CL1.5

5. Peripheral waveform assessment and segmental pressure ratios

General

The continuous wave Doppler probe is placed directly above the vessel at a 45-60 degree angle to the skin surface[1]. Slow movements are used to identify the loudest volume signal then adjustments are made to the angle to achieve the optimum Doppler signal[2]. Alternatively the assessment can be completed using pulsed wave duplex ultrasound.

Patient is rested supine for at least 10 minutes – during this time waveforms can be taken. If patient is unable to lie flat, ABPI should still be taken but the patient position should be noted in the report[2,4]. If it is not possible to obtain ABPI – the reason for not being able to obtain ankle or arm pressures needs to be stated in the report[2,3].

Technique

The common femoral artery is located in the groin using a 12-3MHz probe. Once the optimum signal is achieved, the waveform shape and quality (triphasic, biphasic or monophasic) are recorded[4]. The strength (volume) of the signal is recorded as either: - good, slightly reduced, reduced, weak (?arterial/venous) or absent[1,6].

The patient's leg is flexed to a 45 degree angle and the 12-3MHz probe is placed in the popliteal fossa. The popliteal artery Doppler waveform signal is recorded[2].

A 12-3MHz probe is placed posterior to the medial malleolus with light pressure (excessive pressure on pedal pulses may occlude the arteries)[2]. The posterior tibial artery is identified and the signal recorded. The same probe is then used to identify and record the strength of the anterior tibial artery on the anterior aspect of the ankle. If you are unable to access or identify the ATA and PTA, the dorsalis pedis signal on the dorsum of the foot, and the peroneal artery on the lateral aspect of the ankle can be assessed. The waveform shape and quality of all the present signals are recorded.[5]

A standard blood pressure cuff is placed around the right upper arm. The brachial signal is obtained using either an 8 MHz or a 4 MHz continuous Doppler probe connected to a Doppler waveform analyser[2]. If the Doppler waveform is of a good volume with a triphasic or biphasic waveform then the blood pressure cuff is inflated until the Doppler signals is lost. The cuff is then slowly deflated and the brachial systolic blood pressure is recorded when the Doppler signal is first heard. If the pressure in the right arm is reduced/ brachial signal is poor then use the left arm[1,7].

A standard cuff is placed around the ankle just above the medial malleolus. If an ulcer is present at the ankle a non-adherent dressing is placed beneath the cuff to prevent soiling. The strongest ankle signal is identified using an 8MHz continuous Doppler probe and the cuff is inflated as with the arm and the ankle systolic pressure recorded.[8]

The **ankle brachial pressure index** (**ABPI**) is recorded as the ankle/brachial pressure:

ABPI < 0.8 (reduced)[2]

Segmental pressures are taken using the same pedal Doppler signal but the cuffs are placed just below the knee, the just above the knee and as high as possible around the thigh[2,6]. This allows the operator to identify the level of disease.

ABPI>0.8 (normal)[2]

If patient suffers from angina or has had a recent heart attack then a foot flex exercise is performed. The technician raises the leg into the air (external support can be used – i.e. foam cushion) and the patient dorsi-flexes the foot for 1 minute after which the ankle pressure is retaken[1,2].

If the patient is relatively fit with no evidence of angina and is able to walk unassisted they can perform calf raises as quickly as possible for one minute.[5] Patient should be stood and holding onto the handle of a stool for support while performing calf raises.
The patient returns to the couch and lies supine and the pressure is retaken within 45 seconds. A fall in absolute pressure of greater than 20mmHg indicates a significant arterial stenosis[2].

ABPI >1.2 or incompressible at 220mmHg[15]

Toe Pressures: Patient may have calcified arteries and pressure ratios may be unreliable. In these cases toe pressures need to be performed either manually or using the automated Atys Systoe equipment[1,2]. A small cuff is placed around the base of the big toe - arterial signal obtained with a handheld Doppler or PPG– wearing headphones can help. The pressure can then be obtained. A ratio of greater than 0.6 is regarded as normal, an absolute pressure of 33mmHg or less is indicative of critical ischaemia[19].

ABPI Variability:

How systolic blood pressure is measured in the upper and lower limbs will clearly affect the ABPI calculation:

1. The usual variation in (absolute) BP measurement is between 5-10mmHg but remember the effect of “white coat“ hypertension[1].
Observer error: Due to lack of concentration, poor hearing/loud environment[19].

2. Physiological/pathological variation.

Here several factors can be influential:

a) The effect of patient positioning in relation to the level of the heart:

The patient should be supine and the equipment and limbs at heart level to reduce hydrostatic pressure inaccuracies[2].

b) Cardiac dysrhythmia: if the pulse is irregular (e.g. the patient is in atrial fibrillation) or where heart rate may be as slow as ~40bpm, it is essential that very slow deflation rate is used as too rapid deflation will lead to an underestimation of systolic blood pressure[2,17].

c) Technique-induced hyperaemia: Vowden et al (1996) note that repeated inflation of the cuff, or leaving it inflated for prolonged periods, can induce a hyperaemic response and hence lead to a fall in ankle pressure[16].

3. Variation due to equipment used for blood pressure measurement

a. The effect of cuff size (width):

If too narrow or too short a bladder is used, blood pressure (i.e. that needed to occlude the artery) will be overestimated; this "undercuffing" will hence result in "cuff hypertension" (Beevers et al, 2001 Part I)[11]. Conversely, there is albeit less clear evidence that "over cuffing" (using too long or too wide a bladder) may cause an underestimation of blood pressure (Beevers et al, 2001 Part I). Zwiebel states that **the cuff width should be at least 50% greater than the diameter of the limb in which pressure is being measured**. **The bladder length should be at least 80% of the circumference of the limb**[5,8].

b. The effect of cuff placement:

Anderson (2002) compared pressure and ABPI differences with cuff at ankle versus that 10cm above ankle, and found that the proximal position yields a higher pressure and ABPI by on average 4mmHg and 0.01 respectively. This was statistically but not clinically significant[12].

Waveform analysis:

This can provide much useful supplementary information to the ABPI, and yet is a poorly documented topic in the literature. One of the fundamental principles of Doppler blood flow waveform analysis is that the shape of an arterial waveform varies with the extent of proximal disease (amongst other things, such as disease at the site of measurement and distal disease, etc)[1].

Phasicity:

This is literally determined by how many 'bumps' are present in the contour of the waveform over one cardiac cycle[1,4].

Triphasic = three bumps, biphasic = two bumps, monophasic = one bump[4].

Directionality:

With the correct equipment (ie a bidirectional HHD with a graphical chart output), one may obtain and analyse graphical representations of ankle waveforms, looking for an indication as to the status of the aorto-iliac segment, namely by looking at the phasicity and directionality of the waveform contour over one cardiac cycle[1,2].

Forward and reverse flow = bidirectional.
Forward flow only = unidirectional.
Reverse flow only = unidirectional.[4]

In the peripheral vasculature, one may encounter the following types of waveform shape:

1. Triphasic bidirectional: Usually just referred to as triphasic, as one rarely if ever encounters a waveform with three phases that is unidirectional. This implies that the proximal vasculature is essentially normal/without significant (>50%) diameter stenosis, although in studies of the common femoral waveform it has been shown that the presence of a triphasic CFA waveform does not absolutely exclude significant iliac disease [Shaalan et al 2003 showed that 89%, not 100%, of triphasic CFA waveforms had no significant (<50%) iliac stenosis][20].

2. Biphasic bidirectional: This can be associated with a mild-moderate proximal stenosis, or can indicate normal/<50% stenosis proximally (arteries that have stiffer walls due to disease, e.g. calcification, are less compliant which can result in the loss of the third phase[20].

3. Biphasic unidirectional: This appearance is often called vasodilated – an essentially normal waveform with extended forward flow in diastole and no reverse flow, due to physiological change (e.g. temperature) of pathological change (e.g. ischaemia distally)[1,21].

4. Monophasic: Essentially 'one bump', with or without extended/continuous forward flow in diastole. One type of monophasic waveform which is highly predictive of significant proximal disease is the damped waveform (correctly referred to as tardus parvus, namely with a slow systolic upstroke and a low peak)[22].

Pole Test

In cases when patients have incompressible calf arteries due to medial wall calcification which yield falsely elevated ABPIs - the Pole test can be used to obtain a pressure reading at the ankle[23], however it would be preferable to perform a toe pressure assessment over the Pole Test.
In the pole test, the ankle or toe pressure can be measured without a cuff, using the hydrostatic pressure induced by leg elevation and recording the height above the heart at which the pulse disappears. The height in cm is multiplied by 17.5 to calculate an absolute pressure reading[24].

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CL1.6

6. Lower limb arterial duplex/graft surveillance/angioplasty(stent) surveillance –

a) Thigh arteries

Probe types – 12-3 MHz linear array[2,4,6].

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, medial-lateral ML) in centimetres, length of disease in centimetres[1,2].

Patient lies supine[1,7]. Due to the intimate nature of the scan, a chaperone should be offered[25].

The common femoral artery is visualised in the groin and followed proximal to the inguinal ligament[1,2].
The common femoral artery is then traced distally to the bifurcation and the profunda femoris and superficial femoral arteries are identified. The superficial femoral is traced along its length and through the adductor canal, visualisation is improved by flexing the leg at the knee to a 45 degree angle and turning the knee outwards[1,2,7].

Peak velocity readings and waveform shape and quality are recorded in the common femoral, at the profunda origin and at the superficial femoral origin, and at the proximal, mid and distal SFA[2,8].

If an area of stenosis is identified a peak velocity reading is taken immediately proximal, within and immediately distal to the diseased section. The colourflow and Doppler assessments are used to decide whether the disease is a stenosis or complete occlusion. The disease length and the distance from the medial malleolus is recorded. Any collateral vessels are noted. It should be stated whether the disease appears acute or chronic. It should be made clear in the report whether the distal superficial femoral reforms a disease free segment above the knee[7,8].
If there is a significant stenosis present, measure the maximum PSV through the stenosis (V2) and the PSV just proximal to the stenosis as a "normal" reference velocity (V1), to enable calculation of the velocity ratio V2/V1. Note that at the SFA and PFA origins it may not be possible to obtain a V1 measurement; the absolute PSV will then be used to grade the % stenosis. If within the SFA, mark the position and length of any significant stenosis with a single-use surgical marker pen and measure the distance to the medial malleolus[3,5].

Also remember to scan contralateral CFA when performing lower limb arterial assessments. In addition to our standard protocol if a patient has an iliac occlusion/severe disease (CIA, EIA or both) please scan contralateral iliac system. This may save the patient coming to VSU twice and speeds up the whole patient management process[9].

For assessment of the popliteal artery, the patient sits with legs dependent or lies flat with the leg slightly flexed at the knee and externally rotated[1,2]. Alternatively, having the patient lie on their side can allow a good view of the popliteal artery.

The popliteal artery is identified behind the knee and traced proximally ensuring that the full length of artery through the adductor canal is visualised and assessed[2,5].
The first arterial branch of the trifurcation is the anterior tibial (may not be viewed). The tibio-peroneal trunk is traced into the upper calf until it bifurcates into the posterior tibial and peroneal arteries. Waveforms are recorded and the velocities are measured in the popliteal and at each of the run-off artery origins and in any area where a stenosis is identified[2,11,12]. The number of run-off vessels viewed should be documented (0-3).

Velocity ratios:
Comparing Peak Systolic Velocity (PSV) in reference segment proximal to lesion (V1) with maximum stenotic jet PSV (V2) gives a V2:V1 ratio (namely V2/V1) which can be used as follows[1,2,10.27,28,29]**:**

Classification (diameter reduction)	Velocity Ratio	Disease level
0-49%	**<2.0**	**Mild**
50-74%	**≥2.0**	**Moderate**
75-99%	**≥4.0**	**Severe**

Absolute velocities:
For use when it is not possible to obtain a suitable reference V1:[24]

artery	**mean PSV (cm/s)**	**SD (cm/s)**
Aorta	76	17

CIA	111	17
EIA	112	49
CFA	90	41
SFA prox	89	23
SFA mid	83	25
SFA distal	74	21
Popliteal	59	12

! The above table shows peak systolic velocities for normal legs.
! For a normal distribution, 99% of observations will fall within the range of the mean +/- 2 standard deviations.

For example, if the iliac arteries are largely obscured by bowel gas, but an isolated section of flow is seen in the EIA with a velocity of 300cm/s we can suggest that significant disease is likely. Using the mean velocity in the table above as V1, we can use the same ratio criteria to stratify the severity of disease, e.g. ≥4 would indicate severe disease.

Ankle brachial pressure indices are performed. (See Peripheral waveform assessment)

b) Calf arteries – Calf vessels should be scanned along their length[26].

Probe types – 12-3 MHz linear array/ if needed – 5-1 MHz curved array[2,4]

Measurements – velocities in centimetres per second, length of disease in centimetres[1,5].

Patient lies supine or sits on the edge of the bed with their legs dependent (aids visualisation with severe disease, and allows venous filling which can be used to map the course of the arteries)[2].

The posterior tibial artery is identified posterior to the medial malleolus and is traced proximally. The peroneal artery is visualised deep to the posterior tibial artery (both arteries can be assessed throughout the length of the calf). If unable to visualise the peroneal artery with 12-3MHz – then you must try the 2-5 curved array, or attempt to view from an anterior approach[2,12,13].

The anterior tibial artery is identified on the anterio-lateral aspect of the ankle (do not apply too much pressure as the artery may be occluded by the transducer) and should be traced to the upper calf[12,13].

Velocities and waveforms are recorded from all the calf arteries at the ankle and proximal calf and also at any site of stenosis.
In the presence of proximal disease, calf velocities can be unreliable and disease should be graded mild, moderate, severe or occluded[1,8].

c) Prosthetic grafts (usually above knee femoro-popliteal, aorto-bifemoral grafts (ABG), fem-fem crossover).

Probe types – 5-1 MHz curved array, 12- 3 MHz linear array[2,14].

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, medial-lateral ML) in centimetres, length of disease in centimetres[1,2].

Similar scanning protocols as above, except only the segments just proximal, mid and distal to the grafts are assessed. Particular attention is paid to the proximal and distal anastomosis where waveform shapes and velocities are recorded. ABPI are taken to assess any disease progression in non-treated segments (patient has usually had a full assessment prior to surgery)[16,17].

With fem-fem crossover grafts it is important to record the direction of flow through the graft[1,2,18].

With ABG and fem-fem crossover grafts, the common femoral waveforms are recorded[1,2,18].

Waveforms, peak velocities, ABPIs and any areas of re-stenosis/new disease are recorded[17].

d) Vein grafts (usually below knee)

Probe types – 12-3MHz linear array[2].

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, medial-lateral ML) in centimetres, length of disease in centimetres[1,2].

Similar scanning protocols to above, except only the segments just proximal, mid and distal to the grafts are assessed. Care is taken to scan the length of the graft and velocities and waveforms are recorded at areas of stenosis (usually valve cusps). Waveforms, peak velocities, ABPI and any areas of re-stenosis/new disease are recorded. Avoid taking ABPI on fem-distal grafts as inflating the cuff leads to danger of occluding the graft[2,19,20].

If peak velocity is less than 45cm/s - graft is probably at risk of failure and this must be noted in the report[2].

e) Stent/angioplasty assessment

Probe types – 12-3 MHz linear array[4,6].

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, medial-lateral ML) in centimetres, length of disease in centimetres[1,2].

Similar scanning protocol to above. Care is taken particularly at the just proximal to, mid and just distal to the stent/angioplasty site. Waveforms, peak velocities, ABPIs and any areas of re-stenosis/new disease are recorded[2,20].

f)Pseudo-aneurysm diagnosis and compression.

Probe types – 12-3 MHz linear array[4,6].

Measure site of the feeder jet from the femoral bifurcation – if jet lies at or within 1cm of the bifurcation the pseudo-aneurysm will be usually be suitable for compression. The size of the sac must be measured in LS and TS, this is particularly important if the management results in thrombin injection as the radiologist will judge how much to use based on the size of the sac.

Suitability for compression depends on the position and width of the jet: the wider the jet the less likely it is going to successfully compressed. If the pseudo-aneurysm lies directly above the jet it will make it difficult to compress, the deeper the aneurysm i.e. if it originates off the posterior wall again it will be difficult to compress[1,2,21,22].

The dimensions of the pseudo-aneurysm must be recorded – length, AP and ML[21].

If no colourflow is seen filling a pseudo-aneurysm but there is evidence of fresh haematoma the report should state " no evidence of patent pseudo-aneurysm but areas of fresh haematoma noted, cannot exclude a thrombosed pseudo-aneurysm or slow bleed".

If the pseudo-aneurysm is deemed to be suitable for compression then it is necessary to arrange for the patient to come down on their bed. The patient may require analgesics as the compression can cause significant discomfort – the SHO/HO needs to supply and if necessary administer the pain relief.

Using the L7-5 probe, the vascular scientist needs to apply pressure over the jet of the pseudo-aneurysm and should attempt to occlude it. The first compression should last 10 minutes and the circulation should be checked with a hand held Doppler at the ankle to ensure patency. After 10 minutes the pseudo-aneursym needs to be checked to see if it is thrombosed or partially thrombosed. If still patent further compressions of 10 minutes need to be performed, up to a maximum of three sessions. If after the third session the pseudo-aneurysm is still patent then the patient should referred to interventional radiologist for thrombin injection.
If the pseudo-aneurysm has thrombosed then we need to rescan the patient the next day to ensure it remains occluded[2,22,23].

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g) Popliteal artery entrapment syndrome (PAES)
PAES is a rare developmental defect in which the gastrocnemius muscle, popliteus muscle or tendons neighbouring the popliteal fossa are abnormally formed and can cause extrinsic compression of the popliteal artery when the lower limb is maintained in certain positions[1,2]. Currently five anatomical variants of popliteal entrapment have been identified and are summarised in the table below[3]. However, over-development of the gastrocnemius muscle can produce similar entrapment of the popliteal artery, this sixth form is known as functional popliteal entrapment syndrome and is often observed in professional athletes or in those whose profession require physical activity [3,4,5]

Variant of PAES	Anatomical Abnormality
Type 1	Popliteal artery follows an abnormal course
Type 2	Medial head of gastrocnemius muscle lies in a lateral location impinging on popliteal artery that runs a normal course
Type 3	An accessory slip of gastrocnemius muscle impinges the popliteal artery that runs a normal course
Type 4	Popliteus muscle or fibrous band impinges the popliteal artery that runs a normal course
Type 5	Types 1- 4 and the popliteal vein is also entrapped

Anatomical variants of PAES[3].

Patients with PAES commonly present with intermittent calf claudication and parasthesia symptoms which exacerbate upon exercise. Since the patient demographic of those suffering from PAES is typically young athletic individuals, the symptoms are often likely to be attributable to musculoskeletal disorders rather than vascular disease[6]. However, differential diagnoses can include a number of lower limb disorders such as peripheral vascular disease, cystic adventitial disease, arterio-venous fistulae, compartment syndrome, muscle rupture, neuropathy and venous thrombosis [4,6] . If left undiagnosed, prolonged exposure to PAES can result in micro-trauma to popliteal artery, and can ultimately lead to localised stenoses, aneurysms or complete occlusion[3].

If PAES is suspected, current recommendations stipulate that stress positional assessment using spectral Doppler ultrasound and waveform analysis, when combined with Ankle Brachial Pressure Index measurements, can provide a rapid, non-invasive method for accurate diagnosis [4,6].

Note; approximately 50% of individuals experience popliteal entrapment in extreme plantar flexion and dorsiflexion positions[7].

Scan protocol
A full bilateral arterial duplex should be performed, as per previous protocol, to rule out any significant arterial pathology that could be the direct cause or contributing towards any

symptoms. Care should be taken to note any focal stenosis or aneurysms of the popliteal arteries as prolonged vascular microtrauma at an impingement site can be a contributing factor towards such pathology[3]. If PAES is diagnosed it is likely to be at this level[3].

Ankle Brachial Pressure Indices should be taken pre and post exercise as any enlargement of the gastrocnemius muscle post exercise can contribute towards popliteal entrapment, ultimately leading to a significant impingement of the popliteal artery and a related post stenotic pressure drop.

PAES assessment;
The patient should lie prone on an examination couch with both legs, from mid-calf level, extended past the edge of the couch[8]. Both popliteal arteries are assessed along their length in B-Mode, in both transverse and longitudinal planes, whilst the patient moves the feet into dorsiflexion and plantar flexion positions. If any compression is observed the location should be noted in relation the knee crease as this will aid the CVS when assessing the region further (compression will usually be at the level of the gastrocnemius muscle heads[8]).

Both popliteal arteries should be assessed along their length using colourflow, whilst the patient moves the feet into dorsiflexion and plantar flexion positions. If a narrowing is observed spectral Doppler measurements should be taken in both relaxed and flexed positions at the level of the impingement site. Care should be taken to adjust colourflow settings so that the region of highest velocity is sampled.
It may be necessary to provide resistance in a prone position in order to reach full dorsi-flexion and plantar flexion range and therefore a second CVS or healthcare assistant may be needed in order to aid with diagnosis[8].

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