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B-flow imaging in lower limb peripheral arterial disease and bypass graft ultrasonography

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Introduction

Peripheral arterial disease (PAD) is an epidemic that impacts a large number of patients worldwide. Unfortunately, this number is expected to rise [1]. Doppler ultrasonography plays a key role in the diagnostic pathway of patients with PAD and is the first diagnostic test to confirm and localize stenotic lesions [1]. Doppler ultrasonography is also recommended for the selection of patients that could benefit from endovascular intervention and for the follow up of postoperative lower limb vein grafts [2]. Although Doppler ultrasonography has been reported to be comparable in sensitivity to angiography [4], especially in the diagnosis of femoro-popliteal arterial stenosis or occlusion, its sensitivity in the crural area is relatively lower [5, 6]. This is partially explained by inter-observer variability of the technique and the well-documented limitations of ultrasound in the assessment of PAD [7]. Distal arteries are frequently difficult to image due to their small size. In addition, the presence of diabetes mellitus, which is known to cause calcification in the vascular wall can make the identification of crural vessels further challenging and falsify the Doppler signals, potentially mimicking typical vessel occlusion findings [8, 9].

Doppler ultrasonography was reported to have difficulty in differentiating a 99% stenosis [10] from a complete occlusion and a lower specificity in multilevel stenoses [11]. Angiography, CT scans or MRI scans are used alongside ultrasound in the diagnostic pathway of PAD. However, these modalities are more costly, may not be easily accessible and often use ionizing radiation and/or expensive contrast agents. B-Flow technology is a relatively new imaging mode based on Agile Acoustic Architecture from GE Healthcare and has shown great potential for addressing the various limitations of ultrasound [12, 13, 14]. B-flow imaging has mainly been explored in carotid arteries [15], vascular access for dialysis [16] and in the abdomen [17, 18]; however, there is a lack of research in the use of B-flow imaging in the assessment of PAD. This article presents the authors early experience using B-flow imaging in combination with the traditional Color Doppler Ultrasound (CDU) imaging in lower limb arteries and the potential use of B-flow imaging as an additional tool to assist in the diagnosis of vascular pathology. A series of different pathological cases are presented to show the most frequently encountered issues during ultrasound scans of peripheral arteries and

bypass graft surveillance and demonstrate the potential advantages that B-flow may have to offer relative to CDUS.

Calcification

Calcification of the arterial wall is often encountered during peripheral arterial CDU assessment and can produce shadowing on both the B mode and Colour flow image preventing spectral Doppler samplings (Figure 1a, 1A, 1B, 1b). Acoustic shadowing can also be observed on B-flow image (Figure 1A), however when compared to CDU the shadowing was often of smaller intensity allowing a longer section of the region of calcification to be visualized; this allows for better definition of the residual patent lumen (Figure 1c). Occasionally a complete view of the vessel was possible, particularly in small vessels (figure 1B). The presence of extensive calcified atheromas may not necessarily relate to a significant narrowing, however focal stenoses may be overlooked. B-flow imaging appeared to be superior to CDU in identifying focal calcified stenoses that were not detected on CDU (Figure 1C, 1c). Furthermore, B-flow imaging allowed Doppler velocities to be sampled in these regions that were otherwise obscured by shadowing artefact (Figure 1D). This was predominantly useful in patients being preoperatively assessed for common femoral artery endarterectomy. This may be particularly beneficial when CDU is the only diagnostic investigation that can be adopted to plan revascularization in patients unsuitable for a second radiological imaging modality.

Additionally, the initial appearance of the absence of flow detected by CDU in a small calcified vessel may mislead the sonographer into thinking that the vessel is occluded (Figure 1b). B-flow appeared to be more discriminatory than CDU in identifying true patent calcified vessels (Figure 1B), however the resolution of B-flow appeared to be more dependent on the depth of the vessel when compared to CDU

Multilevel stenoses

CDU is highly sensitive in detecting first-order stenoses in the lower extremities [4]. However, low peak systolic velocities at second order stenoses of limbs with multilevel sequential disease appear to significantly decrease the sensitivity of duplex ultrasound

[11]. To better visualize small-calcified vessels, it is essential to increase the colour gain for better colour fill of the vessel, yet often this may lead to colour 'bleeding' due to excessive noise as a result [19]. The pulse repetition frequency (PRF) must also be adjusted; in this case the PRF is decreased for better detection of lower velocities yet this leads to excessive aliasing. These pitfalls can be misleading as significant arterial disease may be disregarded resulted from the colour 'bleeding and overlooked aliasing. This is particularly true in the presence of in-series stenoses where aliasing is generally lengthy.B-flow is exempt from aliasing and therefore allows for a better morphological analysis and distribution of in-series stenoses, providing a useful implement for sampling of Doppler velocities (Figure 2B, 2b).

Vessel tortuosity

Imaging tortuous vessels can be difficult as the vessel may not appear in a single plane and its path may run parallel to the ultrasound beam producing poor images of the vessel walls. Color Doppler imaging can be used to assist in following tortuous arteries, however the changing direction of the vessel geometry may cause aliasing (Figure 2D). Power Doppler may help to image the vessel in this situation and assist in ruling out filling defects in the vessel due to the presence of atheroma. However power Doppler has increased sensitivity to motion and flash artifact. B-flow imaging is exempt from movement artifact. When tortuous vessels were imaged, B-flow imaging could display a real time distribution of the flow in the tortuous regions of the arterial segment identifying regions of turbulence and filling defects (Figure 2d.) subsequently allowing for Doppler velocities to be sampled.

Collateral pathways

Collateral pathways are a common finding in PAD. To follow collateral vessels for any length using CDU, particularly in the pelvis, it is often challenging and in some cases unsuccessful. However the main purpose of ultrasound is to clarify the length and severity of PAD rather than accurately map the collateral pathways which are secondary to the diagnosis

Collateral vessels can often be misleading as they can resemble native vessels when well-developed, uniform in geometry and when adjacent to a native occluded vessel;

this is particularly the case when assessing the vessels below knee. A prominent, well-established collateral vessel adjacent to an occluded crural artery may appear to resemble a patent crural artery resulting in a wrong diagnosis (Fig); this would be of particular importance when recommending a suitable crural artery as the run-off vessel for bypass surgery.

Additionally, turbulent flow leading to aliasing is frequently seen at the origin of collaterals within the main artery, this can be mistaken for a stenosis. B-flow appeared to be more discriminatory in distinguishing turbulence at the level of a collateral take off from that of an intravascular stenosis. The collateral pathways were generally easier to visualize on B-flow than CDUS (Figure 2 C, 2c).

Near occlusion and occlusion

One of the main limitations of CDU is to distinguish a near-occlusion from an actual occlusion. This is particularly difficult in the presence of heavily calcified plaques. B-flow appeared more discriminatory than CDU in distinguishing a near-occlusion from an occlusion (Figure 2A, 2a).

Bypass graft surveillance

CDU is the main andoccasionally, the only diagnostic imaging modality adopted for bypass graft surveillance. Early postoperative scans can be very difficult and limited if the wound is still healing and dressings or surgical closure devices are present. The proximal and distal anastomoses are occasionally difficult to image clearly, due to surrounding scar tissue or depth. The color flow image demonstrates areas of marked flow disturbance and flow reversal at the proximal anastomosis due to the size (Figure 3B), geometry and orientation of the graft origin from the native artery. B-flow appears to offer a better morphological definition of the graft anastomosis and identification of the stump flow (Figure 3b) with no filling defect areas that are generally shown on CDU. Also flow disturbance is often seen at the level of the distal anastomosis and should not be considered abnormal unless spectral Doppler recordings demonstrate significant velocity changes. However velocities are often raised at this level due to a change in calibre and therefore can falsely lead to a misdiagnosis of a stenosis at the

anastomotic level (Figure 3 A). In such cases, B-flow allowed for better definition of the geometry of the anastomosis (Figure 3a) and identification of subtle vascular lesions (Figure 3d) at this level providing a valid tool to assist in the discrimination of a true stenosis from that of a calibre mismatch (Figure 3a).

Pseudoaneurysm

The role of B-flow in assessing pseudoaneurysms has already been reported and proved to be more accurate than CDU in revealing the 'yin-yang' flow pattern typical of pseudoaneurysms [20]. Thrombin injection and manual compression are the two main treatment options for pseudoaneurysms and occasionally surgical repair is required. The size of the pseudoaneurysm neck plays a key role in defining the best treatment option [21]. A neck with a diameter > 0.5 mm would be a contraindication for thrombin injection. An accurate sizing of the neck is sometimes not possible due to the depth of the pseudoaneurysm or color bleeding. B-flow proved to be of great assistance not only in accurately measuring the size of the neck but also in evaluating the residual patent lumen of the pseudoaneurysms (Figure 3 C and 3c).

Conclusion

Our experience investigating the application of B-flow imaging in assessing PAD and bypass grafts indicates that this relatively new technology has the potential to significantly improve non-invasive peripheral blood flow evaluation. The findings reported in this article should not encourage the use of B-flow as a sole ultrasound image mode for the assessment of PAD and bypass grafts, but as a complementary technique to use in situations where CDU findings are inconclusive or unclear. More prospective comparative studies with gold standard imaging modalities are required to clarify the sensitivity and specificity of B-flow in the study of PAD.

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