Imaging in vascular disease

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Abstract

Accurate imaging and interpretation of the vascular system is fundamental to the management of patients with vascular disease. It assumes particular importance when considering evidence based intervention for carotid and aneurysmal disease. This article introduces the basic principles, advantages and limitations of imaging frequently used to assess patients with vascular disease. The roles of duplex ultrasonography (DUS), magnetic resonance imaging (MRI), computerized tomography (CT) and digital subtraction angiography (DSA) in the vascular patient are reviewed.

Keywords Computerized tomography; digital subtraction angiography; duplex ultrasonography; magnetic resonance angiography; vascular

Introduction

Accurate imaging and interpretation of the vascular system is fundamental to the management of patients with vascular disease. It assumes particular importance when considering evidence-based intervention for carotid[1] and aneurysmal[2,3] disease. Knowledge of the basic principles, advantages and limitations of various imaging modalities is important. This not only allows the clinician to use the most appropriate imaging for the clinical situation, but also to understand the degree of certainty that the imaging modality reflects the real anatomy in the patient. The aim of this article is to review the roles of duplex ultrasonography (DUS), magnetic resonance imaging (MRI), computerized tomography (CT) and digital subtraction angiography (DSA) in the vascular patient.

Duplex ultrasonography (DUS)

Basic principles

Ultrasonography involves the transmission, absorption and partial reflection of high-frequency sound waves in tissue. Anatomical detail (B-mode scan) can be produced because sound waves are reflected at the interface between adjacent tissues in the body, when the tissues have different physical characteristics (density and compressibility). Information about blood flow is reliant on the Doppler effect; that is, there is a change in the frequency of the sound wave if there is a relative change in the position of the observer (the ultrasound transducer) and the source/reflector (the moving blood reflecting the sound wave). The Doppler shift equation is used to calculate the velocity of the blood (see Further Reading suggestion below).

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DUS combines B-mode ultrasound with pulsed-wave Doppler. Using the image to define the anatomy of the blood vessel, the specific area/depth of tissue is then assessed using regular short bursts of ultrasound (pulsed-wave Doppler). Thousands of pulses are sent along the ultrasound beam and as the velocity of the blood changes with systole and diastole, the frequency of reflected pulse changes. These numerous frequency shifts are then mathematically aggregated or gated and displayed as a spectral pattern or in colour.

Beyond a stenosis the waveform will change from triphasic (Figure 1a and b to biphasic (Figure 1c) or monophasic. Flow of a liquid is equal to the product of mean velocity and cross-sectional area. As such, in an attempt to maintain flow, velocity will increase as cross-sectional area reduces. Only when the stenosis becomes critical (>70% diameter reduction) will the flow itself be reduced. DUS involves the measurement of peak systolic and end diastolic velocities up-stream and within the stenosis. These velocities can be used independently to estimate degrees of stenoses using validated tables[4] or most commonly as a ratio (peak systolic velocity ratio (PSVR; before lesion:at lesion). A PSVR 2:1 is associated with >50% stenosis and PSVR 4:1 with a >75% stenosis.

Indications and advantages of DUS

DUS is safe, non-invasive, does not involve ionizing radiation and is well tolerated. It is widely applicable to all peripheral arterial disease. It is the first-line investigation for all venous disease (superficial venous reflux and DVT).

Limitations of DUS

Like all ultrasonography, DUS is operator dependent. Clinicians are not provided with an image, but with a written report and a pictorial representation of the technologists' interpretation of the spectral analysis.

DUS has median sensitivity of 88%/90%, and a median specificity of 96%/99% to detect a >50% stenosis/occlusion, respectively, when digital subtraction angiography is used as the gold standard, though diagnostic accuracy falls below the knee.[5,6] Calcium does not transmit sound waves, thus it is difficult to gain accurate information about blood flow in heavily calcified arteries. Body habitus and overlying gas, often make assessment of the iliac vessels difficult.

Magnetic resonance angiography (MRA)

Basic principles

MR imaging is produced by the application of a high-energy oscillating magnetic field to body tissue to produce images. Charged hydrogen nuclei within the body will either be in alignment (low-energy state) or be out of alignment (high-energy state) with the applied magnetic field, and oscillating the field can make the nuclei move from low to high-energy state. As the nuclei relax back to the low energy state, energy is returned from the tissue – the amount of energy is dependent on how many nuclei are present (proton density images) and the rate is dependent on two processes: T1 and T2. The different relaxation rates of different tissues allow diagnostic images to be formed. More information about MRI can be found in the Further Reading suggestion below.

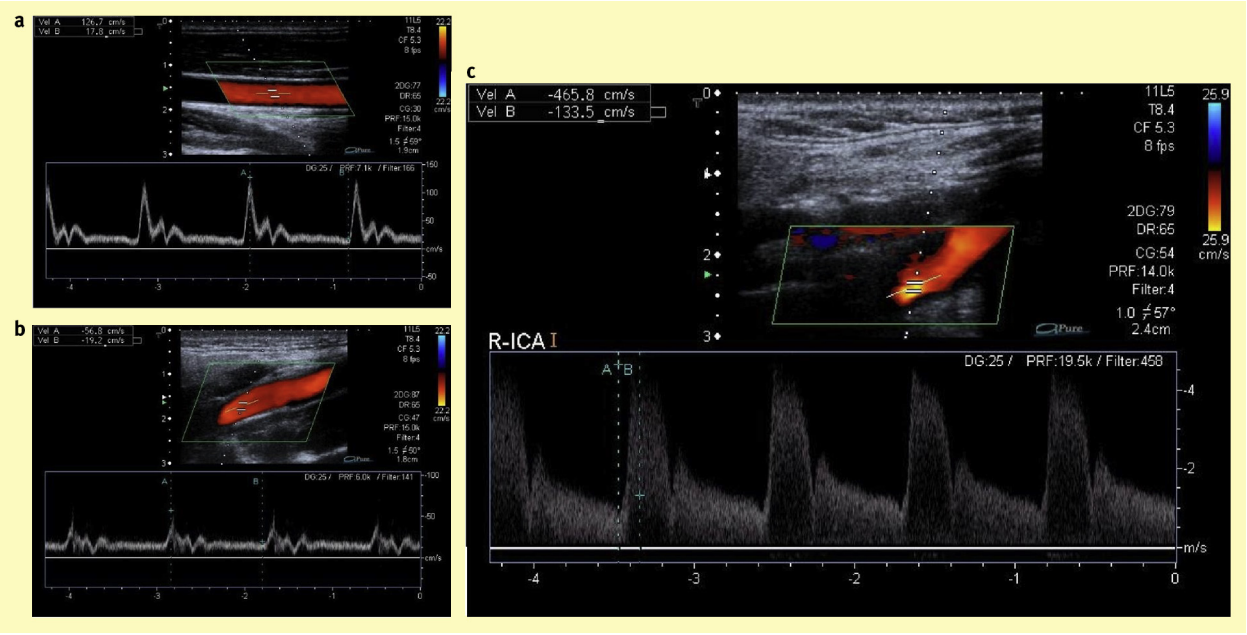

Figure 1 (a) and **(b)** A normal common and internal carotid artery waveform. **(c)** A significant stenosis (>70%) within the internal carotid artery — note the aliasing (yellow colour in the colour flow image) and the high peak systolic velocity of >400 cm/sec.

The flow of blood itself can create a contrast image; thus two-dimensional 'time-of-flight' (TOF) images can be acquired over large areas. TOF is sensitive to changes in direction of flow and movement, and thus the creation of artefacts. These artefacts can be minimized by the use of paramagnetic intravenous contrast agents, most commonly gadolinium. Commonly used post-processing protocols in contrast-enhanced MRA are MIP (Maximum Intensity Projection) and TRICKS (Time Resolved Imaging of Contrast Kinetics). In recent years two new non-contrast MRA techniques have been developed that show considerable promise. Variously named by different MR manufacturers, one is a subtraction technique, gated to the cardiac cycle that identifies pulsatile blood and so overcomes venous contamination problems. This has great potential for peripheral MRA. The other is respiratory gated and suppresses background tissue including venous blood. This is used for visceral imaging and especially for renal applications. Both these techniques promise to be invaluable diagnostic tools for patients with renal failure or who have other contraindications to radiographic contrast medium.

Indications and advantages of MRA

MRA may be utilized to image vascular tree from the diaphragm to the feet; indeed this can be accomplished in one sitting (three-station imaging: Figure 2). Furthermore MR techniques are non-invasive and involve no ionizing radiation, yet provide an image that is as recognizable to the surgeon as those produced by invasive DSA techniques. MIP images of the 3D data set allows multiplanar imaging from one acquisition, so the surgeon can see the vessels from multiple different angles, often clarifying anatomical questions particularly for run off vessels. National Institute of Care Excellence (NICE) guidelines (2012)[6] recommend the use of MRA as the modality to be used after duplex ultrasound for patients in whom revascularization is being considered.

MR techniques are particularly suited to the assessment of vascular soft tissue tumours and vascular malformations.

Limitations of MRA

MR is contraindicated in patients who have metal medical or electronic implants (e.g. pacemakers) or metal fragments in their eyes as the magnetic field may move or damage the object or device. Gadolinium-based contrast agents have been associated with the development of nephrogenic systemic fibrosis in patients with end-stage renal failure; as such it has been suggested that contrast enhanced MRA should be avoided in this group.[7] MRA requires patients to remain still and claustrophobia limits MR acceptability to come patients. MR is relatively expensive compared to other modalities and is not universally available, particularly out of hours.

Contrast-enhanced MRA has a median sensitivity of 95%/94% and median specificity of 97%/99.2% to detect a >50% stenosis/occlusion (compared with DSA). In general MRA tends to over-estimate the severity of vascular disease. Image quality may be degraded below the knee by venous contamination and movement, particularly in those patients undergoing multi-station imaging or with venous reflux. Thus in patients with distal arterial disease in whom it is essential to accurately determine the pattern of occlusion/stenosis it may be necessary to perform 'single station' imaging (below knee only).

Computerized tomography angiography (CTA)

Basic principles

Computerized tomography involves a fan-shaped beam of ionizing radiation delivered from a tube source rotating helically