**Protocols for non-invasive and minimally invasive assessments**

Independent Vascular Services Ltd

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| 25 | Iliac DVT scanning rationale | 286 | 09/08/2021 |
| 26 | Removal of AVP | 291 | 26/01/2023 |
| 27 | Thigh venous reflux – dependent angle | 296 | 29/01/2023 |
| 28 | GCA protocol/CEUS reference | 306 | 01/02/2023 |
| 29 | Measurement of Uncertainty | 331 | 28/03/2023 |

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**Contents Ref. Page no.**

1. **Patient identification preparation and care CL1.1 4**
2. **Basic guidelines CL1.2 6**
3. **Carotid/subclavian/vertebral duplex assessment CL1.3 7**
4. **Trans cranial Doppler assessment CL1.4 14**
5. Pre-operative
6. Intra-operative
7. Post-operative
8. Patent foreman ovale – assessment
9. Oximetry
10. Cerebral reactivity
11. **Peripheral waveform assessment CL1.5 18**

Pole Test

1. **Lower limb arterial duplex assessment CL1.6 24**
2. Thigh arterial
3. Calf arterial
4. Prosthetic graft surveillance
5. Vein graft surveillance
6. Stent/angioplasty surveillance
7. Pseudo-aneurysm compression
8. Popliteal artery entrapment syndrome
9. **Lower limb venous duplex assessment CL1.7 32**
10. General
11. Deep venous thrombosis assessment
12. Varicose vein assessment
13. Venous marking
14. LSV and SSV mapping
15. **TVDU for pelvic vein incompetence CL1.8 40**
16. **Aorto-iliac duplex assessment CL1.9 42**

a) Aorto-iliac segment

b) Aortic aneurysm/ EVAR repair

c) Contrast EVAR and 3D

1. **Visceral artery assessment CL1.10 52**
2. Anatomy
3. Mesenteric arteries
4. Renal arteries
5. **Upper Limb arterial assessment CL1.11 60**
6. Arterial pressures and waveforms
7. Duplex – arm arteries
8. Thoracic Outlet Syndrome
9. Radial artery conduit assessment
10. Hand-Arm Vibration Syndrome Assessment
11. **Upper limb venous assessment CL1.12 67**
12. **Arterio-venous fistula assessment CL1.13 70**
13. **Deep inferior epigastric perforator assessment CL1.14 76**
14. **Temporal and Axillary artery assessment CL1.15 80**

**1.** **Patient Identification, preparation and care**

**CL1.1**

1. Notes and/or referral letter should be read prior to approaching patient to confirm examination type.
2. Patient should be identified in the waiting area by name alone.
3. Patient should be directed to the examination room with aid from the clinical vascular scientist, CVS, (if necessary). If patient is a child or vulnerable adult then always scan in the presence of a parent/carer.
4. Once in the examination room, the CVS should identify themselves, and then the patient details should be confirmed by name, date of birth, and address. These details should be added to the examination sheet.
5. Patient should be asked what symptoms they have been experiencing or ‘do they know why they are here?’
6. CVS should explain briefly what they intend to do, gain verbal informed consent and put the patient at ease. For examination using contrast agents written consent should be obtained.
7. If consent not obtained patient should be directed back to ward/physician or A&E etc. Report on database patient attended but refused scan and any details surrounding visit. Log refusal on incident log on shared drive.
8. Patient is then asked to remove any necessary clothing or jewellery (with help of CVS if required). Explain that the gel is hypo-allergenic and water soluble so will not stain clothes.
9. CVS should assist the patient on to the examination couch and ensure patient is comfortable, (do not lift patients – mandatory manual handling instruction).
10. Examination is performed as per relevant protocol.
11. Patient should be assisted off the couch once they feel able, (do not lift patients). CVS should warn the patient that they may feel dizzy or lightheaded if they sit up too quickly.
12. CVS should explain where the results will be forwarded and who will explain the results. CVS could estimate a timeframe for the results to reach the referring clinician. CVS should not explain the outcome of the examination useless specifically directed by referring clinician.
13. CVS needs to arrange equipment to ensure maximum possible comfort and to reduce the likelihood of musculo-skeletal injury.
14. If there is an unexpected diagnosis that requires urgent clinical management then staff should understand the importance of contacting the vascular team on-call and trying to get the patient an urgent vascular opinion. See ‘Red Flag policy’ on shared drive.
15. If you require to mark the skin, please use the sterile disposal pens and tape measures available. Do not use normal pens to mark the leg – this is a cross infection risk.
16. It is standard policy to issue a report as soon as possible after the completion of the report. Reports from all patients are issued either in an electronic or paper format within 8 hours of completion of the vascular ultrasound report. If inpatient or Red Flag patient the vascular ultrasound report is placed in the notes or placed electronically on the host Trust wide reporting system within 10 minutes. If a Red Flag patient then the report will be immediately faxed to the consultant with a follow up phone call to ensure that is has arrived.

**CL1.2**

**2. Basic guidelines**

**Basic colourflow set-up**

Whilst visualising a vessel optimum colourflow is described as wall-to-wall filling of the vessel without colourflow scatter outside the vessel wall. This can be achieved by selecting the appropriate default setting, steering the colourflow box and adjusting the colourflow gain, wall filter and colourflow velocity functions. In addition, the colour velocity range needs to be set to allow slight aliasing.

**Velocity measurements**

The Doppler sample volume is placed in the area of fastest flow (as indicated by the colourflow map). The angle correct line should be set at 60 degrees and should lie parallel to the blood flow achieved by ‘tip-toe’ the transducer movement. If transducer movement cannot achieve parallel flow then the angle correct line should be altered to lie parallel with the blood flow, (but angle should be less than 60 degrees).

**Safety of Ultrasound and ALARA Principle**

There are two documented potential mechanisms for ultrasound to cause harm to patients. These are heating of soft tissue and cavitation2,4,12.

Both of these bio-effects are related to output intensity and exposure time to ultrasound.

The potential for thermal heating is displayed as the TI or thermal index and the potential for cavitation as MI or mechanical index.

There are three options for TI, being TIS – thermal index in soft tissue, TIB – thermal index with focus close to bone and TIC for trans-cranial imaging applications2.

There are no documented index thresholds for the different modality and control settings. The principle universally accepted by all ultrasound practitioners is the ALARA or ‘As low as reasonably achievable’ principle. This means that the total output energy applied to the patient must be kept as low as possible by reducing output power to its lowest level without compromising on image quality and by limiting exposure time without rushing a scan12.

It is the clinical vascular scientists’ responsibility to control the total energy emitted to the patient and must reconcile exposure time with diagnostic image quality12.

**Measurement of Uncertainty**

The uncertainty of a measurement tells us something about its quality. Uncertainty of measurement is the doubt that exists about the result of any measurement. You might think that well-made rulers, clocks and thermometers should be trustworthy, and give the right answers. But for every measurement - even the most careful - there is always a margin of doubt.

Measurement Uncertainty (MU) relates to the margin of doubt that exists for the result of any measurement, as well as how significant the doubt is. Measurement uncertainties can come from the measuring instrument, from the item being measured, from the environment, from the operator, and from other sources. Such uncertainties can be estimated using statistical analysis of a set of measurements, and using other kinds of information about the measurement process.

The use of good practice – such as traceable calibration, careful calculation, good record keeping, and checking – can reduce measurement uncertainties. When the uncertainty in a measurement is evaluated and stated, the fitness for purpose of the measurement can be properly judged.

In vascular science we are interested in the measurement uncertainty in terms of the calibration of our ultrasound machines and also to determine accuracy of our ultrasound examinations.

Please refer to our Measurement of Uncertainty Policy on how axial, lateral resolution and sphygmomanometer variability can affect our choice of probe for a particular scan type and impact on our measurements.

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1. **Extra-cranial carotid/ brachio-cephalic/ subclavian/ vertebral assessment**

**CL1.3**

Probe types – 12 - 3MHz

Measurements – Velocities in centimetres per second (cm/s), diameter (transverse; anterior-posterior, medial-lateral) in centimetres (cm) (if dilated/pre-op), length of disease (longitudinal) in cm.

Patient positioning and scanning approach – patients can be scanned supine or in a sitting position. A supine approach with the vascular scientist sat behind the patient’s head allows easy access to the neck and reduces the risk of RSI (repetitive strain injury) as the operator can rest their arm on the pillow or on the head of couch. The patient extends the neck and turns the head in the opposite direction to the side being assessed.

Both sides of the neck are always assessed1.

The carotid arteries can be viewed from a lateral or antero-lateral approach using the sternocleidomastoid muscle as an acoustic window2.

**B-mode assessment**

Intimal B-mode assessment is performed to achieve an accurate picture of the anatomy and identify the location of the carotid bifurcation as well as the presence of any plaque morphology2, 3.

Using B-mode, the common carotid artery (CCA) should be imaged in cross-section (transverse plane) and traced proximally to the clavicle until the subclavian artery is visualised. The distal brachio-cephalic artery may be visualised on the right side of the neck. On the left side, the origin of the CCA and subclavian arteries will not be visualised due to depth. The CCA should then be scanned along its length to the level of the bifurcation where the internal carotid artery (ICA) and external carotid artery (ECA) are visualised from their origins as far distal as possible.

The same method should then be repeated in longitudinal plane2.

**Colourflow assessment**

Using the Colourflow modality, the CCA is scanned longitudinally where it is traced from the proximal section at the level of the clavicle to the distal section where the bifurcation, ICA and ECA are visualised as far distal as possible.

Colour should be used to identify ECA branches, filling defects, occlusion and velocity changes/ turbulence, although diagnosis should not be made using colour Doppler alone2,3.

**Grading plaque morphology – greyscale echogenicity**

Switching to the greyscale imaging mode, a note can be made of the site, type and extent of plaque morphology.

The subclavian is visualised along its length in longitudinal section. The CCA, ICA and ECA are then viewed in cross-section and longitudinally. As soft plaque has the same echogenicity as blood, colourflow is the best modality for identification.

Soft plaque – associated with higher lipid content or thrombus. May have an anechoic or echolucent appearance similar to that of blood/fluid2,3

Mixed plaque – variable/ heterogenous appearance of mixed or random echoes with some echogenic and some echolucent areas2,3.

Dense plaque – homogenous appearance of bright white echoes4.

Calcified plaque – acoustic shadowing cast from the hardened plaque2,3.

Irregular – broken or irregular luminal surface but not generally an indication of ulceration16.

Ulcerative – an area of mixed plaque forming a ‘crater’ of at least 2mm depth. May be seen in cross-section as a ‘hook’ of mixed plaque surrounding soft plaque, or with blood visibly swirling within the crater2,3.

**Doppler assessment**

In the absence of significant disease, peak systolic velocity (PSV) measurements are taken from the CCA (1-2cm proximal to bifurcation) 1, 2, ICA and ECA. If the peak velocities are raised above 1.3m/s then the end-diastolic velocity (EDV) is also measured.

If significant plaques have been identified using B-mode and colour flow Doppler then further spectral Doppler samples are taken to investigate velocity increases and analyse the degree of stenosis in particular vessel. Stenosis in the ICA is graded using the criteria explained below. Atypical waveform profiles should also be noted2, 3.

In cross-section, the CCA is traced proximal towards the clavicle and the transducer is angled beneath the clavicle until the subclavian artery is viewed in longitudinal section. The subclavian is traced as far proximal and distal as possible making note of areas of turbulence or narrowing. The PSV is measured using Doppler ultrasound. A second Doppler reading is taken as far distal as possible and the waveform characteristics are recorded (e.g. triphasic, biphasic, monophasic, turbulent, damped etc.).

Velocities in kinked arteries are less reliable as vessel tortuosity can raise velocities17. Care must be taken to ensure that the angle is correct to blood flow rather than the vessel3. In reporting, it will be stated ‘peak velocities indicate x% - y% stenosis but no plaque morphology noted.

**Grading degree of carotid stenosis**

**Normal Velocities**:

**ICA:**

* average (avg) PSV = 54 – 88cm/s (distal to bulb)4
* avg PSV = 74cm/s, avg EDV = 29cm/s (distal to bulb)5
* velocity slightly elevated if patient hypertensive6
* maximum PSV noted in normal = 115cm/s7

**ECA:**

* avg PSV ~=77cm/s (normally <115cm/s)4
* avg PSV = 84cm/s, avg EDV = 16cm/s 5
* ECA velocities can be elevated by an ipsilateral ICA occlusion4

**CCA:**

* avg PSV = 60 – 100cm/s8
* avg PSV = 108 +/- 18 cm/s (mean +/-S.D.)9
* avg PSV = 78-108 cm/s 7
* avg PSV = 99cm/s, avg EDV = 27cm/s 5
* on average, PSV in L CCA exceeds PSV in R CCA by 5cm/s 9
* velocity slightly elevated if patient hypertensive6

**Carotid Criteria**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Diameter Stenosis** | **Morphology** | **ICA PSV**  **(cm/s)** | **ICA EDV (cm/s)** | **PSVica/**  **PSVcca** | **St Mary’s ratio** |
| **<25%** | **Normal** | **<125** | **<40** |  |  |
| **<30%** | **Intimal**  **Thickening** | **<125** | **<40** |  |  |
| **<30%** | **Plaque** | **<125** | **<40** |  |  |
| **<40%** | **Plaque** | **<125** | **<40** |  |  |
| **<50%** | **Plaque** | **<125** | **<40** | **<2** | **<8** |
| **50-59%** | **Plaque** | **>125** | **<40** | **<3.2** | **8.0-10** |
| **60-69%** | **Plaque** | **>125** | **40-110** | **3.2-4.0** | **11-13** |
| **70-79%** | **Plaque** | **>230** | **110-140** | **>4.0** | **14-21** |
| **80-89%** | **Plaque** | **>230** | **>140** | **>4.0** | **22-29** |
| **90-95%** | **Plaque** | **>400** | **>140** | **>5.0** | **>30** |
| **96-99%** | **Plaque** | **Trickle flow** | | | **Variable** |
| **100%** | **Plaque** | **Absence of flow** | | | **N/A** |

Sidhu and Allan. Ultrasound Assessment of Internal Carotid Artery Stenosis. Clinical Radiology, (1997) 52, 654-658. (Developed using data from Moneta et al. 1993, 1995).

CP Oates et al. Joint recommendations for Reporting Carotid Ultrasound Investigations in the UK. EurJ Vasc Endovasc Surg (2008) 20, 1-11.

Criteria are only reliable for internal carotid artery stenosis³.

ICA peak systolic velocities are less reliable in the presence of CCA disease and ratios should be used. The use of the ICA: CCA PSV ratio normalises ICA PSV measurements² ³.

Elevated velocities can be produced in the CCA, ICA19 and ECA in the presence of contralateral CCA or ICA stenosis or occlusion.

A significant proximal (CCA origin or brachio-cephalic) ipsilateral stenosis can reduce velocities in the CCA, ICA and ECA.

Aortic stenosis can reduce the velocities in the CCA only.

Peak systolic velocities from large carotid bulbs may be unreliable, estimate degree of stenosis using grey scale and diameter/area reduction measurement.

**Doppler Waveforms**:

* 1. CCA waveform has a low-resistance pattern (most of the CCA flow goes to the brain). Note that a small amount of post systolic flow reversal (giving rise to a triphasic waveform) is normal; reversal of flow evident for more than 50% of the duration of diastole should be regarded as abnormal (see point 5 below)10.
  2. Normal ICA waveform has low-resistance pattern (all of the ICA flow goes to brain)18.

3. Normal ECA waveform has a high-resistance pattern (vessel supplies a high resistance vascular bed). Note the prominent dicrotic notch, which represents closure of the aortic valve and the onset of diastole10.

4. Severe proximal stenosis (innominate artery, CCA origin, aortic valve) produces a damped waveform (“tardus-parvus”, where tardus infers the pulse is slow to rise and fall and parvus infers a small pulse.)4, 8. Essentially, the acceleration time to systole is increased, hence the slope of the systolic upstroke is reduced, and there is blunting and smoothing of the sharp peak representing a reduction in waveform pulsatility9. This effect is usually most prominent in the CCA, but is also sometimes seen in the ICA & ECA. Note that in the case of aortic valve disease or diminished cardiac output, damping is symmetrical (seen in both CCAs)4.

5. Severe aortic incompetence with or without the presence of significant aortic stenosis often produces either a bisferious (two systolic peaks, well separated from the dicrotic notch, with the second peak being the same height as or higher than the first) waveform10, or persistent reverse diastolic flow in the CCA, or both. Note that these effects are not usually seen in the ICA, but are evident in both the CCA & ECA.

6. Significant stenosis or occlusion of the distal CCA or the ICA causes a high-resistance ipsilateral CCA waveform; reverse flow is evident and often there is complete loss of end diastolic flow. Note that significant ECA disease does not usually impact on the CCA waveform due to its relatively low flow volume4.

**External Carotid Artery Assessment**

From searching the literature (pubmed, medline, science direct, quest) there is no evidence of a radiologically validated method for grading ECA disease using a velocity criteria.

There is normally little requirement for the grading of ECA disease due to its highly branched vascular network and non-cerebral involvement13,15. In cases where a patient experiences cerebral or ocular symptoms in the presence of ipsilateral ICA occlusion it may be useful to grade and characterise ECA disease as a possible cause of emboli and transient ischaemic attack (TIA). There is much published evidence extolling the benefit of surgical or radiological intervention for the treatment of ECA disease where there is ipsilateral ICA occlusion and a thorough examination of disease is important in these cases13,14,15.

At present staff use a visual estimation and/or use of electronic callipers to measure degree and extent of stenotic disease.

In the presence of an ICA occlusion, electronic callipers should be used in the transverse and longitudinal planes to measure degree of ECA stenosis. Length of stenosis, plaque characterisation and degree of turbulence should also be recorded in the report.

**Vertebral artery assessment**

The vertebral artery (VA) can be viewed if the transducer is angled posterior. The flow direction should be the same as the carotid flow direction and is checked using the colourflow, **but more** importantly the Doppler sample volume. Vertebral flow is graded as orthograde, oscillatory (i.e. reversed in either systole or diastole alone) or retrograde2,3. If no colourflow is identified within the vessel lumen – use spectral or power Doppler to investigate as it is more sensitive than colourflow4.

**Normal Velocities:**

* avg PSV = 20-40 cm/s2,3
* PSV<10cm/s should be regarded as potentially abnormal4
* Higher velocities may be normal in the dominant VA of an asymmetric pair.2,3
* Higher velocities may be normal with contralateral VA occlusion. 2,3

**Doppler Waveforms:**

1. Normal VA waveform has a low-resistance pattern (supplying the brain), with cephalad flow throughout the cycle2,4.
2. If the VA has a high-resistance, antegrade (cephalic) flow pattern, there is probably a significant obstruction distal to the site of examination. (The second most common site of VA atheroma is intracranially, just beyond the C1 arch)3.
3. Severe proximal stenosis produces a damped waveform; note that the most common site of VA atheroma is the VA origin, although this can be difficult to image as it originates from the posterior aspect of the subclavian artery3.
4. Subclavian artery origin stenosis can have varying effects on the VA waveform shape and the direction of flow, dependent on the degree of stenosis and the presence of other collateral pathways.

**Pre-operative carotid assessment**.

Staff must follow additional criteria when performing a pre-operative scan for carotid endarterectomy.

1. Length of disease from the bifurcation, into the ICA, must be documented.
2. Bifurcation needs to be marked on the skin surface – the image of the bifurcation is obtained then the probe is moved until the bifurcation is just off the leading edge of the probe, marks are made on the skin surface in transverse and longitudinal section. Where these lines transverse is the position of the bifurcation and an arrow should be drawn to mark the tip.
3. Take a picture of the disease and keep with our hardcopy.
4. Mark MCA signal – see TCD section

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**4. Transcranial Doppler (TCD) assessment**

**CL1.4**

Two prerequisites must be fulfilled before a TCD examination. The status of the extra-cranial arteries must be known and the patient must be positioned comfortably1,2. This avoids major fluctuations of Carbon dioxide pressure (PCO2)and movement artefacts. A 2Mhz pulsed, range gated Doppler with good directional resolution are instrumental requirements for a TCD examination1,2,3.

TCD insonates the cerebral arteries though formina or “windows” within the skull that can be penetrated with the ultrasonic beam. The main TCD approach is via transtemporal window1,2,3. The probe is placed on the temporal aspect of the head, cephalad to the zygomatic arch, anterior and slightly superior to the tragus of the ear. Using an anterior orientation of the beam allows for the insonation of the middle cerebral artery at a depth of 50-55mm.

**a) Pre-operative assessment.**

Turn on the TCD and alter parameters, (depth, power, and gain) to the appropriate settings. Place the probe with jelly on the patient’s head at the transtemporal position. Making small movements of the probe try to locate the middle cerebral artery, (MCA) and maximise the signal. To determine it is the MCA, blood flow should be towards the probe and it will be possible to trace the vessel for a 10mm distance between 45-55mm depth. In 30% of cases it will not be possible to identify any intercranial arterial signal due to the thickness of the skull1,2,3.

The location of the MCA signal is marked on the skin with a marker pen. This is to assist in signal location in the theatre environment the following day.

**b) Intra-operative assessment1,2,3,4**.

The patient enters the theatre in a supine position. It is necessary to place a bracket on the head of the patient to hold the probe in place for the duration of the operation. It needs to be firmly in place, but comfortable for the patient. Using arm pieces the probe is attached to the bracket and placed over the mark from the pre-operative assessment. Once the MCA signal is located the arm is tightened to the bracket to prevent movement artefact.

The peak and mean velocity of the MCA is recorded .A baseline reading is taken before the operation starts. Readings are taken at key points throughout the operation. During the carotid endarterectomy operation, one of key points is the use of the arterial clamps. If this causes a greater than 80% drop in the mean velocity of the MCA coupled with a greater than 12% fall in oximetry (Prof. McCollum’s criteria), (Registrars criteria – 60% TCD fall and 10% fall in oximetry).. Then the clinical vascular scientist recommends that shunt should be employed. When the clamps are removed, readings need to be taken to observe for a 100% increase in the mean MCA blood flow to guard against hyper-perfusion injuries.

Throughout the course of the operation the TCD will count the number of emboli (air or particulate) that are caused by the invasive nature of the procedure. When declamping the arteries an embolic shower is often heard and the number of emboli recorded.

Mr Welch only uses TCD unless there is no window, then he will use oximetry. Prof. Baguneid, Mr Ghosh and Mr Richardson do not use monitoring for routine carotids but may require TCD for redo carotid surgery or combined carotid, CABG or CBT dissection.

**c) Post – operative TCD2,3,4,5,**.

The number of emboli being detected should stop once the operation has finished. If emboli are still being detected it will be necessary to continue monitoring the MCA in the recovery area. In extreme circumstances when the number of emboli fails to diminish, the patient may be returned to theatre for further exploration of the carotid arteries.

**d) Patent Foramen Ovale, PFO investigation6**

The TCD equipment is set up as outlined above. The technique involves insonating blood flowing in the MCA to detect air micro-emboli entering the cerebral circulation. A microbubble suspension is injected via an antecubital vein and the TCD detects the emboli if a PFO is present. A venous to arterial shunt (v-aCS) may be spontaneous or stimulated by coughing or a Valsalva.

The cardiac cycle and the number of emboli after each provocation test are recorded.

**e) Oximetry.**

Throughout the carotid endarterectomy the patient is monitored in a number of ways. The TCD is used to measure the velocity of blood in the MCA – this is outlined above. In addition, infrared spectroscopy is utilised to measure the oxygen saturation of the brain tissue. To make this possible an area of scalp has to be shaved and the sensor containing the infrared emitter and detectors is adhered to the skin. It is made clear to the patient prior to the operation2,3.

The sensor is secured to the scalp at the same time as connecting the TCD equipment.

The oxygen saturation can then be monitored continuously throughout the operation. Any abnormalities are reported to the surgeon, ( mainly Prof. McCollum). Together with the TCD, criteria are used to determine whether an arterial shunt is required, (12% fall in oximetry and an 80% fall in TCD)2,3,4.

**f) Cerebral reactivity**

**General**

Some patients develop symptoms as a consequence of diminished cerebro-vascular function, (CBF); they have cerebrovascular insufficiency. In the presence of extracranial disease, cerebral autoregulation operates to maintain cerebral blood flow which results in progressive arteriolar dilatation, this is known as the cerebrovascular reserve.

When the cerebral micro-circulation is fully dilated it can become less responsive to changes in pCO2 and hyperventilation. Despite compensation via the Circle of Willis, a state may be reached where the cerebrovascular reserve is exhausted, i.e. there is no more capacity to increase the cerebral blood flow as the micro circulation is fully dilated.

The changes in cerebral blood flow may be measured using changes in velocity in the basal cerebral arteries, (MCA). The greater the change in blood flow velocity in response to pCO2 and hyperventilation the better the cerebrovascular reactivity, (CVR).

Absolute blood flow velocity varies with age, sex, posture and blood pressure

**Technique**

The patient is asked to rest supine for 5 minutes prior to the test.

The relative change in mean blood flow velocity can then be calculated non-invasively with transcranial Doppler ultrasound. Two 2MHz pulsed wave Doppler probes insonate the MCA bilaterally via the temporal windows. Mean MCA blood flow velocity is measured at rest, after inhalation of 5% carbon dioxide and after hyperventilation. The relative change in blood flow velocity is calculated as the cerebrovascular reactivity, (CVR).

The relative change in mean MCA blood flow velocity was taken to be the CVR:

CVR = (Vmax – Vmin)/V mean

Where: Vmax = maximum mean MCA blood flow velocity

i.e. after breathing a mixture of 5% CO2 in air

Vmin = minimum mean MCA blood flow velocity

i.e. after hyperventilation

Vmean = mean MCA blood flow velocity

i.e. after resting supine

CVR is 86% in normal (0.86) and significantly reduced in carotid occlusion. CVR has been categorized as follows:

Severe = less than 34% change

Moderate = 34-66% change

Mild = 66-85% change

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**5. Peripheral waveform assessment and segmental pressure ratios**

**CL1.5**

**General**

The continuous wave Doppler probe is placed directly above the vessel at a 45-60 degree angle to the skin surface1. Slow movements are used to identify the loudest volume signal then adjustments are made to the angle to achieve the optimum Doppler signal2. 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 report2.4. 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 report2,3.

**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 recorded4. The strength (volume) of the signal is recorded as either: - good, slightly reduced (slow systolic rise time), reduced (slow systolic rise time, damped sound), weak (?arterial/venous) or absent1,6.

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 recorded2.

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 analyser2. 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 (slow systolic rise time, damped sound)/ brachial signal is poor then use the left arm1,7.

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 thigh2,6. 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 retaken1,2.

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 stenosis2.

**ABPI >1.2 or incompressible at 220mmHg15**

**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 equipment1,2. 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 ischaemia19.

**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“ hypertension1.

Observer error: Due to lack of concentration, poor hearing/loud environment19.

1. Physiological/pathological variation.

Here several factors can be influential:

1. 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 inaccuracies2.

1. 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 pressure2,17.

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 pressure16.

1. Variation due to equipment used for blood pressure measurement
   1. 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.

* 1. 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 significant12.

**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 cycle1,4.

Triphasic = three bumps, biphasic = two bumps, monophasic = one bump4.

**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 cycle1,2.

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 phase20.

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 ankle23, 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 reading24.

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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 array2,4,6.

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, medial-lateral ML) in centimetres, length of disease in centimetres1,2.

Patient lies supine1,7. Due to the intimate nature of the scan, a chaperone should be offered25.

The common femoral artery is visualised in the groin and followed proximal to the inguinal ligament1,2.

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 outwards1,2,7.

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 SFA2,8.

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 knee7,8.

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 malleolus3,5.

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 process9.

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 rotated1,2. 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 assessed2,5.

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 identified2,11,12. 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 follows1,2,10.27,28,29:

|  |  |  |
| --- | --- | --- |
| 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 length26.

Probe types – 12-3 MHz linear array/ if needed – 5-1 MHz curved array2,4

Measurements – velocities in centimetres per second, length of disease in centimetres1,5.

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 approach2,12,13.

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 calf12,13.

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 occluded1,8.

**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 array2,14.

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, medial-lateral ML) in centimetres, length of disease in centimetres1,2.

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 graft1,2,18.

With ABG and fem-fem crossover grafts, the common femoral waveforms are recorded1,2,18.

Waveforms, peak velocities, ABPIs and any areas of re-stenosis/new disease are recorded17.

**d) Vein grafts** (usually below knee)

Probe types – 12-3MHz linear array2.

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, medial-lateral ML) in centimetres, length of disease in centimetres1,2.

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 graft2,19,20.

**If peak velocity is less than 45cm/s - graft is probably at risk of failure and this must be noted in the report2.**

**e) Stent/angioplasty assessment**

Probe types – 12-3 MHz linear array4,6.

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, medial-lateral ML) in centimetres, length of disease in centimetres1,2.

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 recorded2,20.

**f)Pseudo-aneurysm diagnosis and compression.**

##### Probe types – 12-3 MHz linear array4,6.

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 compress1,2,21,22.

The dimensions of the pseudo-aneurysm must be recorded – length, AP and ML21.

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 occluded2,22,23.

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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 positions1,2. Currently five anatomical variants of popliteal entrapment have been identified and are summarised in the table below3. 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 PAES3.

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 disease6. 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 occlusion3.

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 positions7.**

**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 pathology3. If PAES is diagnosed it is likely to be at this level3.

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 couch8. 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 heads8).

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 diagnosis8.

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**7. Lower limb venous duplex assessment**

**CL1.7**

**a) General**

Where possible, patients are assessed whilst standing, the majority of weight on the contra-lateral limb. The ipsilateral limb should be non-weight bearing to avoid muscular contraction of the veins. The knee should be slightly flexed and the foot turned outwards.12 For assessment of the popliteal and calf veins, the patient may sit on the edge of the bed placing their foot in the CVS’s lap, alternatively their feet may be placed on a raised stool. The thigh should slope downwards avoiding compression from the bed; the knee should be flexed with the calf muscles as relaxed as possible.2 There be occasions when you will need to assess for venous reflex in the thigh when the patient is sitting, if possible you need to avoid a horizontal thigh whilst assessing the femoral vein for reflux. Ideally to allow for the assessment of reflex and to minimise any external compression the thigh needs to be dependent for this assessment.

A mid frequency linear array transducer should be used (12-3 MHz linear array) to image the proximal leg and calf veins.1 A lower frequency curvilinear array transducer (5-1 MHz curvilinear array) should be used if it is necessary to image the iliac veins and inferior vena cava (IVC).1 An appropriate venous default setting should be selected on the machineto ensure that low venous flow can be detected1,3.

On calf augmentation all veins should fill from wall-to-wall with uniform blue colour. If the vein does not fill wall-to-wall, thrombus may be present. Investigation using different steering angles, lower colour PRF and wall filter settings should be utilised to optimise colourfilling.3 On release of the calf there should be no or very slight (<0.5s) retrograde flow, which indicates no significant reflux disease. 4 Vein patency or obstruction should also be confirmed by ultrasound compression.1

**b) Deep Venous Thrombosis Assessment (12-3MHz linear array)**

The transducer is placed in the groin in transverse plane and the common femoral vein (CFV) is identified medial to the common femoral artery.3

The Doppler sample volume is placed in the CFV, corrected to a 60 degree angle and steered to align parallel with common femoral vein flow. The sample volume gate should span the full diameter of the lumen.1,8 Venous flow should be phasic with respiration. The patient is asked to perform a Valsalva manoeuvre, i.e. a cough. If a cough does not produce a satisfactory response, a full Valsalva manoeuvre should be performed.1,6 Ask the patient to take a breath in and hold it, then to increase the pressure in their thorax. This is achieved by asking the patient to ‘bear down’ – pretending to go to toilet.1,4 This should result in a temporary reversal of venous flow and indicate patency of proximal veins. With a proximal obstruction, flow in the CFV will be continuous and aphasic with respiration, with poor or no response to Valsalva manoeuvre.1 If this occurs then the CVS should scan the iliac veins and IVC to assess whether there is a proximal DVT and/or a mass causing external compression of the vein.1,5,6

Following completion of the Valsalva manoeuvre, the common femoral vein should be compressed using external transducer pressure, to confirm patency.1 Assessment of competency (using colour/spectral Doppler) and patency (using compression) of all other deep proximal veins should be performed as follows. The distal CFV bifurcates into two deep veins. The deeper vein is the profunda femoris vein, the more superficial vein is the superficial femoral vein (SFV). The profunda femoris origin should be assessed whilst the SFV should be assessed along its length, adopting an increasingly anterio-medial approach.2,5 The popliteal vein is located within the popliteal fossa – care should be taken to scan as proximally as possible to overlap with the distal SFV.1

Manual compression of the deep veins should be repeated at regular intervals (2-3cm); failure to fully compress the veins may indicate the presence of thrombus.2 The echogenicity of the thrombus indicates its age. 11 Thrombus becomes increasingly echogenic over time, as it becomes more organised.1 In time, the vessel may begin to re-canalise – old residual thrombus can be seen to produce a scarred appearance, with multiple channels of flow seen.1 Slow or partial re-canalisation can result in deep venous insufficiency.1 Competency is assessed by calf augmentation using both colour and spectral Doppler - on release of the calf there should be no or very slight (<0.5sec) retrograde flow, which indicates no significant reflux.4

Deep calf veins should be assessed using manual compression, colourflow and spectral Doppler to assess competency. The transducer is placed into the popliteal fossa and the popliteal vein is identified lateral to the mid line. Up to eight gastrocnemius veins may be visualisedin the proximal calf, within the gastrocnemius muscle.2 The soleal veins are imbedded in the soleus muscle and are often less easily identified. Several soleal veins may be present which may have connections with other deep calf veins – often the posterior tibial or peroneal veins. Soleal veins are identified more distally than the gastrocnemius veins.2 If gastrocnemius or soleal veins appear particularly dilated, they should be assessed for competency using colour/spectral Doppler.

The anterior tibial veins may be seen as the first deep communication with the popliteal vein. Distal to this junction the tibio-peroneal trunk veins divide to form the posterior tibial and peroneal veins.1,12 It is sometimes easier to trace the deep calf veins from the ankle proximally. Placing the transducer posterior to the medial malleolus, both posterior tibial veins can be visualised adjacent to the posterior tibial artery.2 If the probe is angled slightly posteriorly the peroneal artery and veins should be visualised deep to the posterior tibial vessels.2 Placing the transducer on the anterior aspect of the ankle, the anterior tibial artery and veins can be visualised and traced.14 Placing your thumb and first finger on the anterio-medial or anterio-lateral aspects of the ankle and applying pressure can augment flow in posterior tibial, anterior tibial and peroneal veins in order to assess competency.1,2

When a DVT scan is requested the LSV, SSV and their junctions with the deep venous system should be assessed for superficial thrombophlebitis and obvious signs of incompetence.1,2,11 If the LSV is incompetent within 0.5cm of the SFJ, it is assumed that the SFJ is slightly incompetent even if no reflux is seen in the CFV.

Differential diagnoses of clinical DVT include (but are not limited to): Bakers cysts, superficial oedema, cellulitis, lymphoedema, thrombophlebitis, popliteal arterial aneurysms and superficial venous incompetence. If you identify an abnormal lesion during the course of your scan, note site, dimensions and descriptive information.

**Iliac Vein Scanning**

We do not routinely scan the iliac veins when scanning for a DVT as the cough or Valsalva manoeuvre is usually sufficient to diagnose any proximal disease. However there are certain scenarios when we need to scan the iliac veins to be clinically certain:

• Negative or poor Valsalva response

• Obvious leg swelling in the thigh

• Evidence of collateral veins in the proximal thigh/groin/abdomen

• Evidence of thrombus in the common femoral or bifurcation

• Previous known iliac DVT

• Unable to adequately visualise the common femoral or bifurcation (eg due to scarring, infection, injection site etc).

**Rescan Policy**

In some situations it is difficult to be certain that a vein is patent along its length. In such cases we state that we are “unable to fully exclude a DVT”. The scan is equivocal and upon the clinicians discretion usually requires a rescan 6-8 days later to check for DVT progression.2 Local protocols differ slightly as below:

**Oldham/NM:** The patient is brought back to have a further scan following an equivocal result. The equivocal vein and up to the popliteal vein is rescanned assessing for progression of the potential DVT.

**South Manchester/Bury/Stepping Hill:** The patient is brought back to have a further scan following an equivocal result. The symptomatic leg is fully rescanned from the CFV to ankle.

**Bolton/Blackpool/Arrowe Park/:** The patient is brought back to have a further scan following an equivocal result. The symptomatic leg is rescanned from the CFV to popliteal vein only, assessing for progression of the potential DVT in line with NICE guidelines

**Stepping Hill – Additional Information**

DVT referrals can be accepted from HASU (ED or A10) or the rapid access stroke clinics to aid patient flow through the ward/clinic. The patients are stent back to the ward/clinic with the result and the ward/clinician is informed of an equivocal result so that the patient can be brought back in a week for a rescan. The ward or clinician in clinic should arrange this and send us a repeat referral.

**c) Varicose Vein Assessment**

A full DVT scan is performed, as per the above protocol. Evidence of deep venous insufficiency and previous DVT should be clearly noted in the report. The superficial system should be assessed as below:

**Long Saphenous Vein**

Moving distally along the common femoral vein, the long saphenous vein (LSV) will appear as a superficial medial branch. Assessment of competency at the level of the sapheno-femoral junction (SFJ) should be performed by calf augmentation using colour/spectral Doppler.1 If the LSV is incompetent within 0.5cm of the SFJ, it is assumed that the SFJ is slightly incompetent, even if no reflux is seen in the CFV. The (LSV) should be traced along its length in longitudinal and transverse planes, as isolated segments of incompetence may be identified. Any incompetent branches/perforators should be noted.2

**Short Saphenous Vein**

The short saphenous vein (SSV) is identified in the upper calf and traced distally to ensure that it remains within the fascia into the lower calf. The SSV is checked for competency and patency and then traced proximal to its junction with the popliteal vein.10 Any incompetent branches/perforators should be noted.2  In the presence of SSV incompetence, the popliteal vein must be viewed proximal and distal to the sapheno-popliteal junction (SPJ) to determine whether the junction is incompetent.1 In some cases an SPJ may not be identified and/or the SSV may communicate with the vein of Giacomini which lies just beneath the fascia and extends into the proximal posterior thigh and may connect to the LSV.12

If the SPJ is incompetent, then its location needs to be recorded – the distance measured proximal to the knee crease and lateral/medial to the mid line.2,5

The distance of any incompetent perforators from the medial malleolus should be noted and marked if the patient is undergoing superficial venous surgery.2

Table: Grading of incompetence.1

|  |  |
| --- | --- |
| **Grade** | **Reflux Duration** |
| Normal | <0.5 seconds |
| Slightly Incompetent | 0.5 – 1.0 seconds |
| Incompetent | >1.0 seconds |

**Primary Varicose Vein Protocol**

The Vascular Consultant will review patient referral letters and specifically request the limited protocol outlined below.13

The protocol should be used in conjunction with the Section 5 ‘Lower limb venous duplex assessment’ from ‘Protocols for non-invasive and minimally invasive assessments’ for explanation of patient positioning probe, colourflow and Doppler settings.2

1. Assess common femoral vein for patency and competency.1
2. Comment of absence or presence of sapheno-femoral junction (SFJ) and its competency.2
3. Comment on absence or presence of long saphenous vein (LSV) and its competency.13
4. Comment on the absence or presence of anterior or posterior veins which form junctions to the LSV within 3cm of the SFJ, measure the distance of the junction to the SFJ, and comment on the competency of the vein.2,13
5. If an incompetent thigh vein is identified but the SFJ is absent, the position the vein reforms should be identified and measured and any incompetent thigh perforators identified and measured.17
6. Assess popliteal vein for patency and competency.2,13
7. Comment of absence or presence of sapheno-popliteal junction (SPJ) and its competency.1
8. Comment on absence or presence of short saphenous vein (SSV) and its competency.2,13
9. Incompetent thigh veins and SSV should be assessed for suitability for EVLT or VNUS as per full EVLT protocol (see copy below).
10. All other deep veins do not need assessment unless there is evidence of thrombus in the common femoral or popliteal veins.14
11. Calf perforators do not need to be assessed or measured.2,13

Patient will be reviewed by the Vascular Consultant and if necessary referred for full

Venous duplex protocol.

**Endovenous Laser Treatment/ VNUS protocol**

The inclusion criteria are as follows:

* 1. The LSV needs to follow a relatively straight course; it will be difficult to pass the laser up a tortuous vein. If the LSV leaves the fascia or becomes tortuous state the distance from the medial malleolus and also comment on general position.
  2. It needs to be checked whether the LSV is bifid – both veins can be treated providing they are of suitable diameter.
  3. The vein diameter (AP) needs to be measured at the junction, mid-thigh, knee level and the minimum diameter stated. If the LSV dilates make another diameter measurement and its distance from medial malleolus.
  4. Need to ensure LSV is widely patent – no evidence of recent/old thrombo-phlebitis.
  5. Any incompetent branches close to the SFJ need to be measured. If there is an incompetent branch less than 1-1.5cm from the SFJ then the patient will not be suitable for EVLT. Other major branches should also be identified.
  6. Redo LSV’s can be retreated with the laser if they are of a suitable diameter so provide measurements as above. State whether there is an intact/reformed SFJ or not.
  7. As with all superficial venous procedures the whole deep venous system needs to be competent and patent (Except for simple varicose vein assessments, where the patency and competency of the CFV and popliteal vein only need to be checked).
  8. Incompetent thigh accessory veins can be treated with EVLT/VNUS. Minimum and maximum diameters of these veins must be recorded, and if they exit the fascia, the approximate treatable length should be measured (from the SFJ to point at which they leave the fascia).

**d) Venous marking**

The patient should be asked to point out the major varicose veins or where they feel discomfort.14 Under direction of the patient any obvious varicosities should be traced to their junctions with the major venous branches and marked. Any perforators should be marked. The sapheno-femoral and sapheno-popliteal junctions should be marked if incompetent.15

When marking the SPJ or perforators prior to surgery you need to ensure the mark is directly above the structure of interest.2,15 In the longitudinal section, move the leading edge of the probe so the structure is just off the screen and mark either side of the leading edge.1 In TS , again move the leading edge so the structure is just off the screen and mark the skin on the upper edge of the probe.1,15 This should result in three marks on the skin surface and where the imaginary lines bisect marks the structure. Extend the dots towards the bisecting point but do not join up as the permanent ink has been known to tattoo the skin during surgery. The final mark should resemble an upside ‘T’ without a connecting section.2,15

e) Long (LSV) and short saphenous vein (SSV) mapping, 12-3MHz probe

In some cases of lower limb bypass surgery the saphenous veins are used as the conduits. Surgery that uses an autogenous vein can be greatly aided by a detailed preoperative venous assessment.2,15 Patient is assessed, when possible, in a standing position or sitting to facilitate maximum filling of veins.1 The LSV or SSV are identified, (outlined above in “venous duplex assessment”) and traced along their length in L.S. and T.S. to confirm patency and compression should be used to exclude thrombus/incompetency.14

In transverse section – A.P. diameters are measured in the proximal, mid and distal thigh for the LSV, and proximal, mid and distal calf for the LSV and SSV. In transverse section the probe is moved so the vein is just off the edge of the screen (ensuring probe is perpendicular to vessel) and marks are made along its length using the indelible pen to map out the vein.1,2,16

The course of the vein is marked on leg, allowing improved use of veins and better planning of the specific surgical approach. It minimises the dissection and reduces the frequency of wound complications.15

To be suitable as a bypass the vein has to be greater than 0.30cm and not varicose, thrombosed or tortuous.2,15

A full length review of the LSV will be produced with the tributaries marked and specific measurements recorded;

**Vessel Inner Diameter (**These will be recorded at 6 specific points)

Proximal Thigh, Mid-Thigh, Distal Thigh, Proximal Calf, Mid Calf, Distal Calf

**Varicosities/Tributaries** (including perforators)

The location and number of tributaries and possible varicosities will be marked and recorded.

**Intramural Thrombus**

The presence and location of any intramural thrombus will be noted.

**Total usable length**

The total usable length will be recorded based on a diameter greater than 0.3 cm and is measured from the sapheno-femoral junction.

**Depth from skin surface**

The depth from the skin surface will be marked.

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**8.Trans-vaginal ultrasound for pelvic vein incompetence (TVDU)**

**CL1.8**

**Consent**:

All patients need a verbal consent for the scan. It is **imperative** that patient understands that scan doesn’t cover general gynae pathology. TVDU is only for identification of pelvic vein incompetence.

All patients will undergo a trans-vaginal ultrasound, performed by a fully accredited Clinical Vascular Scientist (CVS) using a standardised imaging protocol:

Trans-vaginal imaging will be initiated with the patient supine pelvic resting on a foam wedge or pillow. The pelvis will be scanned in both longitudinal and transverse sections to identify bilateral internal iliac veins (IIVs) and bilateral ovarian veins (OVs).

Pelvic vein incompetence will be identified using a strong Valsalva manoeuvre to generate reflux. Reflux is currently classified as greater than 0.7s. Diameter of dilated pelvic veins should be measured (in LS view). Dilated pelvic veins can be reliably seen and ovarian vein and internal iliac vein incompetence detected with excellent positive predictive value. At the point of writing this protocol it has been agreed that IIVs and OVs greater than 5mm in LS diameter are dilated (based on review of 3 papers).

The patient will then be asked to stand up and the above steps need to be repeated in semi-standing position (couch raised, bottom resting at the edge of the couch, legs on a step).

Incompetence will subsequently be confirmed by descending venography prior to coil occlusion of incompetent veins.

All images are saved and appropriately annotated.

TVDU References

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**10. Aorto-iliac duplex including aneurysm surveillance and EVAR**

**CL1.9**

**a) Aorto-iliac – patient should attend fasted where possible.**

Probe types – C5-1 MHz curved array1,3

**Measurements**

Velocities in centimetres per second (cm/s)

Diameter in centimetres (cm)

Length of disease in centimetres (cm) 4

**Scanning protocol**

When possible, the patient should be starved for 10 hours1

Probe type – C5-1 MHz curved array1,3

The patient, where possible, should be examined in a supine position 1,12, and needs to be able to transfer and lie supine independently. If this is not possible then alternative arrangements need to be found within the department, this may involve manual handling with a hoist or suitable transfer equipment. Please adhere to local trust moving and handling protocols. CVS should not attempt to lift or transfer without suitable equipment or training.

[](http://www.google.co.uk/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0ahUKEwi11Ifcq4nPAhWLVxQKHaO7CusQjRwIBw&url=http://agam.dvrlists.com/abdominal-aorta-anatomy/&psig=AFQjCNG-DeoY0twn4MnKAE-ALKBsbj80fA&ust=1473752927615922)

Abdominal aorta and common side branches detailed in the above diagram13

A survey scan using B-Mode should be made in both Longitudinal (LS) and Transverse (TS) orientation in order to positively identify the abdominal aorta, in accordance with common surrounding structures/landmarks13. This allows the sonographer to take into account vessel positon and tortuosity before taking measurements.

The aorta should be assessed, using B-Mode and Colourflow (making sure to optimise image) from the proximal extent of the supra renal abdominal aorta (at the level of the xiphisternum, where possible use the coeliac axis and superior mesenteric arteries as a landmark2), to the level of the aortic bifurcation13.

Measure the cross-sectional AP diameter in transverse and cross-sectional AP in longitudinal planes. Also measure the ML dimension if the aneurysm is irregular in shape or if the ML dimension is larger than the AP. Measuring the ML dimension is more accurate from the coronal plane (scanning from the side)2. An aorta is aneurysmal if the aorta is greater than 3cm or if there is a 50% focal increase in diameter. If the aorta is aneursymal, a scan of the iliac, common femoral and popliteal arteries should be routinely performed.9

Always measure AP of the aorta even when doing a scan for disease.4,9

Measure and record the peak velocity of blood flow and the shape of the Doppler spectral waveform in the aorta (angle correct).6

Scan distal to the common iliac arteries. Measure and record the peak velocities/waveforms at their origins and distally. Visualise the external and internal iliac origins and record velocities and waveforms, (internal iliac arteries may not always be viewed). Follow the external iliac distally, alternatively it may be easier to trace the external iliac proximally from the inguinal ligament.5,6

Make a note of any turbulence or plaque morphology and record any increases in peak velocities.4

**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**:**

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

A greater than two-fold increase in peak velocity indicates a significant stenosis and the length of disease should be recorded.

If the common or external iliac arteries appear aneurysmal then measure diameter (AP x ML).1

**CIA Aneurysms**

There is no definitive evidence on surveillance frequency or measurement method (inner to inner or outer to outer wall). Sites should follow local protocols as agreed with local vascular clinicians to ensure reproducibility.

**b) Aortic aneurysm repair with Endo vascular arterial repair (EVAR)**

Probe types – C5-2MHz curved array3

Measurements – velocities in centimeters per second, diameter (anterior-posterior AP, medial-lateral ML) in centimeters, length of disease in centimetres.4

The stent graft/aneurysm is visualised and traced to the proximal margin. The neck of the aneurysm is measured in a longitudinal plane, to ensure oblique angles are not obtained, (AP). With a low colourflow velocity or power Doppler colourflow setting care is taken to ensure no leak is present at the proximal attachment site.7

The aortic aneurysm sac diameter is measured in both transverse (AP) and longitudinal (AP) planes. Also measure the ML dimension if it is larger than AP. 4

Measurement of the aortic diameter should be taken by both inner wall to inner wall and outer to outer wall. The diameter is measured at the transition between the bright echogenic echoes of the inner or outer anterior and posterior aortic wall boundaries and the more echolucent lumen or thrombus. 4

B-Mode images, Colorflow images and Doppler spectral waveforms are obtained of the aneurysm, graft body/neck, bilateral graft limbs and bilateral external iliac arteries. This is to ascertain that there are no impingements, compression, kinking, thrombosis, stenosis, effacement of attachment sites or dislocation of limbs and endoleaks1,5.

**Additional UHSM protocol:**

Recordings of a 5 second cine-loop of every AAA/EVAR in transverse should be taken where aorta is at its maximum diameter.

**Endoleak Definitions:**

An endoleak is defined as flow outside the endograft but within the aneurysm sac. The following definitions of an endoleak are used to classify the type of leak:

Type I- Leak at graft attachment site due to inadequate seal (Ia- Proximal attachment site, Ib-distal attachment site and Ic- In cases of uni-iliac stent; backfilling of aneurysm sac from a contralateral non-stented iliac artery).

Type II- Branch or reconstitution leak, whereby the excluded sac fills and empties via one or multiple aortic side branches. (IIa- single vessel, IIb- two vessels or more).

Type III- Structural failure of the endograft (IIIa- Limb disconnection, IIIb- Graft fabric disruption)

Type IV- Graft porosity

Type V- Endotension (continued expansion of the aneurysm sac greater than 5 mm, without radiographic evidence of a leak site). 8,10,14, 15

**c) Aortic aneurysm repair with Endo vascular arterial repair (EVAR) with contrast – 40mins**

**There is currently no available literature that states CEUS is safe for use during pregnancy or in paediatric patients. Until this is available these patient demographics should be avoided.**

Probe types – C5-1MHz curved array3

Measurements – velocities in centimetres per second, diameter (anterior-posterior AP, long section LS and medial-lateral ML) in centimetres, length of disease in centimetres.4

The stent graft/aneurysm is visualised and traced to the proximal margin. The neck of the aneurysm is measured in a longitudinal plane, to ensure oblique angles are not obtained. With low colourflow velocity or power Doppler colourflow setting care is taken to ensure no leak is present at the proximal attachment site.7

The aortic aneurysm sac diameter is measured in both transverse (AP x ML) and longitudinal (LS) planes. 4

Measurement of the aortic diameter should be taken by both inner wall to inner wall and outer to outer wall. The diameter is measured at the transition between the bright echogenic echoes of the inner or outer anterior and posterior aortic wall boundaries and the more echolucent lumen or thrombus. 4

B-Mode images, colorflow images and Doppler spectral waveforms are obtained of the aneurysm, graft body/neck, bilateral graft limbs and bilateral external iliac arteries. This is to ascertain that there are no impingements, compression, kinking, thrombosis, stenosis, effacement of attachment sites or dislocation of limbs and endoleaks1,5.

Patient requires cannulation for the administration of an initial dose of 1ml of contrast agent IV bolus via a peripherally inserted 20 gauge (BD-Pink) cannula. Smaller cannulas cannot be used as the micro bubbles will be destroyed. The contrast agent is mixed with 5ml of sodium chloride within the vial prior to being drawn into the syringe (see instructions below) and injected immediately into a peripheral vein followed by a 5ml saline flush.16

**Sonovue suspension instructions by manufacturer:16**

1. Connect the plunger rod by screwing it clockwise into the syringe.

2. Open the MiniSpike transfer system blister and remove syringe tip cap.

3. Open the transfer system cap and connect the syringe to the transfer system by screwing it in clockwise.

4. Remove the protective disk from the vial. Slide the vial into the transparent sleeve of the transfer system and press firmly to lock the vial in place.

5. Empty the contents of the syringe into the vial by pushing on the plunger rod.

6. Shake vigorously for 20 seconds to mix all the contents in the vial to obtain a white milky homogeneous liquid.

7. Invert the system and carefully withdraw SonoVue into the syringe.

8. Unscrew the syringe from the transfer system.

**Do not use if the liquid obtained is clear and/or if solid parts of the lyophilisate are seen in the suspension.**

**Sonovue suspension instructions by CVS:16**

1. Remove the vial from the box and remove the blue cap (cap can be disposed)
2. Remove the pre-filled syringe and remove the plastic cap at both ends.
3. Screw the plunger into the syringe.
4. Push the vial into the single use transfer sleeve.
5. Screw the syringe into the single use transfer system.
6. Slowly depress the syringe pushing the saline into the vial. This must be done slowly as not to destroy the phospholipid.
7. Shake vigorously for 20 seconds to mix all the contents in the vial to obtain a white milky homogeneous liquid.
8. Invert the system and carefully withdraw Sonovue into the syringe.
9. Unscrew the syringe from the transfer system.

**Do not use if the mixed liquid obtained is clear and/or if solid parts of the lyophilisate are seen in the suspension.**



Contrast administration is to be carried out by a physician unless the vascular scientist is qualified under the patient specific directive and is on the host trust indemnity for venous cannulation and drug administration. Ability to do so must be authorized by a manager and the lead for contrast. Any persons administering contrast must be immediate life support, Acute illness management and aseptic non touch technique trained. 16

**Sonovue Storage**

Sonovue does not require any special storage conditions. 16 Do not use it if after the expiry date stated on the label. 16 The dispersion should be administered within six hours of it’s preparation. Keep Sonovue out of the reach and sight of children.13, 16

**2D CEUS:**

The standard contrast pre-set is selected on the scanner. Contrast scans must not be performed without this pre-set due to the risks around MI and contrast. The microbubble contrast is then given IV bolus 1mL with a 5Ml Flush. 16 The transducer is then swept backwards and forwards over the abdomen and stent graft as to visualise its entire length to ensure no stenosis or compression is missed relating to the main body or limbs. Once this is complete a sweep is performed focusing on the detection of endoleaks. If a leak is detected it is interrogated to identify its source and its exit. The flash or destruct function can be utilised to destroy the micro-bubbles. You then note the time it takes for the contrast to re-enter the limbs and the leak. If there is a time delay this indicates a type 2 endoleak. If a type 1 endoleak is detected the attachment site is interrogated for effacement.

Upon completion of the contrast scan the colour Doppler mode is selected or the flash/destruct mode is used repeatedly to destroy/burn off the resolving microbubbles. The average half-life of Sonovue is between 6 and 12 minutes depending on transducer frequency. 16

It is possible to have complications associated with Sonovue. 16 Delayed reactions are rare but can occur. The ‘crash trolley’ must be immediately available and within the vascular studies department whilst CEUS scans are taking place. If the scan is taking place in other locations, e.g. ward or theatre, the scientist must ensure there is a trolley nearby before commencing the scan. 16

Patients must be kept in the department for a minimum of 30 mins from the point of the last IV bolus of Sonovue and the cannula must be left in situ for this time period for the administration of emergency medication in the event of anaphylaxis. 16

**Endoleak Definitions:**

An endoleak is defined as flow outside the endograft but within the aneurysm sac. The following definitions of an endoleak are used to classify the type of leak:

Type I- Leak at graft attachment site due to inadequate seal (Ia- Proximal attachment site, Ib-distal attachment site and Ic- In cases of uni-iliac stent; backfilling of aneurysm sac from a contralateral non-stented iliac artery).

Type II- Branch or reconstitution leak, whereby the excluded sac fills and empties via one or multiple aortic side branches. (IIa- single vessel, IIb- two vessels or more).

Type III- Structural failure of the endograft (IIIa- Limb disconnection, IIIb- Graft fabric disruption)

Type IV- Graft porosity

Type V- Endotension (continued expansion of the aneurysm sac greater than 5 mm, without radiographic evidence of a leak site). 8,10,14, 15

**3D CEUS**

At the same as the 2D CEUS scan is performed, 3D data is simultaneously acquired.

The 3D system comprises of a computer, tracking sensors attached to the IU22 or RE7 C5-1probe and an electromagnetic box

These tracking sensors measure the position of the ultrasound probe in time and space. The system then utilises its pattern recognition algorithms to transform the thousands of 2D ultrasound images into a single 3D volume of the observed area.

The 3D scan will not add any extra time to the CEUS scan or result any further intervention with the patient. It will simultaneously produce five visual displays from the one scan.

1. Each 2D US image is displaced in sequence and can be scrolled back and forth through the data like a cineloop. It will create a 3D image that can be enlarged, and rotated so the aneurysm sac, and the graft can be identified from every single angle.
   1. It will concurrently capture three different planes of the 2D images termed multi-planar reconstructions. These 2D images can be manipulated to enable the viewer to virtually peer around the edges of the anatomy being observed, whilst simultaneously seeing the same point of the anatomy on the screen in the two other planes. It is also possible to enlarge these images and travel along the length of the aorta at any angle selected. This function creates a super slow playback enabling extra-ordinarily detailed interrogation of the vessels.

The images are automatically saved.



(Fig 2. Screen shot of the tomographic ultrasound following EVAR. Left image is the 3D reconstruction that has been cropped to demonstrate the stents and Endoleak. Top middle is the 2D US images. Top right is the transverse MPR of the EVAR. Bottom middle is the sagittal MPR of the EVAR. Bottom right is the coronal MPR of the EVAR. The slide bars on the right hand menu are for cropping diameter (makes the sphere larger or smaller) and to adjust the contrast and brightness of the image such that the stent and leak can be visualised more clearly. The (3D) button in the bottom right of the 3D volume will change the render mode).

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**10. Visceral artery assessment**

**CL1.10**

Probe – C5-1 MHz curved array

1. **Anatomy**

First branch from abdominal aorta – Coeliac axis (CA), characteristic seagull shape in T.S. is the most cephalad visceral branch of the abdominal aorta. It arises anteriorly and bifurcates approximately 1 - 3 cm from its origin into the common hepatic (right side of body) and splenic arteries (left side of body)1,2.

Second branch – Superior mesenteric artery (SMA) extends superficial and parallel with the aorta in L.S. SMA arises from the anterior surface of the aorta just distal (<=1cm) to the coeliac axis and gives rise to multiple branches. It is generally most easily identified in longitudinal section, although in transverse section it is distinctive by virtue of the triangular mantle of fat which surrounds it, as well as its relationship to the SMV (which it lies to the right of), pancreas and splenic vein (which lie anterior), and left renal vein (which lies posterior to SMA and anterior to the aorta)1,2.

Renal arteries should be identified less than 3cm distal to the origin of the SMA1,2.

Third branch – left renal artery and is crossed by the left splenic vein and sometimes the inferior mesenteric vein.

Fourth branch – right renal artery and is crossed by the inferior vena cava.

Both renal arteries divide to give the inferior suprarenal artery which feeds the lower part of the kidney. Accessory renal veins may arise above or below the renal arteries.

Half to three quarters of the way between the renal arteries and the aortic bifurcation, the inferior mesenteric artery arises anteriorly and runs parallel with the aorta. The IMA is the most caudal branch to come off the antero-lateral surface (usually to the left) of the abdominal aorta. It is occasionally difficult to visualise sonographically, presumably due to it being a narrower calibre vessel than the SMA or coeliac axis1,3.

1. **Mesenteric arteries**

Symptoms – Epigastric pain following eating (post –prandial) and weight loss.

#### Doppler velocities and waveforms of the mesenteric vessels

A normal SMA or IMA waveform in a fasted patient has a triphasic, high-resistance pattern with low diastolic flow1,3,4. After the ingestion of a meal, this changes to a low-resistance flow pattern1. PSV in the SMA increases post-prandially by only 40% but, due to the large increase in diastolic flow, the mean flow velocity increases by about 160%1,3. In contrast, the coeliac axis has a low-resistance flow pattern, because most of the blood flowing through this vessel supplies the liver and spleen. There is no noticeable change in flow pattern upon eating1,3.

**Normal signals** –

**CA**- monophasic waveform fasted, Mean PSV 148cm/s, EDV 40cm/s5, increased velocity post prandial (PSV> 200cm/s).

**SMA** – triphasic waveform fasted, increased velocity and monophasic post prandial Mean PSV – 161cm/s, EDV 29cm/s5 .

**IMA** – triphasic waveform fasted, increased velocity and monophasic post prandial**:**

* PSV = 98+/-30cm/s, EDV = 11+/-5cm/s6.
* PSV = 141 +/- 48 cm/s, EDV = 10 +/-16cm/s7.

The tables below detail abnormal fasting peak systolic (PSV) and end diastolic (EDV) velocity criteria for both stenosed and stented coeliac axis and superior mesenteric arteries5,21. A third table also provides abnormal aorta and CA/SMA PSV ratios. Stenting of the mesenteric vessels can be considered as an alternative to open revascularisation in cases of chronic mesenteric ischemia, this often leads to altered vessel compliance and elevated peak systolic velocities21.

Table 1- PSV Criteria

|  |  |  |  |
| --- | --- | --- | --- |
| Native Vessel Stenosis | PSV(cm/s) | Sensitivity | Specificity |
| CA >50% | 240 | 87 | 83 |
| CA >70% | 320 | 80 | 89 |
| SMA >50% | 295 | 87 | 89 |
| SMA>70% | 400 | 72 | 93 |
| In Stent Stenosis | PSV(cm/s) | Sensitivity | Specificity |
| CA >50% | 274 | 96 | 86 |
| CA >70% | 363 | 88 | 92 |
| SMA >50% | 325 | 89 | 100 |
| SMA>70% | 412 | 100 | 95 |

Table 2 – EDV Criteria

|  |  |  |  |
| --- | --- | --- | --- |
| Native Vessel Stenosis | EDV(cm/s) | Sensitivity | Specificity |
| CA >50% | 40 (45) | 84 (80) | 48 (58) |
| CA >70% | 100 | 58 | 91 |
| SMA >50% | 45 | 79 | 79 |
| SMA>70% | 70 | 65 | 95 |
| In Stent Stenosis | EDV(cm/s) | Sensitivity | Specificity |
| CA >50% | 58 | 83 | 100 |
| CA >70% | 105 | 77 | 100 |
| SMA >50% | 27 (30) | 92 (88) | 50 (67) |
| SMA>70% | 110 | 85 | 89 |

Table 3- SMA/CA Aorta ratio cuts off for >50% and >70% stenosis.

|  |  |  |  |
| --- | --- | --- | --- |
| Native Vessel Stenosis | SMA or CA/Aortic PSV Ratio | Sensitivity | Specificity |
| CA >50% | 2.75 | 82 | 71 |
| CA >70% | 4.5 | 76 | 87 |
| SMA >50% | 3.5 | 72 | 78 |
| SMA>70% | 4.5 | 72 | 83 |
| In Stent Stenosis | SMA or CA/Aortic PSV Ratio | Sensitivity | Specificity |
| CA >50% | 3.52 | 91 | 100 |
| CA >70% | 5.75 | 81 | 100 |
| SMA >50% | 3.46 | 88 | 67 |
| SMA>70% | 8.45 | 69 | 100 |

The table below details >50% native IMA stenosis criteria including fasting peak systolic (PSV), end diastolic (EDV) and IMA/Aortic PSV cut off values22.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Native IMA Vessel Stenosis | PSV (cm/s) | Sensitivity | Specificity | Overall Accuracy |
| ≥50% | ≥250 | 90 | 96 | 95% |
| Native IMA Vessel Stenosis | EDV (cm/s) | Sensitivity | Specificity | Overall Accuracy |
| ≥50% | ≥80 - ≥90 | 60 | 100 | 86% |
| Native IMA Vessel Stenosis | IMA/Aortic PSV Ratio cut off | Sensitivity | Specificity | Overall Accuracy |
| ≥50% | ≥4 - ≥4.5 |  |  | 93% |

**Assessment**

Patient should be assessed supine, after an overnight fast. PSV should be recorded using a 1-1.5mm sample volume and less than 60 degree of insonation5,21.

1. Scan the aorta in longitudinal section and look at the general condition of it and the SMA, CA and IMA, documenting the PSV in the proximal abdominal aorta (check) and the patency of the mesenteric vessels.
2. In turn, scan the SMA, CA & IMA, obtaining representative flow velocities (PSV & EDV) and waveforms, whilst ensuring that in the presence of a stenosis the maximum PSV is measured. [Most commonly a stenosis may be found at the origin of the artery, although fibromuscular dysplasia will manifest itself as a diffuse narrowing throughout the vessel and in particular the SMA should be scanned over several centimetres to exclude this condition].
3. If the coeliac axis cannot be identified, examine the common hepatic artery to check for retrograde flow.

CA should be assessed both with inspiration and expiration to exclude extrinsic compression by the median ligament – median arcuate ligament syndrome (MALS) (i.e. increased velocity with normal respiration which reduced with deep inspiration indicates extrinsic stenosis). If MALS is suspected follow the MALS protocol.

1. **Renal arteries**

Normal signals – Monophasic waveforms, Average PSV – 104cm/s +/- 25cm/s.

Parenchyma velocity should be >10cm/s, if the renal arteries are not viewed and < 10cm/s may indicate occlusion10,11.

Kidney length should be greater than 9cm10,11.

Assessment3,10,11

*Patient assessed supine with head at 30% elevation.*

Identify renal artery origin, midsection and distal renal artery. It is not always possible to identify the midsection but proximal and distal segments should be enough to assess.9

Record the PSV and acceleration time should be recorded in the aorta and in the renal arteries along their lengths10.

*Turn patient on side and visualise kidney from posterio-lateral aspect.*

Measure the maximum length of the kidney and the peak velocities in the distal/mid renal arteries and the parenchyma of the kidney.

Hilar Doppler assessment – *Press the Doppler button (top left section on ATL 5000) and change measurements to Frequency and make note of transmitted frequency.* View kidney in a cross section from the flank. Then take the readings with a 0 degree angle from the Hilar artery.

Once Doppler signal is on screen, press the Adv calcs. Button and select time/ slope measurement.

Place the first cursor at the base of the systolic up stroke, press select then place the second cursor at the top of the up stroke. Record the acceleration time in milliseconds and kHz/second reading (hypotenuse)

b

a

a = acceleration time(ms), b = change in frequency (kHz) – record kHz/sec.

Acceleration time (ms) is the time interval between onset of systole and the initial peak.

Acceleration index calculated by the hypotenuse of the slope divided by the transmitted frequency.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Normal | <60% | >60% | Occluded |
| Aorta velocity | >60cm/s |  |  |  |
| Renal velocity | 104 +/- 25cm/s | <180cm/s | >180cm/s |  |
| Renal/aorta |  | <3.5 | >3.5 |  |
| Hilar acceleration time |  | <100msec | >100msec |  |
| Hilar Acceleration index |  | <3.78kHz/s/MHz | >3.78kHz/s/MHz |  |
| Parenchyma velocity |  |  |  | <10cm/s |
| Kidney size | >9cm |  |  |  |

1. **Median Arcuate Ligament syndrome (MALS)**

Diagnosis of MALS (Median Arcuate Ligament Syndrome) is typically made using a combination of radiological findings (such as Duplex, MRA or CTA) and clinical symptoms that cannot be attributed to any other factor 19. In comparison to atherosclerotic coeliac artery stenosis, where PSV is increased regardless of breathing phase, patients with MALS typically demonstrate an increase in PSV during expiration, returning to normal velocity range during inspiration 14,15 as the coeliac artery descends in the abdominal cavity, moving away from the medial arcuate ligament (MAL).

Patients under investigation for MALS should be scanned both supine and erect, as several case studies have found a decrease in observed vessel narrowing and subsequent PSV decrease when patients were scanned erect 14. This positional change may be key to correctly distinguishing MALS from atherosclerotic coeliac artery stenosis.

The patient may present with symptoms including the following;

1. Weight loss, nausea, vomiting, diarrhoea, post-prandial pain 20
2. Epigastric pain during exercise19
3. Expiratory systolic bruit 18

SCAN PROTOCOL – MALS

Probe – C5-1MHz Array

A full mesenteric Duplex assessment should be performed as described in section 11b above. This is important as any other cause of possible ischaemic post-prandial abdominal pain needs to be excluded before MALS can be potentially diagnosed.

The patient should initially be scanned supine after an overnight (>8hr) fast (clear liquids allowed). PSV should be assessed using a 1.5mm sample volume and an angle of insonation of less than 60 degrees.

The coeliac axis (CA) should be imaged and identified as follows;

1. The abdominal aorta should be identified in transverse plane using B-mode imaging as far proximally as can be visualised. The vessel should be followed distally until the origin of the CA can be visualised.
2. Once the level of the CA has been identified, the CA should be followed distally in transverse as far as its bifurcation into the common hepatic and splenic arteries. (Note typical ‘seagull’ appearance).
3. The CA should then be assessed in longitudinal plane in B-mode imaging. Care should be taken to note the appearance of the CA; the typical appearance of MALS positive CA is a ‘hooked’ appearance, especially at the anterior wall.
4. Repeat steps B and C using colour Doppler imaging, identifying any areas of turbulence or possible raised velocities.
5. Spectral Doppler waveforms should be obtained in the aorta just proximal to the origin of the CA 12,13.
6. Spectral Doppler waveforms should then be obtained in the proximal-mid CA during three phases of breathing 12,13;
   1. Maximum expiration,
   2. Maximum inspiration,
   3. Neutral.
7. Normal CA waveform should be low resistance, with continuous forwards flow during diastole. Average normal PSV has been found to be approx. 98-105cm/s 17.
8. Velocity criteria to determine significant CA narrowing in MALS has been defined as follows;
   1. PSV >200cm/s within celiac artery; Celiac Artery-Aortic ratio >3.0 during expiration, with velocities returning to normal values during inspiration 12,13,14,15,17,18.
9. At this point, the patient should be asked to stand and spectral Doppler measurements should be repeated in the CA as in step (f). When standing, the CA descends deeper into the abdominal cavity, and typically results in relief of compression via the MAL. Therefore a reduction in PSV in the CA, reduction in observed narrowing and turbulence may be noted upon standing 13,16.

\*Suggestion – to allow adequate transducer pressure to be applied to the abdomen (to obtain satisfactory image) perhaps the bed could be raised to a height that allows the patient to lean against.

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**11. Upper limb arterial assessment.**

**CL1.11**

1. **Arm arterial pressures and waveforms.**

Patients are examined in a seated position with their arms extended, elbows resting on an examination couch or supported by pillow.

Using continuous ultrasound Doppler an 8MHz probe is used to obtain a brachial signal and the waveform is recorded. The signals in the radial and ulnar arteries are obtained and the waveforms recorded.

Using a sphygmomanometer and a cuff around the upper arm, the blood pressure is obtained using the brachial signal. Then placing the cuff around the lower arm, the blood pressure is recorded using the radial and ulnar arteries.

To obtain a post exercise pressure ratio, the patient is requested to flex the arm at the same time clenching and unclenching a fist for a minute. Then the blood pressure is recorded using the radial artery. Repeat for left arm.

1. **Duplex scanning of upper limb arteries – 12-3MHz probe.**

The patient is examined in the sitting or supine position. The scanning room should be warm (>20°C)1

The subclavian artery may be visualised through a supraclavicular, infraclavicular or sternal notch approach1. Whenever possible, the origin of the left subclavian artery, and origin of the right subclavian artery from the brachiocephalic should be visualised. The subclavian artery should be followed distally as crosses under the clavicle and over the first rib (checking for stenosis or dilatation) where it becomes the axillary artery1,5. The subclavian artery is the most difficult of the upper limb arteries to visualise and a combination of approaches is often necessary.

As the axillary artery travels distally, it becomes progressively more superficial. The axillary artery becomes the brachial artery where it crosses the teres major muscle. The brachial artery moves anteriorly as it travels distally. It is subcutaneous in the antecubital fossa and crosses the elbow where it bifurcates into the radial and ulnar arteries.

Forearm arteries can be followed from the antecubital fossa to the wrist. As the arteries are traced distally, they initially dive beneath the forearm flexor muscles but become superficial at the wrist. CVS need to be aware of anatomical variations of the arterial anatomy in the upper limb.

Normal waveforms in the upper extremity arteries are triphasic1. In normal individuals, haemodynamic resistance in the arm may decrease markedly due to vaso-dilatation with arm exercise or in a warm room and the flow pattern may become good but monophasic1. Velocities and waveforms need to be taken throughout the vessels – noting areas of turbulence and stenosis1.

Bilateral brachial pressures should be taken when scanning upper limb arteries to rule out proximal subclavian and/or brachiocephalic stenoses.

**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**:**

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

1. **Thoracic Outlet Syndrome assessment –** always perform as part of a full upper limb assessment (modified Wright’s test).

Subclavian arteries are scanned recording patency especially looking for aneurysms beneath the clavicle, intimal damage, and plaque morphology1,2,5. Velocities and waveforms should be taken1,2,5.

Using continuous wave ultrasound and an 8MHz probe the brachial signal is located. Maintaining the maximum signal strength, slowly move the arm until it is fully abducted and then repeat with a full rotation of the arm. The aim is to try to move the arm through all possible planes, (allow for patient limitation) whilst maintaining a brachial signal.

If the signal strength remains good and the waveform is biphasic then a diagnosis of TOS is unlikely. However, if the signal strength diminishes and /or the waveform becomes monophasic then TOS is likely. 50% of normal patients will show some degree of brachial signal diminishment with this test2.

1. **Radial artery assessment for bypass conduit and free-flap assessment, - 12-3MHz or 17-5MHz probe.**

The radial artery is assessed using a colourflow duplex scanner on a low flow arterial setting3,4,6,7.

The radial artery is identified at the wrist, and colourflow is maximised using colour velocity range, pulse repetition frequency and colour gain. Using the Doppler sample volume a signal is obtained and the shape and strength of the signal is recorded. The L.S. diameter of the artery is recorded. The radial artery is traced proximal to the brachial bifurcation with regular Doppler assessments to exclude stenosis. Diameters are measured mid-forearm and just distal to the origin. These measurements are repeated for the ulnar artery3,4,7.

The brachial and ulnar arteries are also assessed for patency/stenosis as many patients have undergone brachial catheterisation for cardiac angiograms3,4

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**e.) Hand-Arm Vibration Syndrome Assessment (HAVS).**

**(Also vibration assessment of the lower limb).**

**Equipment –** 12-3 MHz or 5-1 MHz probe, 8 MHz continuous wave transducer. Moor FLPI-2 laser speckle contrast imager.

Formally known as Vibration White Finger. Vibration-Induced White Finger is now classed as a sub category of HAVS. Requests may be made for assessments of any of these terminologies. Vascular scientist should follow the HAVS protocol as outlined.

**(a.i) Upper Limb**

Bilateral upper limb arterial duplex scanning must be performed (see duplex scanning of upper limb). Bilateral TOS must be performed (see Thoracic Outlet Syndrome Assessment). Palmer arch patency of bilateral hands must be performed (see modified Allens test). A cold provocation test must then be performed, see below for protocol.

**(a.ii) Lower Limb**

Bilateral aorto-illiac duplex assessment must be performed (see aorto-illiac duplex assessment). Bilateral lower limb arterial duplex assessment must be performed (see Lower limb arterial duplex assessment of the thighs and calf’s).

**(b) Cold Provocation with Moor FLPI-2 (Laser Speckle Contrast Imager (LSCI)**

All patients must be sent a patient information leaflet in the post/via email prior to examination date. On arrival the patient must be given a HAVS questionnaire to fill in sitting in the waiting room to acclimatise to department temperature. If private/medico-legal patients then payment discussion may need to take place, Re. Brian.

The LSPI produces a map of perfusion at a total measurement depth of 1 – 2mm therefore assessing thermoregulatory microvasculature accounting for around 90% of flow within the phalange/finger pulp by averaging perfusion per unit area per unit time1, 2. A consequence of this technique is a patient must remain very still as the slightest movement will create a blurring of the speckle2. This blurring reduces the standard deviation (measures using averaging of previous and next perfusion units) and is seen as altered perfusion through reduced speckle contrast2.

Patients must refrain from alcohol intake for 12 hours prior to the exam. Patients must also refrain from nicotine and caffeine intake for 4 hours prior to assessment3, 4.

Room temperature, ambient lighting and sound can all effect data collection and all topical skin lotions or creams must be removed5. Room temperature should be above 20◦C but ideally around 24◦C3,6. Air temperature, skin movement and deep breathing can also effect the data and can been seen in perfusion2, 10.

Micro-perfusion is highly variable over time and test conditions; the use of a well formulated cold provocation test can improve reproducibility and diminish variability7 therefore staff must not deviate from this protocol to ensure high quality data acquisition.

All cold provocation tests can cause severe pain in some patients with HAVS (or non-freezing cold injury). It is unethical and therefore an infringement on a patients human rights to assess at temperatures below 15◦C without consent. The test must be fully explained to the patient including that it is designed to bring about symptoms and will be painful. Verbal consent from the patient **MUST** be obtained by the vascular scientist as per all duplex examinations. The patient **MUST** be reminded that they can remove their hand at any time to stop the test but that the results are important for their claim/assessment.

The hand or foot is placed on the acquisition mat/pillow and the ranging lasers are used to ensure hands or feet are within the acquisition area. A baseline level of perfusion is measured using the Moor instruments FLIP-2 for 5 minutes or less if a well-established baseline is identified. This allows the patient to settle into the assessment and allows tracings of perfusion to level. This is required due to wildly fluctuating traces being often found within the first five minutes of acquisition. Vascular scientists calculate recovery time by using the mean perfusion of this baseline, perfusion is measured in perfusion units (PU); a semi quantitative unit that has no angle correction.   
  
Both hands and feet are placed in around 5◦C (+/-1◦C) iced water for 60 seconds.

The ISO (international standards office) recommend that immersion does not take place within waters below 10◦C as this can cause hunting phenomenon leading to false positive and negative results8,9.Hunting phenomenon is not believed to occur in HAVS patients due to vascular damage caused through vibration exposure; therefore to induce vasospasm a colder temperature (5◦C) must be used.  
  
The hand or foot is then allowed to rewarm ensuring hands are placed back within the sample volume exactly as before removal. Data acquisition must then take place for fifteen minutes. The reasons for this are as follows;   
  
No papers that cite recovery times for perfusion using laser speckle contrast imagers can be found. Pauling et al (2012) found strong correlation between thermography and laser speckle contrast imaging in terms of perfusion and skin temperature. Murry et al 2009 found thermography and laser Doppler imaging (another form of laser imaging) could be used interchangeably. However a study done in bath did find strong correlation between thermography and laser speckle imaging for maximal perfusion within 15min post removal from 15°C water for 1min. Coughlin et al. (2001) found that 5°C for one min provided much greater sensitivity and specificity with a recovery time of finger skin temperature at the tips of 4min and at the base 6.5min. Pauling et al (2012) still monitored for 15min post removal. Murry et al (2009) and Pauling et al (2012) suggest that the slope/gradient of recovery is not reliable and Pauling et al (2012) went on to state that there is poor correlation between modalities (e.g. LSCI and thermography) for gradient measurements.

Acquisition or recovery for 15 minutes will be enough to confirm if HAVS is present but also keep assessment time to a minimum. If mean perfusion of the rewarming phase has not recovered to pre-immersion baseline within 15 minutes results are concordant with a positive result for HAVS and the test can be stopped. Vascular scientists will only write on the summary report (results of imaging) the time to recovery. No diagnosis of HAVS will be stated on results; this must be left to the reporting surgeon/physician who will make the diagnosis from the time of recovery and clinical judgement.

Please note that these rewarming times are based on finger skin temperature assessment using thermo-cupules and thermography imaging cameras. It has been reported to provide a sensitivity of around 70% and a specificity (between SWS grading’s) of between 73% and 97% 6,12,13.

Preliminary data acquired by IVS Ltd suggest that normal perfusion will recover to pre-immersion levels post removal from 5 degree water for 60 seconds below or equal to 4min. Any recovery time greater than 4min is indicative of vaso-spastic disease but only if there is a positive occupation history of vibration and if a patient has experienced symptoms routinely within the last 12months post cessation of vibration exposure.  
  
Total assessment time for cold provocation should take 21 - 26min for bilateral hands or feet with a total cold provocation assessment time for bilateral hands and feet being 42 – 54min.

**(c) Cold Provocation - No Moor FLPI-2 or staff not trained in use**

Digital mapping of bilateral hands must be performed (see digital mapping). The patients hand is then submerged in iced water for 2 minutes then the digital map is repeated.

**(d) Non-Freezing Cold Injury Assessment.**

Vascular Scientists must follow the protocol for HAVS for the upper or lower limb as appropriate with a cold provocation test.

**(e) Digital Mapping**

Using an 8 MHz continuous wave Doppler probe identify signals in the palm of the hand just distal to the wrist. Then identify signals at the base of each finger and distal to each phalange – record signals as present + or absent -.

**(f) Palmar arch patency (modified Allen’s test)**

In a normal hand there should be two ‘arches’, deep and superficial, connecting the lateral and medial palm blood supplies6,7. Perfusion should be maintained to all fingers even if the radial or ulnar artery is occluded. Cross-over flow can be checked by listening to the proximal palm signals and the signals at the base of each finger and then occluding the radial and ulnar arteries in turn with manual compressions. Loss of the palm signals on radial/ulnar compression indicates the deep arch is not complete. Loss of signals at the base of the fingers on compression indicates the superficial and deep arches may not be patent6,7.

The test should be performed for each signal with radial and ulnar compression.

**Assessment time scale**

TOTAL ASSESSMENT TIME = **21 - 26min**

(For bilateral Hands **or** Feet)

TOTAL ASSESSMENT TIME = **42 - 54min**

(For bilateral Hands **and** Feet)

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**12. Upper limb venous assessment**

**CL1.12**

The prevalence of upper limb venous thrombosis is increasing due to a number of factors, most notably; the increasing use of central venous catheters, cardiac pacemaker placement and increasing malignancy rates1,2.

Other risk factors for upper limb venous thrombosis include, inherited thrombophilia, developed hypercoagulable states, trauma, surgery, and thoracic outlet syndrome (Paget Schrotter syndrome)1,2,3. Symptoms of upper limb DVT include upper extremity swelling, pain/tenderness on palpation, cyanosis, visible or dilated collateral superficial veins, and jugular vein dilation1,2.

Doppler examination of the upper limb venous system is an important primary test for the diagnosis of DVT with studies demonstrating sensitivity ranges from 78-100% and specificity ranges between 82-100%4,5,6,7,8,9.



The patient should be assessed supine using a linear L12-3MHz transducer with the arm extended 60⁰ from the chest1. Care should be taken to avoid hyperextension as this can alter the observed venous waveforms1.

The above diagram demonstrates normal upper limb venous anatomy. A routine ultrasound examination should include assessment of the accessible sections of the internal jugular, subclavian, axillary, brachial, radial and ulnar veins10. The superficial basilic, cephalic and median cubital veins should also assessed1,10. Ultrasound examination should consist of grayscale, colour and spectral assessment of accessible portions of the brachiocephalic (if seen), subclavian, axillary, and internal jugular veins. Venous compression should be applied to all accessible veins as incomplete compression remains the most sensitive and specific sign of venous thrombosis1. Compression should be performed in the transverse plane, with enough pressure to completely close the vessel lumen1,10.

The subclavian (brachiocephalic where possible) and internal jugular veins should be assessed bilaterally (even if a unilateral referral) using colour and spectral Doppler to evaluate for loss of cardiovascular pulsatility and respiratory phasicity1,10,11.

Non-pulsatility and absence of respiratory phasicity can be suggestive of central venous obstruction (thrombosis, stenosis or extrinsic compression)1. In a case where central venous thrombosis is considered as a result of abnormal spectral waveforms, examination of the contralateral side should be performed to ensure the abnormal spectral trace is present only on the symptomatic side11. This allows the sonographer to overcome limitations associated with innate variations in spectral trace observed in differing patients11. It must be noted that the study used as evidence for assessment of bilateral systems acknowledges that spectral abnormalities may be difficult to diagnose in the presence of bilateral subclavian, brachiocephalic or superior vena cava occlusion11.

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**13. Arterio-Venous Fistula Assessment**

**CL1.13**

It is recommended you read SVT Vascular Laboratory Practice Manual sections on upper limb arterial and venous assessment and renal dialysis fistula in conjunction with this protocol.

Arterio-venous fistulae may be congenital or acquired.

Congenital fistula assessment is rare and thus this protocol is for access grafts created for end stage renal patients who require dialysis.

Fistula are normally created within the upper limb but may be placed in the lower limb when required – protocol can be adapted to assess these fistula¹

**Fistula types**

**Autogenous**

**One** anastomosis between a native artery and vein1,3.

1. Radio-cephalic – an anastomosis is formed between the radial artery and the cephalic vein usually at the level of the wrist (called Brescia-Cimino fistula).
2. Brachio-basilic transposition fistula
3. Brachio-cephalic fistula

**Access Graft (AG) Synthetic**

Require **two** anastomoses, to an artery and to a vein1,3.

1. Forearm
2. Arterial anastomosis to the distal brachial artery then synthetic graft extends into the forearm forming a loop before extending proximally to form a second anastomosis to the median cubital vein (positioning of anastomosis can vary).
3. Straight graft - distal radial artery anastomosis to median cubital vein anastomosis.
4. Upper arm

Straight graft between

1. Distal brachial to proximal basilic vein
2. Distal brachial to axillary or subclavian vein

Grafts can also be placed in the lower limb and diagnostic velocity readings can be used.

**Changes following AV-fistula formation¹,2,3,4**

Venous:-

1. Venous valves will become incompetent and veins will dilate.
2. Distal to fistula, venous flow may mimic high resistance arterial flow.
3. Collaterals may cause retrograde flow in native veins distal to the fistula.

Arterial

1. Velocities in the native arteries proximal to the fistula will increase.
2. Velocities in the native arteries distal to the fistula may be reduced and may be insufficient enough to cause distal ischaemia – ‘steal fistula’.
3. Collaterals may form which cause retrograde flow in the native artery immediately distal to the fistula.

**Potential complications of AV-Fistula,2,3,4**

1. **Stenosis/thrombosis/occlusion1,4,5**

Stenosis can occur at several sites:-

1. Inflow anastomosis stenosis (all graft types)
2. Mid graft – (AG only)
3. Outflow anastomosis (AG only)
4. Inflow – stenosis of native artery
5. Outflow – stenosis of native vein
6. **Arterial steal1,4,5**

High velocities at the fistula cause reduced or retrograde flow in the distal native artery. Common risk factors are brachial artery origin of fistula as greater flow rate capacity, diabetes mellitus and female gender.

Steal may present as pain, motor and sensory complaints and/or isolated digital necrosis.

Obstructive inflow disease is uncommon in the upper extremity but should be suspected when steal combines with low AV access flow.

1. **Venous hypertension1,2,4**

Increased venous pressure caused by proximal vein obstruction causing regional oedema, pigmentation and several superficial collateralised veins.

1. **Oedema1,4,5**

Fluid in the interstitial spaces caused by changes in venous function as a result of fistula, which can cause symptoms but may be due to outflow obstruction eg subclavian venous stenosis or occlusion.

1. **Infection1,4,5**

Swollen red arm and patient may have fluid collection around anastomosis and graft (AG only).

1. **Fistula swellings1,4,5**
2. Haematoma around graft due to poor needle placement.
3. Pseudoaneurysm/aneurysm – common in older grafts and may contain thrombus which can embolise or occlude venous system. Risk of rupture.
4. Peri-fistula fluid collections – infection, haematoma undergoing lysis or lymphocoele.
5. **Calcification** common in old grafts4,5
6. **Neuropathy4,5**

Peripheral neurological dysfunction is common with advanced renal insufficiency. Other neuropathies may include ischaemic neuropathy involving all three forearm nerve trunks. Entrapment and uremic or diabetic polyneuropathy are other forms.

1. **High Output Cardiac Failure1,4,5**

This is a rare complication characterised by symptoms indistinguishable from cardiac failure – which is common in patients who are dialysis dependent.

Very high flows through of more than 1.5 - 3L/min can lead to cardiac failure. Management may include ligation if necessary or banding to restrict flow.

**Assessment**

**Pre-examination**

**DO NOT take blood pressure in arms with fistula as it may cause rupture1,8.**

**Patient positioning**

Remove clothing to expose upper limb. Patient can be assessed sitting or supine sitting position allows veins to dilate and offers better access to IJV and subclavian veins1,6.

**Equipment**

Use 5-10MHz frequency probes.

May need to use plenty of gel or stand-off if fistula is very superficial.

**Clinical**

1. Ask patient about any problems with fistula
2. Check they have not had previous failed fistula
3. Ask if they have had lines inserted in the neck, if so check subclavian vein.

Check for raised flattened areas, oedema and discolouration of hand or fingers.

Palpate fistula – should be a ‘thrill’ or ‘buzz’ if absent maybe occluded or stenosed.

**Duplex**

**For all grafts**

1. Scan the native feeding artery, anastomosis, artery and vein distal to the anastomosis, fistula along its length1,6,8, and check following:-

a) Take velocity readings at several intervals in all vessels.

b) Check for any areas of dilatation and record diameters and whether thrombus present.

c) Check for fluid collection around the graft or haematoma at needle sites.

d) For the native feeding artery take peak and end diastolic velocities.

1. Take the average of three flow volumes in:-
2. Brachial artery
3. Native feeding artery
4. Mid graft in an area which is linear and easier to obtain accurate diameters
5. Outflow veins.
6. At the arterial anastomosis:-
7. Greyscale check for luminal irregularities or narrowing and measure diameter
8. Take velocity measurements – these are not ideal for serial comparison at later scans.
9. Do not take volume readings at the anastomosis as they are unreliable.
10. In the native outflow vein:-
11. Take velocity readings
12. Take flow volume readings if an adequate straight segment is available.
13. If the limb is swollen, outflow is poor or the patient has a history of line usage check the subclavian and axillary veins for thrombus or narrowing.
14. Create a report of flow, velocities, narrowing, tortuosity, dilation and evidence of thrombus. Provide a diagram.

**For AG fistula only**

1. Check length of graft and take diameter measurements at several levels.
2. Take velocity measurements along the graft and one flow volume measurement
3. Assess the distal anastomosis as per the proximal anastomosis.

**Flow volumes**

Fistula takes 5-6 weeks to mature to their peak volume flow and measurements will be unreliable. The flow within the first week is low1,7,8.

Due to the tortuosity and high potential error of measuring vessel diameter, three flow volumes should be taken at each site and averaged. In sequential scans a change is flow volume is only significant if it has changed by more than 30%1,7,8.

**Duplex diagnostic criteria**

**Greyscale/colourflow readings**

A significant stenosis is defined as a luminal diameter of <0.2cm or a 50% diameter reduction1,7,8.

Record any areas of thrombus, fluid collection, diameters of any aneurysmal segments and whether they contain thrombus.

**Doppler findings**

**Table 1. Doppler and B-mode criteria1**

|  |  |  |
| --- | --- | --- |
| **Classification** | **Doppler** | **B mode** |
| **Normal** | Mid-graft >150cm/s  Anastomosis>300cm/s | No visible narrowing  Distended outflow veins |
| **Moderate stenosis** | Mid graft 100-150cm/s | Reduced luminal diameter  Echogenic narrowing |
| **Severe stenosis** | Mid graft <100cm/s  >2 fold increase in velocity at stenosis | Luminal diameter <2mm  50% reduction in luminal diameter |
| **Inflow stenosis** | Anastomosis >300cm/s with turbulence  Monophasic signal on graft compression  Velocity does increase at outflow anastomosis | Luminal diameter <2mm or 50% reduced. |
| **Outflow** | Inflow anastomosis >300cm/s  Mid graft <100cm/s  >2 velocity increase at outflow anastomosis or outflow vein | Luminal diameter <2mm or 50% reduced.  Collateral veins around outflow |

**Table 2. Flow volume criteria1**

|  |  |  |  |
| --- | --- | --- | --- |
| **Site** | **Normal volumes** | **Abnormal** |  |
| **Brachial artery** | 700-3000 ml/min | <500 ml/min |  |
| **PTFE loop graft** | 800 ml/min | <500ml/min |  |
| **Radial fistula** | 250-465 ml/min |  |  |
| **Brachial fistula** | 309-750 ml/min |  |  |
| **Outflow vein distal to graft** | 364-1532 ml/min |  |  |
| **Risk of cardiac failure any graft** |  | >1500ml/min |  |

**Inflow1,8**

The native artery proximal to a fistula should have high flow PSV >300cm/s and exhibit low resistance flow characteristics (ie monophasic waveform and high diastolic component) a ratio of PSV/EDV of less than 0.4 can be indicative of an AV fistula problem.

**Increase peak velocity readings1,8**

A doubling of velocity in a narrowed segment indicates a significant stenosis but this is not predictive of fistula failure.

Note:

Velocities can increase without luminal reduction and are probably not significant.

Proximal venous occlusion or stenosis may affect readings.

A well collateralised fistula can cause localised increases in velocities without narrowing.

**Flow volume readings1,4,8**

Flow in fistula must be greater than 300ml/min for it to function. In the presence of a confirmed graft stenosis a flow volume of less than 500ml/min is associated with graft failure. A flow volume of <350ml/min has very high risk of failure.

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**14. Deep inferior epigastric perforator assessment**

**CL1.14**

Breast reconstruction using the deep inferior epigastric perforator (DIEP) flap method is a microsurgical technique that involves identification and dissection of the tiny DIEPs, to provide perfusion to the newly reconstructed breast following mastectomy.

Until recently, CT has been used routinely to identify the location of these vessels, but CT gives limited information and requires a large dose of contrast, which is unsuitable for patients with contrast allergy or renal disease; and exposes the patient to a large amount of radiation.

We have performed methodical investigations of the abdomen on several patients to identify the location of the DIEP vessels. When our ultrasound scan results were compared to the CT results and dissection in surgery; we found that ultrasound was equal in accuracy to CT and provides a reliable radiation and contrast free alternative along with additional information that CT cannot supply.

Along with increased accuracy, ultrasound provides information on the velocity of flow and volume flow in the DIEPs, at the point the perforator crosses the fascia. The ability to measure the volume flow can be beneficial when trying to identify a suitable vessel, as the largest vessel may not always be the most suitable, but the volume of flow through the artery should provide a good indication of how much flow the vessel will carry.

Ultrasound can easily depict arteries and veins separately and therefore measure the dimension of the DIEPs, whereas CT can only measure the vein and artery together. The scan also enables us to communicate to the surgeon the length of vessel, the route the vessel takes within the muscle and the number of branches that arise from each perforator. This information can considerably reduce the amount of time the surgeon has to spend dissecting the vessel out of the muscle.

**DIEP Scan Protocol**

The objective of this scan is to identify the most haemodynamically efficient perforator that is going to take the least amount of time for the surgeon to dissect. Therefore the ideal perforator will take the shortest route through the abdominus rectus muscle or bypass it altogether. It will be good size (>1mm) have no or few branches and have a good amount of flow (PSV equal to or greater than 100cm/s).

The Surgeon will need one good perforator per breast.

Probe L12-3

This is the preferred probe as it is easier to obtain the correct angle when taking velocities and volume flow. The L12-3 should be appropriate for most patients, as if the patient has been very slender the plastics team will have advised them to gain some weight to ensure there is enough tissue to harvest for the breast reconstruction. The ideal position is inferior to the umbilicus and as medial as possible (Blondel et al).

Anatomy

The deep inferior epigastric artery arises from the external iliac vessel and most commonly forms a medial and lateral branch and transverses proximally through the abdomen. Less often there may be a single deep inferior epigastric trunk vessel and rarely branching into more than two branches.

The perforators arise from the epigastric vessel and transverse superficially through the abdominus rectus muscle through to the superficial tissue where they can be visualised bifurcating and branching. However, these perforators can sometimes transverse either medially or laterally to the muscle, through to the superficial tissue.



Scan

There should be three to six perforators identified on each side of the umbilicus

The deep inferior epigastric veins can be visualised alongside the arteries. (Phillips et al 2008)

Area of interest

The area of interest incorporates the anatomy 2cm superior to the umbilicus and 10cm lateral to the umbilicus left and right; and distally through to the inguinal ligaments and pubic bone. (Cina et al 2010)

Scan technique

The patient is scanned whilst laying in supine.

The abdomen is assessed using a uniform method to ensure the entire area of interest is carefully interrogated.

Medium to firm pressure with the probe is required, but not so much pressure that the patient is in any discomfort.

Perforators are labelled by number for reporting purposes.

The vessel can be visualised crossing the rectus abdominus anterior fascia, and they should be marked on the abdomen at the point perforator crosses the fascia.

At the point the perforator crosses the fascia –

* Record the position of the perforator in its relation to the umbilicus as follows: ?cm inferior/superior, and ?cm right/left lateral
* The Anterior posterior diameter is recorded (normally from a longitudinal view). Normal dimensions have been noted to be between ~0.5mm to 2mm.
* The PSV is recorded.
* On the most suitable perforators the volume flow is also taken (average over three waveforms)

Any abnormalities noted such as tortuosity, narrowing or dilations should be recorded.

The route the vessel takes through the muscle must be assessed and record in a diagram with the vessel labelled with their approximate lengths. It is important to note in the report and draw any branches in the diagram.

e.g.

Perforator 1

3.5cm

3.5cm

2cm

Branch

Finally we assess for venous insufficiency in the superficial tissue, as diffuse venous insufficiency may threaten flap survival (blondel et al 1997). To look for insufficiency the probe needs to be held lightly and a slow sweep is performed looking for any large, tortuous and dilated veins that have very obvious flow. However, as this scan is still in its early stages no definite parameters have been set for what constitutes venous insufficiency with ultrasound in this part of the anatomy.

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**15. Temporal and Axillary artery assessment for GCA**

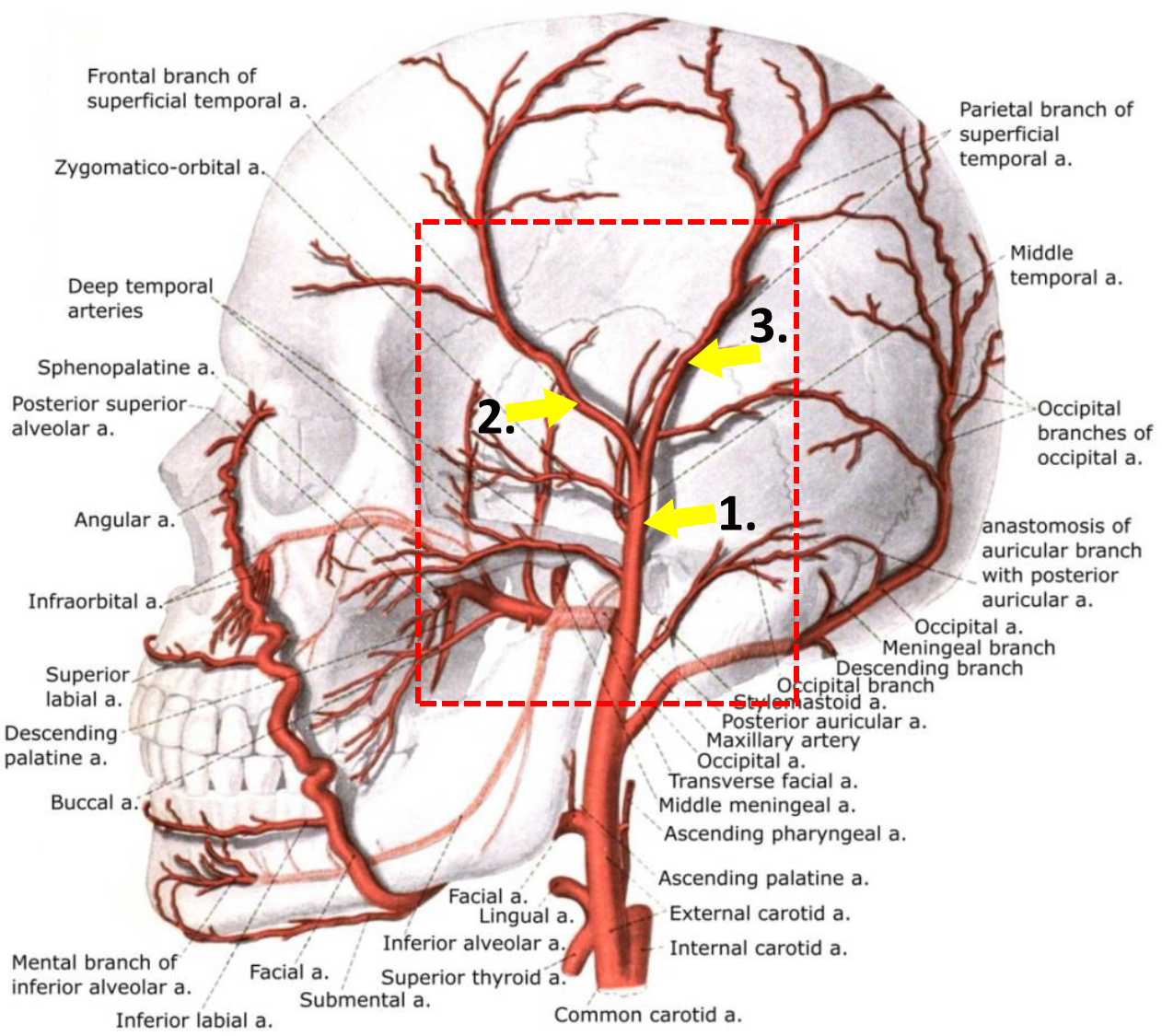
**CL1.15**

**Background**

Duplex ultrasound examination is used to assess the temporal and axillary arteries for the presence of inflammation suggesting possible Giant Cell arteritis (GCA) [sometimes called temporal arteritis as the temporal arteries are often inflamed]. The main area of investigation can be depicted in the figure below (red box) which includes the common branch of the superficial temporal artery (arrow 1.), the frontal branch (arrow 2.), and the parietal branch (arrow 3.).

Diagnosis of GCA is usually done by temporal artery biopsy. Temporal artery biopsy is painful and invasive, can sometimes be inconclusive and may miss so called “skip lesions” leading to a false negative test1. Biopsy of the temporal artery is currently considered the gold standard in the diagnostics of GCA. Nonetheless, the likelihood of getting a positive biopsy reduces significantly two weeks after the initiation of corticosteroids2.

Ultrasound is cheap and non-invasive and can lead to a positive diagnosis of GCA potentially reducing the need for biopsy3. With highly trained individuals, ultrasound has been shown to have high sensitivity (88%) and high specificity (96%) for the detection of GCA4.

****

*Temporal artery anatomy: 1. Common branch of the superficial temporal artery 2. Frontal branch 3. Parietal branch [Adapted from BMUS Recommended practice guidelines, November 2021]18.*

***Common indications*** for the performance of this examination include:

* Age >50 years old
* Visual disturbance
* Sudden permanent loss of vision in one eye
* Throbbing headache (usually temples)
* Tenderness of the scalp or over the temporal arteries
* Jaw claudication

**Scanning**

**Probe:** A linear high frequency 15-18MHz transducer is ideal to assess the superficial temporal arteries due to the small size of the vessels. Assessment of the axillary arteries is better suited to a medium/high frequency transducer.

**Patient preparation:** The patient is asked to remove their clothing to expose the axilla region and tie back their hair to expose the temporal arteries. The patient is examined supine with the arm raised above the head when scanning the axillary artery. The head can be turned to one side for examining the temporal arteries.

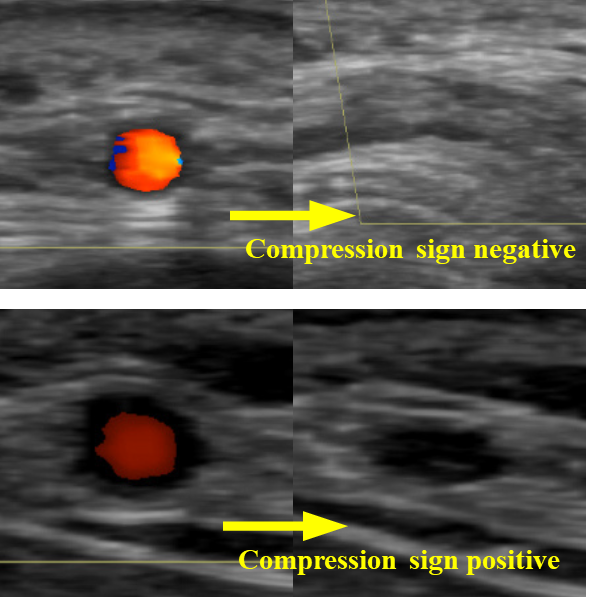
The examination should be bilateral as specificity reaches 100% in the case of bilateral halos8and should include assessment of the temporal arteries, and axillary arteries in both transverse and longitudinal views. Ultrasound examination of axillary arteries increases diagnostic yield in the detection of GCA9.

***The following appropriate techniques should be used:***

* Turn the patients head away or toward you to access the temporal region.
* Locate the common branch of the superficial temporal artery in transverse by the ear/parotid, where the vessel is at its largest.
* Once you have located the STA in transverse, slowly rotate the probe into longitudinal orientation to assess the rest of the vessel in B mode and colour.
* Follow the STA caudally in transverse until you reach the bifurcation.
* Follow the frontal and parietal branches as far as possible, using colour/power Doppler and compression to assess the vessel **(positive compression test depicted in figure below).**
* Patients will often demonstrate a region of focal tenderness, which is always worth rescanning at the end of the exam.
* Where there are signs of wall thickening (reduced luminal size with circumferentially thickened walls) confirm this by compressing the vessel with the probe; a non-diseased vessel will fully compress leaving no residual vessel behind, diseased vessels with positive halo will have circumferentially thickened walls that do not compress known as the Halo sign - a dark ‘hypoechoic’ area around the vessel lumen probably due to arterial wall oedema10. The halo should be present in two planes and be circumferential11. Inflammation can cause occlusion, stenosis or may not be flow limiting10. **The Halo intimal thickness values that can be considered abnormal differ in each vessel assessed, with Table 1 detailing the cut off values16, moreover, a halo thickness of 0.7mm or greater in the temporal arteries can predict a positive biopsy result**12**.**
* For the axillary artery (a halo can often present within the axillary artery11) a wall thickness of < 1mm is normal, 1.0-1.5mm is abnormal and could be suspicious of GCA16, but >1.5mm a sign of definite vasculitis9.
* Subclavian artery can be assessed in younger patients if the referral states there is clinical suspicion of Takayasu’s Arteritis.
* Spectral Doppler should be used to determine direction of flow, stenotic flow (usual V1:V2 velocity criteria applies for significant stenosis12) and absence of flow.
* Colour Doppler should be used to assess for the presence/absence of flow and aid the position of spectral Doppler when quantifying stenosis. Care should be taken when setting the colour gain, as gain too high may lead to masking of the halo.
* The waveform within a temporal artery is usually high resistance with low diastolic flow (the common temporal artery is a branch of the ECA and has a similar waveform).

**Compressions**

The compression sign should be assessed by applying pressure via the transducer until the lumen of the temporal artery occludes and no arterial pulsation remains.

**A positive compression sign** (figure below) is indicated when the two layers of the thickened arterial wall remain visible; the hypoechoic, vasculitic vessel wall thickening contrasts against the mid-echoic to hyper-echoic surrounding soft tissues.

*[Adapted from BMUS Recommended practice guidelines, Guidance for GCA ultrasound and service provision, November 2021]18.*

**IMT measurements 16**

|  |  |
| --- | --- |
| **Giant Cell Arteritis Values** | |
| **Artery** | **Cut Off Value (mm)** |
| Temporal Artery **Common Superficial** | 0.42 |
| Temporal Artery **Frontal Branch** | 0.34 |
| Temporal Artery **Parietal Branch** | 0.29 |
| **Axillary** Artery | 1.00 |
| ***Common Superficial Temporal Artery***  Halo thickness **0.42 – 0.70mm** = suspicious of GCA  Halo thickness **>0.70mm** = GCA high likely | |
| ***Frontal Branch***  Halo thickness **0.34 – 0.70mm** = suspicious of GCA  Halo thickness **>0.70mm** = GCA high likely | |
| ***Parietal Branch***  Halo thickness **0.29 – 0.70mm** = suspicious of GCA  Halo thickness **>0.70mm** = GCA high likely | |
| ***Axillary Artery***  Halo thickness **1.00 – 1.50mm =** Suspicious of GCA  Halo thickness **>1.50mm =** GCA Highly likely | |

***Limitations*** for duplex ultrasound assessment of the temporal arteries may include the following:

* Very small vessels are very difficult to image (typically temporal arteries are less than 2mm) and can be compressed with too much probe pressure.
* Very tortuous vessels.
* The temporal arteries usually pass beyond the hairline, which can make imaging difficult. Copious amounts of gel may be needed in order to image the vessels.
* When insufficient imaging is obtained due to hair, patients may be required to return for a rescan following a haircut to improve access to the temporal region.

**Treatment with steroids and implications for the ultrasound examination:**

The timing of the examination must be considered when performing ultrasound for temporal arteritis. It is desirable to perform this examination before starting steroid therapy13. In diverse studies, the halo sign seems to disappear within a period of 2 days to 6 months after the start of treatment with corticosteroids 13,2,14. In addition, the halo sign reappears in GCA patients suffering a flare 2. Nevertheless, the Halo sign has been said to rarely disappear before 2 months and can persist for up to 7 months in patients in remission and under steroid treatment15. It has been suggested that patients with a smaller number of affected branches require less time for halo disappearance2.

Considering that current guidelines are very clear about the importance of starting high-dose steroids immediately on suspicion of TA (symptoms can be very severe, including permanent sight loss if left untreated), ultrasound must be performed immediately rather than delaying steroids while this examination is being arranged13. With the literature unclear on how quickly the halo sign may disappear with steroid treatment, caution must be observed when using ultrasound for diagnosis in patients treated with steroids. ***Rapid access to both ultrasound and biopsy on the day of presentation would be optimum for diagnosis. As per the literature, with the halo sign known to disappear within a period of 2 days to 6 months, it is suggested rapid assessment is arranged for patients within 48 hours from the day of presentation***13,2,14***. If the ultrasound scan occurs after >48 hours it is suggested that the date since commencement of steroids is noted in the report if known.***

**Probe Resolutions to discern margin of error**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Probe** | **Depth** | **Lateral Resolution** | **Axial Resolution** | **Service report date** |
| Stepping Hill Hospital  L15-7IO  s/n: F001D8  for Philips Epiq5G | 20mm | 0.4mm | 0.5mm | Aug 2021 |
|  |  |  |  |  |

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