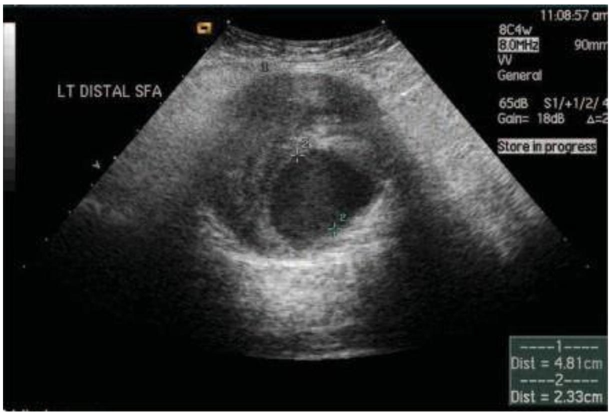
Occlusion of the distal popliteal artery can be provoked by dorsi or plantar flexion of the foot in patients suffering from popliteal entrapment [(36)]. It can be assessed by a reduction in ankle blood pressure, reduction in CW flow signals at ankle level or by colour flow ultrasound, which shows the site of occlusion and the presence of collateral circulation. The phenomenon of popliteal occlusion in response to these manoeuvres is, however, sufficiently prevalent (over 50% in young healthy volunteers [(37)]) to render this test of limited diagnostic use.

Aneurysms

The role of ultrasound in diagnosis and follow-up of abdominal aortic aneurysms and aortic stents is covered in another chapter. Aneurysms also occur in the limbs, most commonly in the popliteal artery [Figure 15], less often in the femoral artery [Figure 16]. Iliac artery aneurysms are usually associated with aortic aneurysms, and isolated iliac aneurysms are rare. Complications are acute thrombosis, rupture and compression of the adjacent vein possibly causing deep vein thrombosis.

Figure 15 Popliteal artery aneurysm.

Figure 16 SFA aneurysm, transverse view, partially filled with thrombus.



High rates of coexistent aneurysms have been found in patients with popliteal aneurysms (78%) and common femoral aneurysms (95%) [(38)]. If an aneurysm at the iliac or distal level is identified during an investigation of leg arteries, the patient should be screened for aortic aneurysm. In cases of suspected embolism, the major arteries from the popliteal artery proximal to the aorta should be investigated.

Arterial injuries

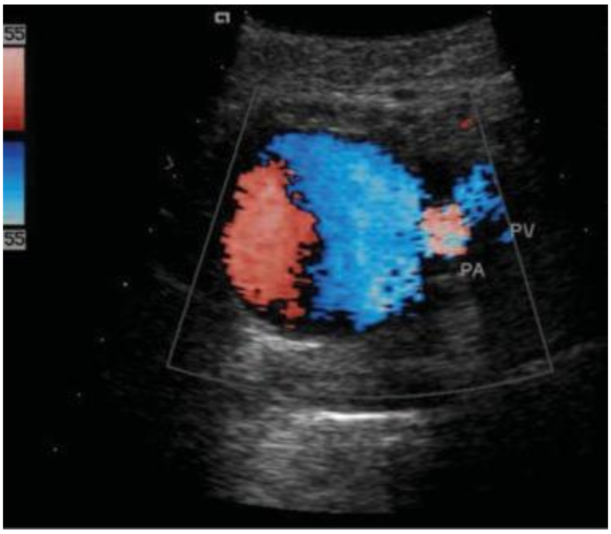
Duplex ultrasound is a rapid and accurate means for the diagnosis of arterial injuries following arterial puncture or compression damage. The most common complication is a pseudoaneurysm [Figure 18]; others include arteriovenous fistula, thrombosis, dissection [Figure 17] and intimal flap [(39, 40)]. The most common iatrogenic injury is as a result of catheterisation at the common or proximal superficial femoral artery but these complications can occur in any of the major arteries in the upper or lower limb.

Figure 17 Dissection of an axillary artery.

Pseudoaneurysms appear as a B-mode echo-lucent region adjacent to the artery in which blood leaks from the artery into adjacent tissue. Colour demonstrates multidirectional flow in the pseudoaneurysm sac; it is characterised by a swirling motion that produces bidirectional colour flow signals [Figure 18]. There may be evidence of thrombus within the sac. Flow within the tract from the damaged artery to the pseudoaneurysm exhibits high velocities systolic inflow with low velocity reversed continuous diastolic emptying in diastole (the" to and fro" sign) [Figure 18].

Figure 18 Pseudoaneurysm adjacent to a femoral artery and vein resulting from injury from catheterization. The swirling flow by colour has been described as a "yin yang" sign (a). Typical to and fro flow in tract leading to a pseudoaneurysm (b).

a

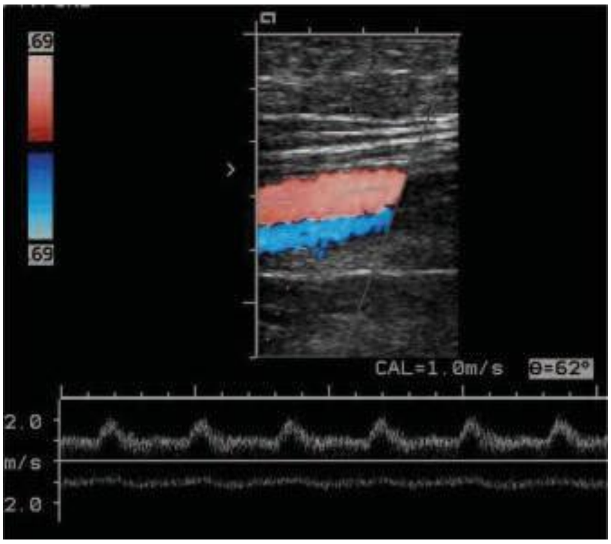


b

Ultrasound can be effective in compression closure of pseudoaneurysm with a high rate of success reported [(41)]. After locating the neck of the aneurysm, pressure can be applied and colour flow used to observe cessation of flow into the pseudoaneurysm. An effective alternative is ultrasound- guided thrombin injection [(42)], which is quicker and causes less discomfort to the patient and the operator.

Traumatic arteriovenous fistulas result from a puncture of adjacent artery and vein with a corresponding low resistance, high-pressure gradient and consequent high flows [(43)]. Flow in the supplying artery exhibits a high velocity; low resistance flow waveform and the draining vein may show arterial-type pulsations [Figure 19]. At the site of the fistula, there is a high velocity flow jet with possible artefact from adjacent tissue vibration.

Figure 19 Damped flow in a femoral artery and vein leading to and returning from a fistula.



Arterial disease in the arm

Patients presenting with ischaemia of the arms and hands do so for a more diverse range of aetiologies than for the legs and feet in which atherosclerosis is the predominate cause. Duplex ultrasound can be used to investigate the arteries from innominate/brachiocephalic and subclavian arteries to axillary, brachial, radial and ulnar arteries.

Resting flow waveforms in the arm are usually pulsatile and exhibit characteristics typical of high distal resistance. In comparison with the leg arteries, flow waveforms in the arm are altered more by changes in temperature, which reflects the thermoregulatory nature of skin blood flow in the hand and the comparatively low muscle mass. In response to heating or exercise, the tri- (or more) phasic flow waveform shape becomes monophasic, although often with pulsations superimposed on a raised mean velocity.

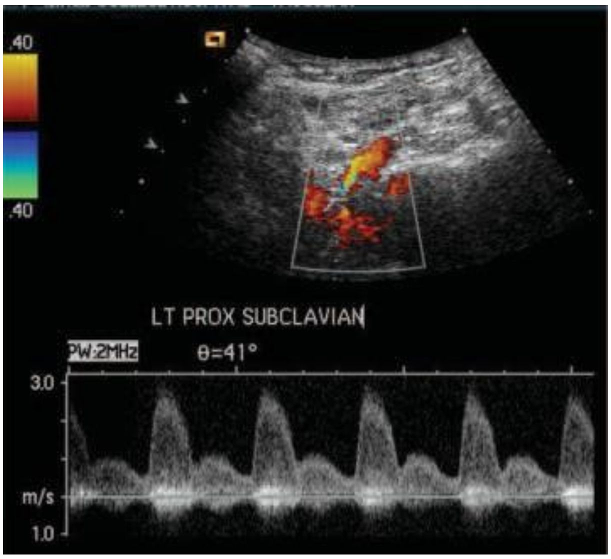
Clinical applications

Atherosclerosis occurs most frequently in the proximal arteries, particularly at the origins of the innominate and subclavian arteries. Depending on its location, plaque may be imaged on B-mode ultrasound. If the stenosis at the subclavian artery origin is severe enough to cause a pressure loss, a subclavian steal may result. Ultrasound characteristics of steal include high velocity and disturbed flow at the subclavian artery stenosis [Figure 20] with either reduced systolic flow or partial or completely reversed flow in the ipsilateral vertebral artery. Distal arteries in the affected arm demonstrate damped flow. The effect of the stenosis can be quantified by non-invasive pressure measurements, bilaterally. Exercise of the ipsilateral hand increases blood flow in the supplying arteries and exacerbates the haemodynamic effects of the stenosis including increased steal with increased mean reversed velocities in the vertebral artery. The subclavian steal syndrome is most often a benign and asymptomatic condition, but it must be carefully studied and defined if incidentally discovered during a routine preparatory evaluation in patients undergoing a CABG procedure. Indeed the use of a mammary artery stemming from an obstructed subclavian artery can lead to otherwise unexplained unsuccessful coronary surgery.

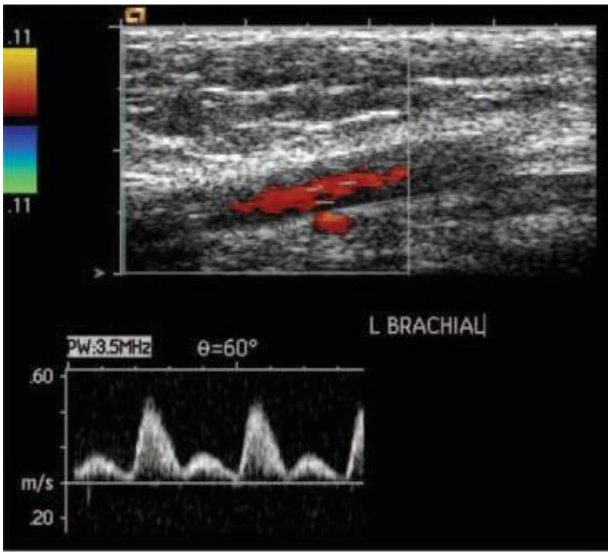
The major source of emboli in the arm is either the heart or proximal aneurysms, the latter occurs most commonly in the subclavian artery. The arteries can be imaged in B-mode to look for aneurysms and mural thrombi. Duplex ultrasound can identify sites of occlusion in vessels at the radial and ulnar level.

Figure 20 **Subclavian stenosis. There is evidence of high velocities indicating a proximal L subclavian stenosis (a). L brachial artery flows show more damping (b) than the R (c). There is damped flow in the L vertebral artery (d) and L arm exercise brings on incipient steal (e).**

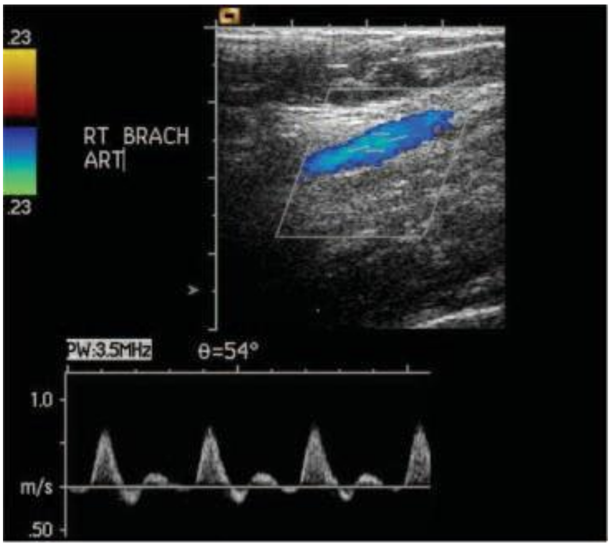
a



b


.11
.11
L BRACHIAL
PW:3.5MHz
θ=60°
.60
m/s
.20

c


.23
.23
RT BRACH
ART
PW:3.5MHz
θ=54°
1.0
m/s
.50

d

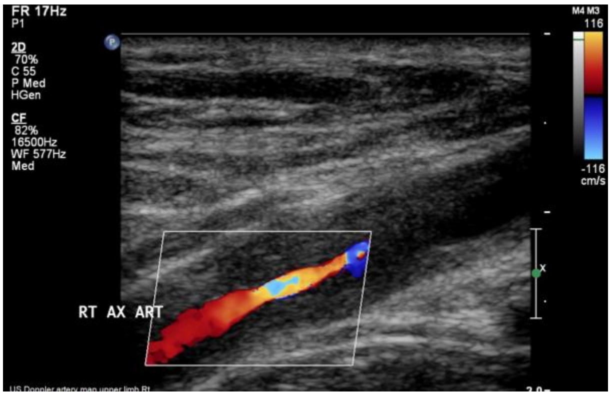

FR 16Hz 62°
Left Vert
AGC
PW
70%
WF 50Hz
SV3.0mm
M2
3.5MHz
2.9cm
4.0
-120
-80
-40
cm/s
-40
6.6sec

e

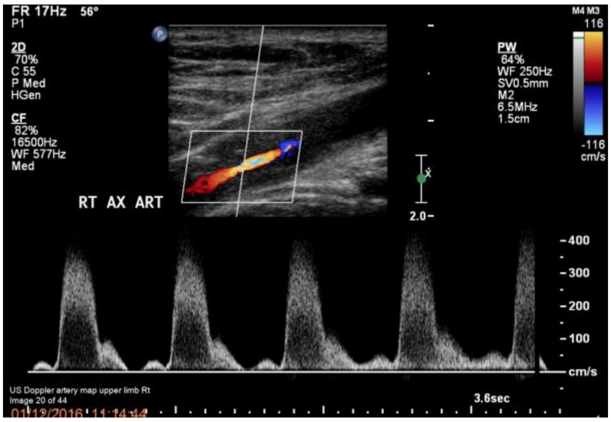
Takayasu’s arteritis is a rare autoimmune disorder that is characterised by long segment stenoses or occlusions [Figure 21]. Duplex ultrasound has been shown to be of use in monitoring regression in response to therapy [(44)].

Figure 21 Takayasu’s arteritis. Evidence of extensive thickening in an axillary artery a resulting in high velocities (b).

a



b

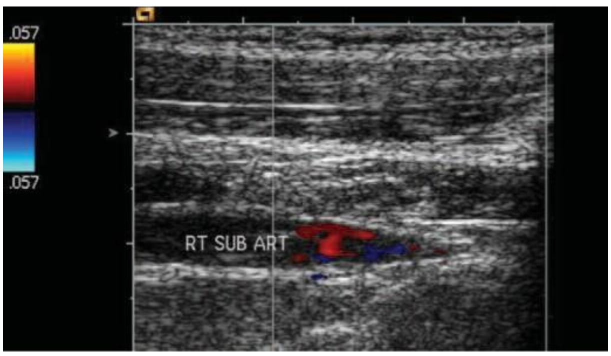


Thoracic outlet syndrome

Thoracic outlet syndrome describes a range of disorders arising from the passage of the subclavian artery and vein and brachial plexus through the narrow thoracic outlet. Duplex scanning can detect stenotic [Figure 22] or aneurysmal causes for vascular thoracic outlet syndrome as described above.

Flow in the distal arteries can be diminished or ceased in many patients by abduction or rotation of the arm [(45)]. This effect, caused by compression of the subclavian or axillary artery, can be measured by duplex or CW Doppler ultrasound. However, it is not diagnostic of thoracic outlet syndrome because of the general prevalence of the effect in the normal population [(46)]. Therefore symptoms should accompany the abnormal waveform changes.

Figure 22 Subclavian artery compression. On raising the R arm, compression of the subclavian artery is evident to the right of the image.



Ultrasound of haemodialysis access

Permanent haemodialysis access, through a fistula or graft, requires high flows through a superficial vein or graft that can be repeatedly accessed by needle, is easy to keep clean and is comfortable for the patient during periods of dialysis. American and European reviews and guidelines (NKF-K/DOQI, EBPG – European Best Practice Guidelines) [(47, 48)] for dialysis advocate the use of ultrasound in planning access [(49)], for follow-up of problems [(50)] in the access circuit and as a means of measuring volume flow. The role of ultrasound in routine surveillance is still controversial.

Access sites

Permanent haemodialysis access can be either through an arteriovenous fistula in which the vein is used for needle access or a prosthetic graft between an artery and vein. Recommendations are initially to use fistulas where possible because they are less prone to complications.

There are several possible sites for fistulas and grafts in the arms. The main sites in the arm are:

- Radiocephalic fistula
- Brachiocephalic fistula
- Brachial artery – transposed basilic vein fistula
- Forearm graft from radial artery to cubital fossa vein
- Looped graft from brachial artery to cubital fossa vein

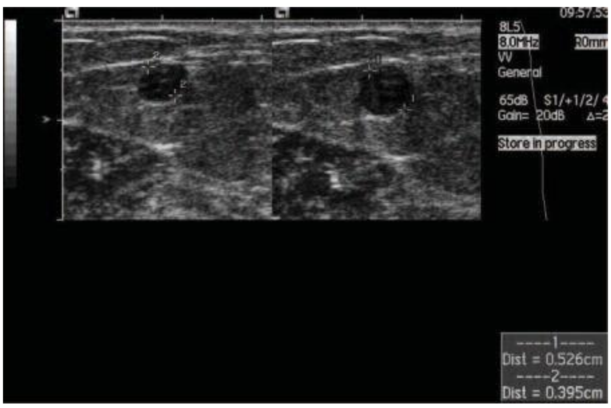
Once arm access is exhausted, femoral artery to femoral vein grafts can be used.

Permanent access

Pre-assessment for permanent access

Poor selection of vessels for permanent access is associated with high failure rates. Ultrasound has an important role to complement physical examination in identifying the most suitable site for access surgery, especially in older patients and in patients with diabetes and arterial disease. The following is a checklist for examination of arm vessels prior to surgery:
Cephalic and basilic vein. Measure the vein diameters and ensure patency along the vein length. Minimum diameter is 2.5mm. A tourniquet should be used to aid vein distension [Figure 23]. Note any anomalies (bifid veins, large communications to the deep veins).
Check patency of the deep veins for brachial to innominate vein level, especially if central vein catheters have been used.
Assess arm arteries for normal flow waveforms and velocities. Minimum radial artery diameter is 2 mm for radiocephalic fistulas. Note the level of the brachial artery bifurcation. Note the presence of occlusions or stenoses, especially in the radial and ulnar arteries.
When imaging the arm vessels, a high frequency linear array should be used with light pressure; even with a tourniquet, veins are readily compressed and the diameter may be underestimated. The arteries should be examined for normal pulsatile flow to wrist level.

Figure 23 Pre assessment dialysis. Cephalic vein diameter assessment with (R) and without a proximal tourniquet (L).



Post-operative assessment of fistulas and grafts

Post-operatively, flow through the fistulas causes the vein to enlarge. The initial high flow into the vein is followed by a gradual further increase for several weeks. An early scan at 6 weeks post- operation can measure flow, assess early problems and record the size and depth of the fistula vein as a baseline record. This early scan also shows potential practical problems including multiple venous returns, venous occlusions and abnormal flows, particularly low flows. In radiocephalic fistulas, early post-operative flows <400 ml/min have a high incidence of non-maturation and failure [(50)]

Complications of fistulas and grafts include:

- Stenosis. In fistulas this occurs most commonly in the vein or more central veins but can also occur in the artery or anastomosis. In grafts the most common site is the venous anastomosis.
- Thrombosis.
- Aneurysms/pseudoaneurysms.
- Infection.

That can all lead to poor dialysis access function, and:

- Steal.
- Venous hypertension.
- Congestive heart failure.

That can all require revision of the fistula or graft.

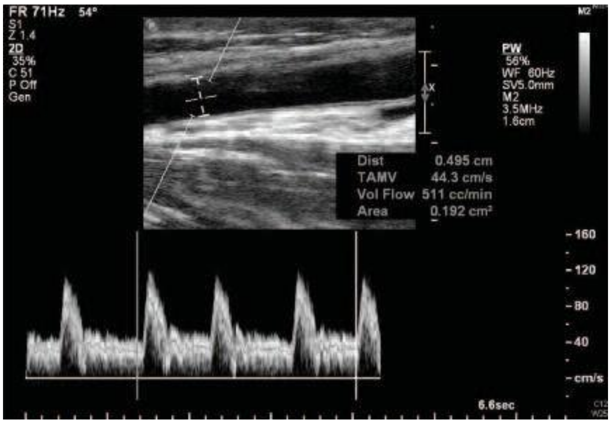
Ultrasound scanning

It is important to liaise with the nursing staff to identify the reason for the scan and any specific problems, for example high venous pressures that have been identified. Patients are often able to describe the problem.

Volume flow

The scan should start with the measurement of volume flow in the artery that supplies the fistula. This should be measured at the subclavian, axillary or brachial artery [Figure 24]. Remember that a radiocephalic fistula may draw flow from the radial and ulnar artery through the palmar arch. Arteries are a more reliable site, at which to measure the flow because the flow is usually laminar and the cross-section is circular, which is not always true in the vein. A small proportion of arterial flow will not go to the vein/graft but this, in comparison with access flow, is negligible.

Figure 24 Flow measurement in a brachial artery supplying a fistula.



Errors in flow values can occur from the measurement of mean velocity or artery diameter (see introduction to ultrasound in vascular disease). The latter in particular can be large because the diameter measurement is squared in the calculation of area. Repeating measurements can reveal random errors. When first attempting this, it is worth measuring at different sites so that systematic errors can be identified. Volume flow is an important indication of the health of the access. Most flow volumes fall in the range 600–1500 ml/min. Fistulas tolerate lower flows better than do grafts. There is a high risk of thrombosis if flow falls below 300-500 ml/min in a fistula or 600 ml/min in a graft. A full investigation for the cause of low or reduced flow should be made if flows fall below these levels or there is significant deterioration (-25%) since the previous scan.

An ultrasound examination should include the following:

- Measure flow in the brachial or subclavian artery supplying the access. Measure volume flow in a straight non-aneurysmal segment of fistula/graft.
- Scan the circuit from feeding artery through the fistula/graft to the draining veins to the central veins.

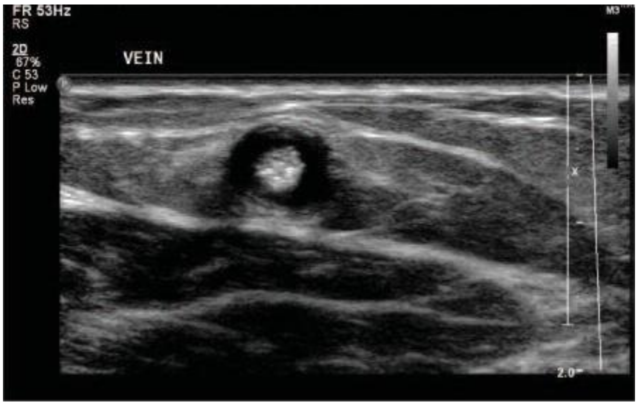
- Note any abnormality (thrombus, aneurysms, pseudoaneurysms, collections).
- Note any abnormal flows (unusual flow velocities or pulsatility, flow direction in veins).
- It there are multiple venous paths, draw them and state approximately the flow through each.
- Note where flow returns to the deep veins.
- Measure vein diameter and depth, especially if there are needling problems. Note any sudden change in vein direction and the presence of thrombus/intimal flaps, etc. in the needling area.
- Note any stenoses and measure them on B-mode and with peak systolic velocity and ratios of stenosis to pre- or post-stenosis velocities.

For fistulas with good a function, flow in the supplying artery is characterised by high velocity, low pulsatility flow [Figure 24]. At the site of a fistula, velocities are usually very high with sudden changes in direction and turbulent flow in which velocities may be difficult to measure accurately. The vein normally exhibits arterial-like pulsations up to axillary or the subclavian vein level.

Abnormalities and complications

In cases of occlusive thrombus in the access, flow in the supplying artery shows a high distal resistance that is usually a triphasic flow waveform. Thrombus is evident in the artery, vein or graft and there may be a small channel of flow around it [Figure 25]. It is important to determine the site and length of thrombus to help plan intervention.

Figure 25 Thrombus in a cephalic vein at a site of dialysis needling.



Accesses frequently contain stenoses [Figure 26] aneurysms [Figure 27] and/or pseudoaneurysms [Figure 28]. By themselves they do not necessarily preclude successful dialysis. The size of aneurysms and the change over time can be reliably established. Ultrasound can be used to plan intervention if required.

Figure 26 Flow through a cephalic vein stenosis showing a 4-fold velocity increase, velocities to 5 m/s, and distal turbulence.

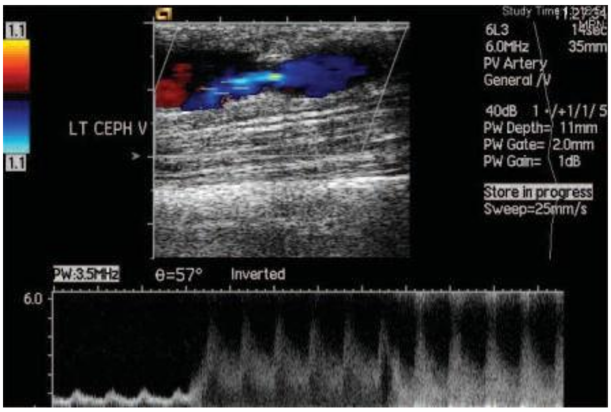


Figure 27 Colour flow in a bi-lobed superficial aneurysm. The valley between them is filled with ultrasound gel for contact.

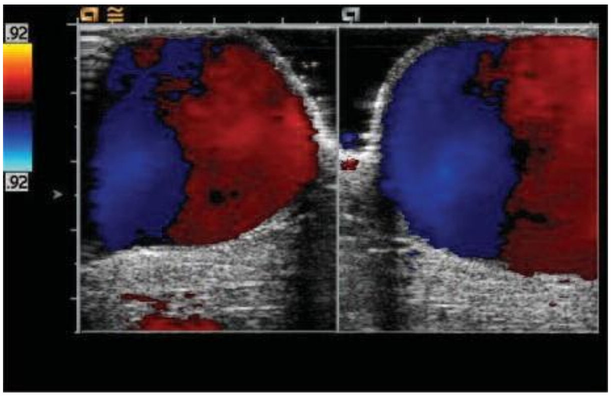
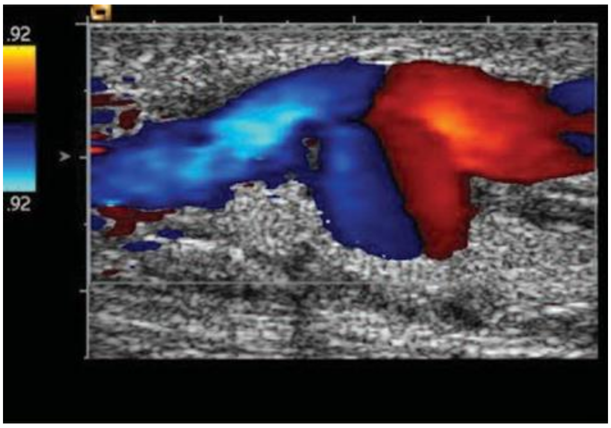


Figure 28 Pseudoaneurysm in a cephalic vein.



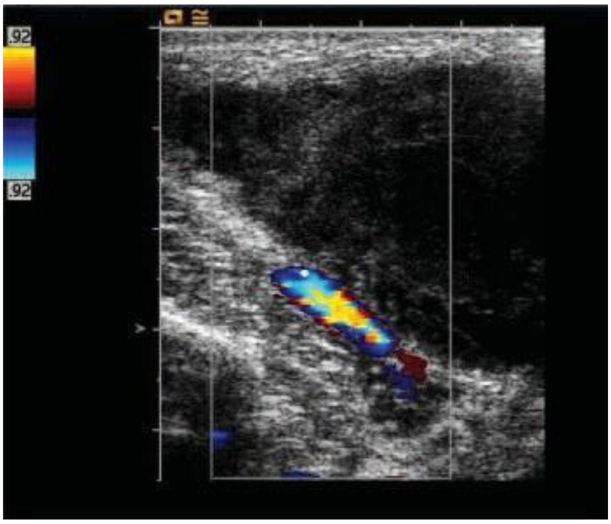
Stenoses are quantified by the PSV and the PSV ratio [Figure 26]. Typical criteria at the arterial anastomosis are PSV ratios of >3:1 [(51)]. Stenoses should, however, be assessed in the context of the flow measurement or changes in flow from a previous scan and from the clinical indications for the scan. Moderate stenoses - for example twice the PSV increase and a maximum velocity of 200 cm/s - may be not impair flow or access function and even more severe stenoses may be found in fistulas with good function. PSV ratios for stenosis along the fistula are >2:1 in narrowing in the draining vein or graft.

When reporting stenoses, measurement of PSV ratios should be made in combination with absolute measure of PSV to give an assessment of the anatomy, and severity and functional importance of the stenosis. Very high velocities (400–600 cm/s) are indicative of high pressure gradients.

Flow waveform changes are useful in identifying severe stenosis with more pulsatile flow up-stream of a narrowing and damped flow downstream and turbulent flow in the post-stenotic region.

Steal may occur in haemodialysis with inadequate flow to the distal tissue that results in pain in the hand and fingers and, if severe, tissue changes associated with ischaemia. Steal is associated with a high incidence of arterial stenosis in the arterial supply to the hand [(52)]. Pressure measurements in the digits show diminished pressure. Steals may be associated with high, normal or low volume flow in the fistula and are helpful and are an aid to plan therapy.

Figure 29 Haematoma compresses a cephalic vein post-operatively.



Collections and haematoma should be noted [Figure 29]. These can lead to difficulties when needling fistulas and can cause extrinsic compression of the access circuit. Very high volume flows are possible and can lead to cardiac problems. Ultrasound can be used to quantify the flow and monitor therapy.

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