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● *Technical Note*

B-FLOW IMAGING IN LOWER LIMB PERIPHERAL ARTERIAL DISEASE AND BYPASS GRAFT ULTRASONOGRAPHY

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Abstract—Doppler ultrasonography plays a key role in the diagnosis of peripheral arterial disease, but is often limited by pitfalls that may be overcome by B-flow imaging. Thus far, there is little information on B-flow imaging for the assessment of peripheral arterial disease and bypass grafts in lower limbs. This article describes the authors' early experience with B-flow in the lower extremities. Sixty patients were included among a large cohort of patients routinely referred to the vascular laboratory for peripheral arterial disease and bypass graft assessments. Two experienced vascular sonographers performed all scans, comparing color Doppler ultrasonography with B-flow imaging. All scans were performed using a combination of the 9 L linear and C2-9 curvilinear transducers with the LOGIQ E9 system (GE Healthcare, Waukesha, WI, USA). Our experience indicates that this relatively unexplored technology has the potential to significantly improve peripheral blood flow evaluation. Nevertheless, B-flow imaging is not exempt from limitations and should be considered complementary to color Doppler ultrasonography. (E-mail: fabrizio.dabate@hotmail.it) © **2016 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **B-Flow imaging, Color Doppler, Pulsed wave Doppler, Ultrasound, Peripheral arterial disease, Calcification, Artifacts, Duplex.**

INTRODUCTION

The prevalence of peripheral arterial disease (PAD) is increasing worldwide (Tendera et al. 2011). Doppler ultrasonography plays a key role in the diagnosis and management of patients with PAD. It confirms and localizes PAD lesions (Tendera et al. 2011) and aids decision making on revascularization and in the surveillance of vascular interventions (Fowkes et al. 2013; Hirsch et al. 2006).

Although Doppler ultrasonography has been reported to be comparable in sensitivity to angiography (Aly et al. 1998), particularly in the diagnosis of femoropopliteal arterial stenosis or occlusion, its sensitivity in the crural area is lower (Koelemay et al. 2001; Winter-Warnars et al. 1996). This is partially explained by the inter-observer variability of the technique and the smaller size of distal arteries (Winter-Warnars et al. 1996). Calcification of the arterial wall, common in patients with diabetes and/or renal failure, poses further challenges (Hingorani et al. 2008; Mazzariol 1999).

Doppler ultrasonography is reported to have difficulty in differentiating a near occlusion (Sensier et al. 1996) from a complete occlusion and has a lower specificity in multilevel stenoses (Bergamini et al. 1995). Angiography, computed tomography angiography and magnetic resonance imaging are used alongside ultrasound in the diagnostic pathway to PAD. However, these modalities also have imaging limitations, especially in calcified small vessels. Other factors include cost, accessibility, their invasive nature, ionizing radiation and the use of nephrotoxic contrast agents.

B-Flow technology is a relatively unexplored non-Doppler ultrasonography imaging mode based on Agile Acoustic Architecture from GE Healthcare (Waukesha, WI, USA) and has been found to have great potential for addressing the various limitations of ultrasound. The physics underlying this non-Doppler technology has

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been widely described (Chiao et al. 2000; Henri and Tranquart 2000; Weskott 2000). B-Flow imaging has been used mainly to explore carotid arteries (Finkenzeller et al. 2008), vascular access for dialysis (Yucel et al. 2005) and explore the abdomen (Wachsberg 2003, 2007).

Thus far, there is little experience in using B-flow imaging for the assessment of PAD. This article describes the authors' early experience using B-flow imaging in combination with traditional Color Doppler ultrasonography (CDU) and pulsed wave Doppler (PWD) ultrasonography in the diagnosis and assessment of patients with lower limb arterial disease and highlights the potential advantages and limitations associated with the technique.

METHODS

This study was approved by the institutional review board. Sixty patients (37 males, 23 females, aged 75 ± 9 y) were included from a selection of a large cohort of patients routinely referred to the vascular laboratory between June 2015 and October 2015 for the assessment of lower limb arteries and bypass grafts. The clinical information that formed the inclusion criteria for each referral were short-distance claudication (200 meters), non-healing ulcers, post-angiogram procedure and routine bypass graft surveillance. The selection criteria for the use of B-flow imaging were suboptimal ultrasound assessments of the arteries caused by the presence of artifacts, particularly calcifications, and aliasing that would cause incomplete visualization of an arterial segment. Furthermore, patients with multilevel stenoses, tortuous vessels and arterial occlusions with collateral pathways; near occlusions; pseudoaneurysms; and bypass grafts were also included in this descriptive study. These are considered the most common challenges encountered during PAD ultrasound assessments when using CDU and PWD alone. Two experienced vascular sonographers performed all scans and compared traditional CDU and PWD with B-flow imaging in the presence of the aforementioned circumstances. Each ultrasound scan was performed using a combination of the 9 L linear transducer and C2-9 curvilinear transducer with the LOGIQ E9 system (GE Healthcare). The lower limb arteries were scanned according to the local scanning protocol and vascular laboratory recommendations (Gerhard-Herman et al. 2006). For the purposes of optimizing flow visualization, continuous changes were made using key parameters throughout each assessment. Pulse repetition frequency (PRF) was adjusted according to arterial blood flow velocity. A low PRF (generally <15 cm/s) was set to detect low velocities, particularly in the tibial vessels. Furthermore, the PRF was lowered in the presence of acoustic shadowing caused by arterial wall calcification with the intention of optimizing the visualization of the arterial flow within the lumen. A low wall filter was selected for detection of low velocities. Color gain was increased and PRF was reduced in the presence of extensive calcifications and low velocities. The color Doppler box was adjusted accordingly for better visualization of color fill without compromising diagnostic information. When B-flow was applied, the sensitivity (gain) was increased in the presence of extensive calcification, low velocities and unclear resolution of the B-flow image. The sensitivity was increased as high as 20 PRI. In addition, the transducer transmit frequency was adjusted appropriately for the depth being assessed.

RESULTS

During this study, our experience with B-flow imaging proved useful in many key areas that otherwise would have presented with an inconclusive diagnosis. These key areas are discussed here.

Calcifications

Calcification of the arterial wall is often encountered during peripheral arterial CDU assessments and can produce acoustic shadowing on B-mode, color and power angio flow imaging, preventing spectral Doppler samplings (Fig. 1A, a, B, b). Acoustic shadowing can also be observed on B-flow imaging (Fig. 1A). Compared with power angio/CDU (Fig. 1a, C), the acoustic shadowing artifact was often less pronounced on B-flow imaging, allowing short sections of the vessel to be visualized that could not be seen using CDU alone. B-Flow imaging also enhanced the definition of the residual patent lumen of some calcified vessel segments (Fig. 1c). The presence of extensive calcified atheroma does not necessarily equate to significant vessel narrowing. However, acoustic shadowing artifacts caused by calcification can mask significant stenosis, causing them to be missed when using CDU alone. The authors found use of B-flow imaging in combination with CDU to be superior to CDU alone in detecting significant stenoses within calcified vessels (Fig. 1C, c).

Furthermore, B-flow imaging allowed Doppler velocities to be sampled in these regions that were otherwise obscured by acoustic shadowing artifact (Fig. 1D). This may be useful in avoiding the need for other additional imaging modalities such as computed tomography angiography, magnetic resonance angiography and angiography. Additionally, the initial appearance of the absence of flow detected by CDU in small calcified vessels may mislead the sonographer into concluding that the vessel is occluded (Fig. 1b). B-Flow imaging appeared to be more discriminatory than CDU in identifying true patent calcified vessels (Fig. 1B); however,

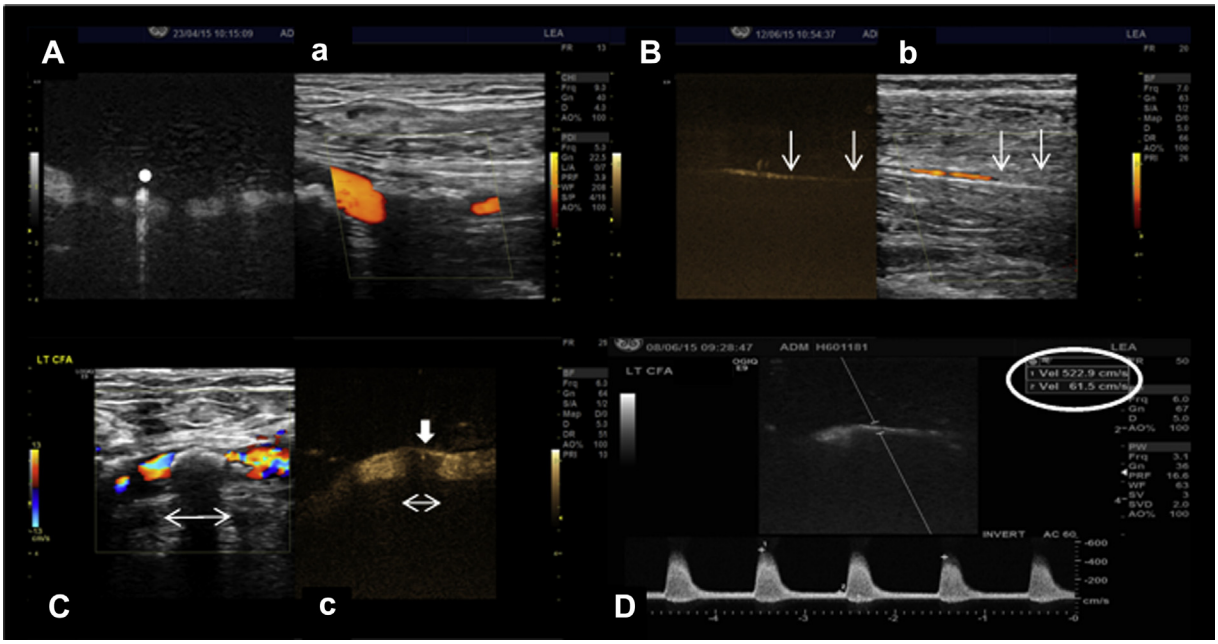

Fig. 1. (A) B-Flow image of the distal common femoral artery and SFA origin. There is marked calcification of the SFA walls, indicated by the strong reflections (*circle*). The calcification is more prominent on the power angio flow image (a). There is no obvious evidence of flow within the calcified region; therefore, the patency of the vessel cannot be determined using Power angio alone, yet on the B-flow image there is evidence of a partially patent lumen within the same region of calcification (a), resulting in valid information for interpretation of the scan. (B) B-Flow image and power angio image of an anterior tibial artery taken from a diabetic patient. On the power angio image (b), the distal segment of the proximal ATA appears occluded (*arrows*); however, on the B-flow image, the artery is patent but of small caliber (*arrows*). (C) Color flow image of a calcified CFA. There is a calcified plaque with acoustic shadowing (*double-headed arrow*). The scale was lowered to 13 cm/s to optimize flow; however, aliasing is observed with no significantly raised velocities proximal and distal to the plaque. Flow waveforms were monophasic with low velocities in the proximal SFA, suggesting a possible CFA occlusion. On the B-flow image (c) a significant reduction of the lumen was noted. Doppler velocities were measured (D), and a severe stenosis (>90%) rather than an occlusion was identified. SFA = superficial femoral artery; ATA = anterior tibial artery; CFA = common femoral artery.

the resolution of B-flow appeared to be more dependent on the depth of the vessel compared with CDU.

Multilevel stenoses

Color Doppler ultrasonography is highly sensitive in detecting first-order stenoses in the lower extremities (Aly et al. 1998). Nevertheless, low peak systolic velocities at second-order stenoses of limbs with multilevel sequential disease appear to significantly decrease the sensitivity of CDU (Bergamini et al. 1995). To better visualize small-calcified vessels, it is essential to increase the color gain for better color filling of the vessel. Often this leads to color "bleeding" outside the vessel wall (Machi et al. 1994). The PRF must also be adjusted; in this case, the PRF is decreased for better detection of lower velocities, yet leading to excessive aliasing. These pitfalls can be misleading as significant arterial disease may be disregarded as a result of the color "bleeding" and aliasing artifact. This is particularly true in the presence of in-series stenosis, where aliasing is generally lengthy. B-Flow is exempt from "bleeding" and aliasing artifacts, therefore allowing better morphologic analysis and distribution of in-series stenoses. This proved to be a useful implement for sampling Doppler velocities (Fig. 2B, b).

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. CDU imaging can assist in following tortuous arteries; however, the changing direction of the vessel geometry may cause aliasing (Fig. 2D). Power Doppler may help to image the vessel in this situation and assist in ruling out filling defects in the vessel caused by the presence of atherosclerosis. 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 was able to display a real-time distribution of the flow in the tortuous regions of the arterial segment, identifying regions of turbulence and filling

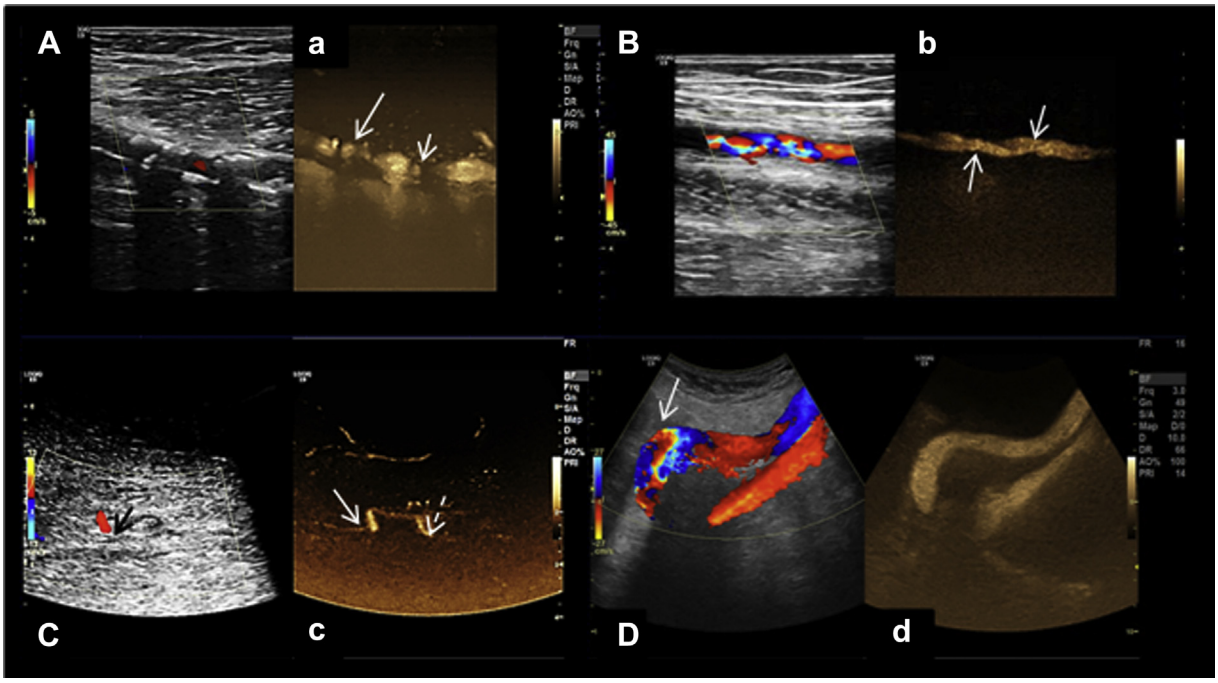

Fig. 2. (A) Color flow image of a SFA with diffuse calcified plaques. The PRF is lowered to 5 cm/s to detect low-velocity flow; however, the vessel appears severely diseased/occluded. The B-flow image (a) indicates that the SFA is severely diseased with a significant stenosis (*big arrow*). Acoustic shadowing artifact is noted in the more distal portion of the SFA (*short arrow*). (B) Color flow image of a SFA with diffuse atherosclerotic disease. Evidence of aliasing is noted throughout the entire length of the arterial segment, suggesting a single lengthy stenosis. The B-flow image (b) suggests the presence of multilevel stenoses (*arrows*). (C) Color flow image of an occluded PTA. The PTA occlusion is difficult to diagnose because of arterial wall calcifications. A possible collateral (*black arrow*) is seen arising off the PTA. (c) B-Flow image of an occluded PTA with evidence of collaterals arising off the PTA at the origin (*solid arrow*) of the occlusion and at the level of re-establishment of flow (*dotted arrow*); a definitive diagnosis can be made based on the B-flow findings. (D, d) Color flow and B-flow images of a tortuous EIA. On color flow, aliasing is observed at the curvature of the vessel (*arrow*). A decrease in color gain allows for better filling of the vessel in the region of tortuosity; however, this often gives rise to color bleeding and possible overwriting of the arterial wall. The B-flow image (d) provides better definition of the vessel with no evidence of color filling defects. SFA = superficial femoral artery; PRF = pulse repetition frequency; PTA = posterior tibial artery; EIA = external iliac artery.

defects (Fig. 2d) and subsequently allowing Doppler velocities to be sampled.

Collateral pathways

Collateral pathways are a common finding in PAD. Following collateral vessels for any length using CDU, particularly in the pelvis, 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 that result from PAD. Collateral vessels can often be misleading as they may resemble native vessels when well developed, uniform in geometry and adjacent to a native occluded vessel; in particular, this is the case when assessing vessels below the knee. A prominent, well-established collateral vessel adjacent to an occluded crural artery may incorrectly resemble a patent native artery (Fig. 2C, c). Such an error is of greater significance when recommending a suitable crural artery as the runoff vessel for bypass surgery.

Additionally, turbulent flow leading to aliasing is frequently seen at the origin of collaterals within the main artery, and 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 intra-vascular stenosis. The collateral pathways were generally easier to visualize on B-flow than CDU (Fig. 2C, c).

Near occlusion and occlusion

One of the main limitations of CDU is distinguishing 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 (Fig. 2A, a).

Bypass graft surveillance

Color Doppler ultrasonography is the primary diagnostic imaging modality adopted for vein bypass graft surveillance. Early postoperative imaging of the bypass graft can be suboptimal or incomplete because of overlying fresh surgical wounds and dressings. The proximal and distal anastomoses are occasionally difficult to image because of surrounding scar tissue or depth. CDU illustrates areas of marked flow disturbance and flow reversal at the proximal anastomosis because of the size (Fig. 3B), geometry and origin of the graft in relation to the native artery. B-Flow appears to offer superior morphologic definition of the graft anastomosis (Fig. 3b) without the presence of filling defects generally associated with CDU. Flow turbulence is often seen at the level of the distal anastomosis and should not be considered abnormal unless spectral Doppler recordings indicate significant velocity changes. Velocities are often raised in this region because of a change in caliber between the graft and native vessel and, therefore, can falsely lead to a misdiagnosis of a stenosis at the anastomotic site (Fig. 3A). In such cases, B-flow allows improved definition of the geometry of the anastomosis (Fig. 3a) and identification of subtle vascular lesions (Fig. 3d), providing an additional tool to assist in discriminating a true stenosis from that of a caliber mismatch (Fig. 3a).

Pseudoaneurysm

The role of B-flow imaging 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 (Jung et al. 2001). Thrombin injection and manual compression are the two preferred treatment options for pseudoaneurysms, and occasionally, surgical repair is required. The diameter and length of the pseudoaneurysm neck play a key role in defining the best treatment option (Jung et al. 2001). A neck with a diameter >0.5 mm would be a contraindication to thrombin injection. Accurate sizing of the neck is sometimes not possible because of the depth of the pseudoaneurysm or color bleeding. B-Flow proved to be of great assistance not only in accurately measuring the diameter of the neck, but also in evaluating the residual patent lumen of the pseudoaneurysms (Fig. 3C, c).

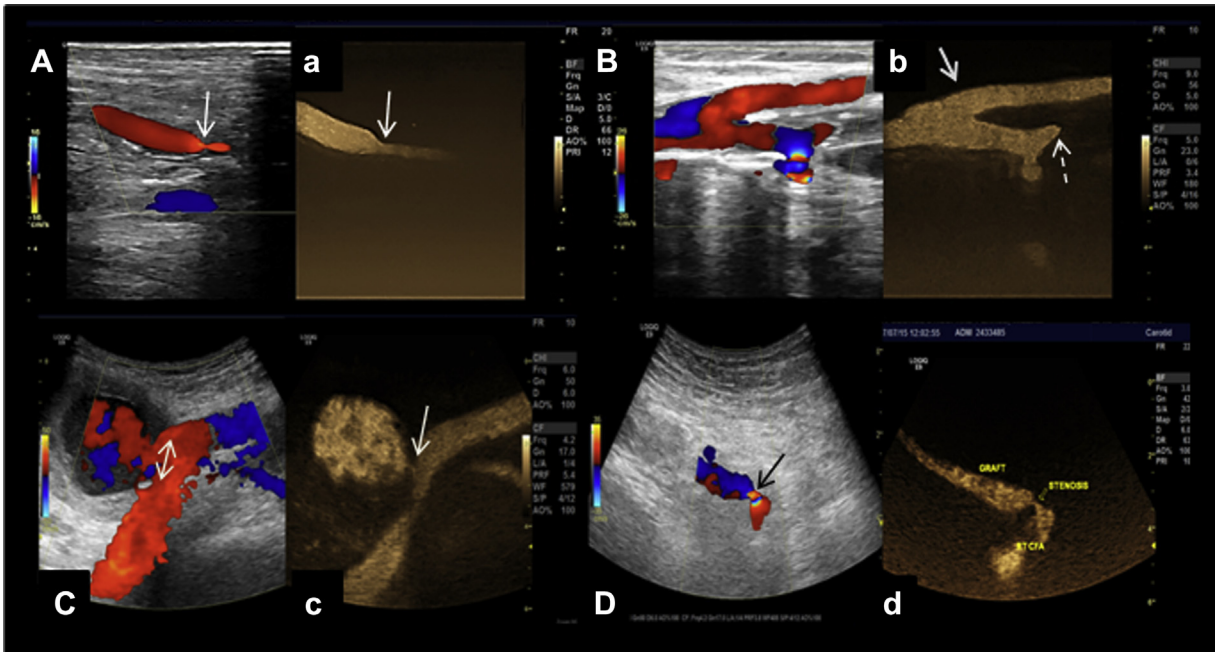

Fig. 3. (A) Color flow image of the distal anastomosis of an interposition venous bypass graft of the SFA. The color flow image suggests a possible focal narrowing of the anastomosis (*white arrow*). (a) B-Flow image of the distal anastomosis revealing better morphology of the graft anastomosis (*white arrow*), ruling out the presence of a suspected stenosis from the color flow image. (B, b) Color flow and B-flow images of a proximal CFA-to-distal vein bypass graft anastomosis (*solid arrow*). The B-flow image allows better definition of the anastomosis and identification of the stump (*dotted arrow*) flow. (C) Color flow image of a large pseudoaneurysm arising off the proximal CFA. This image reveals a large neck (*double-headed arrow*) of the pseudoaneurysm, which would warrant surgical repair as the most appropriate treatment plan. (c) B-Flow image of the same CFA pseudoaneurysm. This image reveals a narrow neck (*white arrow*). This patient underwent successful thrombin injection treatment as a result of the B-flow findings. (D) Color flow image of the distal anastomosis of a CFA-to-popliteal artery bypass graft. Aliasing (*black arrow*) is seen at this level, and the view of the distal anastomosis is limited. On the B-flow image (d), atherosclerotic disease (*arrow*) is noted at the distal anastomotic level. B-Flow allowed for a better understanding of the stenosis. SFA = superficial femoral artery; CFA = common femoral artery.

DISCUSSION AND CONCLUSIONS

Our experience investigating the application of B-flow imaging in assessing PAD and bypass grafts indicates that this technology has the potential to significantly improve non-invasive peripheral blood flow evaluation. B-Flow imaging, however, is not exempt from limitations. One of the key limitations we encountered is depth. In using B-flow to image deep vessels, it is often difficult to visualize flow. In these cases, without the assistance of CDU, an occlusion may convincingly lead to a misdiagnosis. Presence of edema is often a further limitation; resolution in the presence of edema can be poor.

It is possible to obtain reasonable information on flow direction with B-flow based on movement of reflective echoes within the blood vessels. This is particularly true in large vessels such as the iliac arteries and veins, where movement of flow in opposite directions can be appreciated; however, when imaging a small vessel with low velocities, it is not often possible.

In patients with cardiac pathologies giving rise to a pulsatile venous flow, it is difficult to distinguish between the pulsatile artery and pulsatile vein, particularly in the crural vessels. Directional flow given by CDU and/or Doppler is therefore required to identify the vessel.

In addition, B-flow is a proprietary technology exclusive to GE Healthcare; therefore, the application of B-flow in PAD studies may remain limited to few vascular laboratories. To guarantee the best management of patients with PAD, an accurate description of the distribution of the arterial disease is essential. Along with B-flow, there are new emerging non-invasive imaging technologies (Nyrnes et al. 2007; Yiu and Yu 2013) that may improve the imaging of lower limb arteries in patients with PAD and overcome the most common limitations encountered when using CDU and B-flow.

The findings reported in this article should not encourage the use of B-flow as the sole ultrasound imaging 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. A significant limitation of this first descriptive report is the lack of statistical analysis indicating the superiority of B-flow over CDU. Therefore, 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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