What’s new in vascular ultrasound

William H. Pearce, MD\textsuperscript{a,b,*}, Patricia Astleford, BSN, RN, RVT\textsuperscript{b}

\textsuperscript{a}Northwestern University, Feinberg School of Medicine, 201 E. Huron, #10-105, Chicago, IL 60611, USA
\textsuperscript{b}Vascular Laboratory, Northwestern Memorial Hospital, 251 E. Huron, #8-305, Chicago, IL 60611, USA

Traditionally, the vascular laboratory is used to diagnose a wide variety of vascular diseases and to provide objective tools to assess operative interventions. Duplex ultrasound scan is the method of choice for diagnosing deep venous thrombosis, evaluating patients for carotid artery stenosis, and monitoring lower extremity bypasses for neointimal hyperplasia. However, the role of the vascular laboratory is now changing with the introduction of new technology. Arterial mapping of the lower extremity is currently replacing contrast angiography (CA) and magnetic resonance angiography (MRA) as the sole imaging modality for lower extremity bypass procedures. This approach has followed what in many centers has been the standard for patients with carotid artery stenosis (Figs. 1 and 2). In addition, new procedures such as carotid stenting and endovascular aneurysm repairs have created new applications for duplex ultrasound in detecting in-stent stenosis and endoleaks. The duplex ultrasound is also being used intraoperatively to evaluate in situ vein bypasses and to monitor endovenous procedures such as lasers and radiofrequency ablation. Finally, duplex ultrasound is used to treat common femoral pseudoaneurysms, either by compression or to guide thrombin injections.

**Duplex arteriography (DA)**

In patients with lower extremity ischemia, a variety of imaging techniques are used to define the inflow and outflow vessels. CA is generally considered the gold standard. However, in recent years the gold standard has been
challenged by the use of prebypass intraoperative arteriography, MRA, and duplex scanning. Huber et al suggested that intraoperative arteriography is perhaps the most accurate way of identifying distal targets in patients with severe distal ischemia when compared with CA [1]. However, timing and site of injection greatly influence the accuracy of both CA and MRA. In addition, the quality of MRA studies varies greatly depending upon local expertise.

Duplex arteriography (DA) has been advocated as the sole method for evaluating patients undergoing lower extremity bypass by a number of authors [2–6]. Unfortunately, to scan the entire arterial tree from the aorta to
the pedal vessels is time-consuming (average times ranging from 75 minutes to more than 150 minutes). Furthermore, imaging the iliac vessels may be difficult in patients who are obese or who have bowel gas or tortuous iliac arteries (Figs. 3 and 4). In these cases, the arterial waveforms may be useful in identifying a proximal occlusive stenosis. Mazzariol reported that a severely

Fig. 3. Duplex scan of the common femoral and proximal profunda femoris and superficial femoral (SFA) arteries. There is some evidence of plaque present in the proximal SFA, but it is hemodynamically insignificant (less than 60% diameter reduction).

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abnormal common femoral artery waveform was 100% predictive for detecting stenosis greater than 50% [7]. Mildly abnormal common femoral artery waveforms unfortunately did not exclude significant proximal stenosis and, therefore, additional imaging modalities were required. Mazzariol concluded that DA was able to provide enough information for surgery in more than 83% of patients. For infrainguinal disease, a significant stenosis is defined as a twofold or greater increase in peak systolic velocity (PSV) or the absence of blood flow consistent with an occlusion. In similar studies, Proai and Grassbaugh reported that DA was predictive in 88% of patients compared with 93% of patients undergoing CA [3,4]. These investigators used PSV, end diastolic velocity, and transverse images of the arteries to determine arterial diameter and wall calcification. The majority of tibial and pedal vessels can be visualized using DA. However, heavy calcification or nonvisualization of the peroneal artery may limit usefulness. Also, painful ulcers precluded distal imaging. Proai found that graft patency was greater when the PSV was 30 cm/s or greater in the distal artery [4]. In evaluating long-term results, he found that patency was also increased for patients with high PSV, when compared with those patients with lower values. Similarly, end diastolic velocity was less in the group that failed (14 ± 8 cm/s versus 22 ± 7 cm/s; P = 0.08). Ultrasound contrast agents are being used to improve imaging in the lower extremity. Eiberg and colleagues from Denmark were able to improve overall accuracy by 70% in poorly visualized segments using contrast agents [8]. Unfortunately, the short half-life of these agents require repeated dosing or continuous intravenous infusion.

When comparing the results of MRA versus DA, it appears that MRA has a greater sensitivity for detecting arterial disease of the lower extremity. In a meta-analysis comparing MRA and DA, the authors concluded that the sensitivity for MRA was 97.5% compared with 87.6% for DA [9]. The specificity of the two tests was similar, 96.2% versus 94.7%. Unfortunately, gadolinium-enhanced MRA is not available in all institutions, and the technique varies widely. Furthermore, gadolinium may be nephrotoxic in patients with borderline renal function [10]. In these instances, DA may provide a better alternative to either CA or MRA.

**Intraoperative duplex scanning**

Following arterial reconstruction, completion angiography has been recommended to detect technical flaws, which may limit long-term patency. Single-shot arteriograms or fluoroscopy is currently used in most institutions. However, a high concentration of contrast may hide a significant defect. Johnson et al have reviewed intraoperative duplex monitoring as a completion technique [11]. At completion, the entire bypass graft is scanned for anatomic and flow abnormalities. Measurements of PSV and ratio at the lesion divided by proximal velocity are used as criteria to detect defects. In addition, postoperative management of perioperative
anticoagulation was based upon graft flow velocity (cm/s). PSV of more than 25 cm/s was generally the threshold for detecting a graft abnormality. However, this velocity may be recorded from small diameter grafts. The defect was more closely examined if the velocity ratio (VR) was greater than 2 VR. Revision of the graft occurred when the PSV was greater than 180 cm/s and a VR of greater than 2.5 (Fig. 5). In venous segments with borderline velocities, the scan was repeated following administration of papaverine. If the PSV increased more than 200 cm/s, the graft was explored or revised. In patients with impaired outflow (a PSV of less than 45 cm/s), postoperative anticoagulation was given. In this study, Johnson found a 15% revision rate that was comparable to that detected by CA. Reintervention was only 2.5% in 30 days. Continued postoperative surveillance was also performed.

Surveillance duplex scanning is an essential component of patient follow-up following lower extremity revascularization. Other studies by Mills [12] and Bandyk [13] have demonstrated the utility in detecting hemodynamically significant lesions. Identification of these lesions and intervention has increased secondary patency and limb salvage.

Venous ablation

The treatment of varicose veins has changed dramatically over the past several years. Percutaneous or intraoperative ablation of the greater
saphenous vein can be accomplished using radiofrequency or laser energy [14,15]. Using these devices, the groin incision is avoided. A catheter is placed under ultrasonic guidance to within 1 cm of the saphenofemoral junction. Before using this technique, the vein must be evaluated to assure appropriate venous anatomy and vein diameter. Large varicosities greater than 2 cm, venous aneurysms, and varicosities at the saphenofemoral junction are contraindications. These procedures are performed in the office using local anesthesia. To avoid thermal injury to the skin, the anesthesia agent is injected in the space directly above the varicose vein, again using ultrasound guidance. The device is placed from the knee to the groin. The location of the probe is identified just below the saphenofemoral junction, and ablation occurs by pulling the device distally and monitoring venous occlusion.

Preoperative evaluation of patients undergoing varicose vein stripping and venous ablative surgery is needed to assure that the deep system is competent and without clot. Preoperative duplex scanning also provides information regarding the location of perforators and accessory veins and the presence of lesser saphenous reflux. Many techniques have been used to define reflux and are detailed elsewhere [16].

**Endovascular aneurysm repair (EVAR)**

Endovascular repair of abdominal aortic aneurysms (EVAR) was described more than a decade ago by Juan Parodi, MD [17]. Since then, a variety of graft manufacturers have developed endovascular prostheses (Fig. 6). The basic principle of these devices is to bridge the aneurysm defect using a modular graft system. The devices require adequate landing zones, both proximally and distally (aortic leg 1.5 cm and iliac 1 cm), minor degrees of neck angulation, and adequate iliac diameter and tortuosity. Each device is slightly different, and the reader is referred to specific manufacturer’s instructions for use. Currently, helical CT is the imaging technique of choice for determining suitable aortic morphology. However, once the graft has been placed, long-term follow up is mandatory. Long-term follow up is needed to determine whether the aneurysm sac has shrunk and to monitor for the presence or absence of an endoleak. Between 15% and 25% of patients will develop an endoleak. The most common endoleak, Type II, is of uncertain significance, particularly if the sac is stable or shrinking. Types I and III endoleaks, on the other hand, are dangerous and require reintervention. Early experience with these devices relied upon contrast CT scans with delayed venous filling. Even in these instances it was sometimes difficult to identify the exact source of endoleak. As a result, some patients with continued pressure within the arterial sac but without demonstrable endoleak are labeled as having endotension. Because of the expense and potential contrast nephrotoxicity associated with repeated CT scans, many investigators have used duplex ultrasonography as a method to determine endoleaks. Type I endoleaks are characterized by arterial flow outside of the
graft at either the proximal or distal attachment system. Retrograde branch flow Type II endoleaks are characterized as periprosthetic flow, which is characterized as biphasic (high resistant) or monophasic (bi-directional) (Figs. 7–10). Using this criteria Carter et al evaluated 89 EVARs in whom 12 had endoleaks [18]. Two patients were found to have false-positive endoleaks by CT scan, probably due to artifact either from calcium or adjacent hardware. Of the 12 patients, 10 had branch endoleaks, while 2 had both attachment system and branch vessel endoleaks. Although a small series, the endoleaks that persisted exhibited biphasic arterial flow. Monophasic arterial flow was more likely to occlude. In a more recent study by Bendick, conventional duplex scanning was only 60% accurate in detecting the nature of the endoleaks [19]. However, an infusion of ultrasonic contrast agent increased the sensitivity 100% when compared with CT scans. These results are similar to those reported by McWilliams, who found improvement in the diagnostic accuracy of ultrasound using contrast-enhanced color Doppler [20]. The value of duplex ultrasound scanning in patients with EVARs is that repeated studies can be performed frequently. Repeated CT scans and CTAs are not only expensive but also increase the likelihood of contrast-induced nephropathy. In addition, metal artifacts, from adjacent spinal hardware or the attachment systems, may make interpretation of the CT scan difficult.

**Femoral pseudoaneurysms**

Femoral pseudoaneurysms are relatively uncommon following cardiac catheterization (1% to 2%). Pseudoaneurysms occur more often with
catheters, sheaths, and antiplatelet agents. Kent et al reported that, although many of these pseudoaneurysms thrombosed spontaneously, repeated duplex scanning was necessary for their diagnosis [21]. In 1991, ultrasound-guided compression of pseudoaneurysms replaced watchful waiting. Using this technique, the pseudoaneurysm is externally compressed to

Fig. 7. Aortic endograft with a Type 2 endoleak originating from the inferior mesenteric artery. This leak lies anterior to the graft.

Fig. 8. All suspected leaks need to be confirmed by spectral Doppler analysis. The Doppler signal will be able differentiate between a true leak and a spurious artifact caused by the metal appliance. Type 2 endoleaks of the inferior mesenteric artery and lumbar arteries have a characteristic to-and-fro waveform.
promote thrombosis. Compression times ranged from 10 to 90 minutes. Cox reported an overall success rate of 94% with a mean occlusion time of 33 minutes (range 10 to 120 minutes) [22]. Pseudoaneurysms occluded in more than 98% of patients receiving anticoagulation. However, there were 10 recurrent pseudoaneurysms; 6 of these occurred in patients receiving anticoagulation. Recurrence developed within 24 hours. There were no

Fig. 9. Type 3 aortic endoleak. There is evidence of a leak coming from the left common iliac artery modular connection.

Fig. 10. Type 3 aortic endoleak. There is evidence of a leak coming from the left common iliac artery modular connection.
other complications. Two patients required surgical repair. Due to patient discomfort and long periods of time required for compression, Kang introduced the use of duplex ultrasound-guided thrombin injection. In the initial report, 20 of 21 patients were successfully treated with thrombin injections [23]. Under ultrasound guidance, thrombin (0.5 to 1 mil thrombin solution; 1000 units/mL) was injected into the aneurysm. There were no procedure-related complications. A later study performed by Kruger found that the mean dose of thrombin could be reduced to under 500 units in a majority of cases [24]. Primary success (closure) for simple pseudoaneurysms was 97% and 61% for complex pseudoaneurysms. Secondary success rate in this group, however, was 100% (Figs. 11 and 12). There were no thromboembolic, infectious, or allergic complications during this study. Similarly, Kruger also studied antithrombin II complex and found slight elevations following thrombin injection. Unfortunately, others have reported serious complications following thrombin injections. There are case reports of extravasation of the thrombin into the arterial system leading to arterial embolization or thrombosis of the femoral artery. Complex and multilobe pseudoaneurysms are often difficult to treat, and may require multiple injections. In addition, we have been cautious in using this technique for patients with short, wide communications between the artery and the pseudoaneurysm (Fig. 13). The likelihood for infusing the thrombin into the arterial lumen is greater in such instances. We have seen one case in which additional compression of the thrombosed pseudoaneurysm forced thrombotic debris into the arterial lumen with distal embolization.

Fig. 11. Right groin pseudoaneurysm originating from the superficial femoral artery. A pseudoaneurysm will have the characteristic to-and-fro Doppler signal.
Carotid stenting

Carotid artery stenting (CAS) is currently being clinically evaluated as an alternative to carotid endarterectomy (CEA). Duplex ultrasound (DU) is commonly being used to monitor restenosis in patients following CEA. For CAS to be compared with CEA, a similar follow-up must be performed. Recent reports of DU follow-up of CAS suggest that critical restenosis is low and that DU velocity criteria may be inaccurate, particularly in patients with less than 20% stenosis [25]. Lal found that a PSV of 130 cm/s or greater was less specific (63%) than a value of 150 cm/s (specificity 96.4%). In addition, the positive predictive value rose from 16.2% to 60%. Lal suggests that the higher velocities may be normal in a stented artery and that arterial compliance is decreased by the stent, increasing velocity. Further studies will be needed to validate this observation and to determine the restenosis rate following CAS.

Comment

The vascular laboratory has adapted to changing technology. Virtually all peripheral arterial and venous structures may be imaged with color duplex ultrasound. The identification of occlusions, the characterization of plaques, and the monitoring of vascular interventions are just a few examples. The low cost and noninvasive aspect of duplex ultrasound make it the technique of choice for the repeated studies that these technologies require.
The vascular laboratories will be playing a greater role in the detection and prevention of asymptomatic vascular disease. The Society for Vascular Surgery has launched a national effort to screen large populations for carotid artery stenosis, abdominal aortic aneurysms, and lower extremity arterial disease. The screening program consists of a truncated carotid artery scan, an abdominal ultrasound to detect abdominal aortic aneurysms, and an ankle–brachial index. In addition, a rhythm strip is obtained to identify patients with atrial fibrillation. Flinn recently reported the finding of unsuspected aneurysms in 2.2% of patients, carotid stenosis >50% in 7.6% of patients, and peripheral arterial disease in 7% patients [26]. Furthermore, he found that less than 50% of patients with peripheral arterial disease were on antiplatelet agents or lipid-lowering medication. Hopefully, the United States government will recognize the importance of screening for vascular disease and provide funding. At present, screening studies are not reimbursed.

References


