Intraoperative color-flow Doppler imaging of AVM’s and aneurysms

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The use of intraoperative color-flow Doppler sonography to image cerebral and spinal arteriovenous malformations (AVM’s) and a giant aneurysm is reported in 10 patients. The technique is a useful adjunct in localizing vascular lesions, identifying feeding or draining vessels, and confirming intraoperative surgical excision of AVM’s or ligation of giant aneurysms. Imaging of lesions deeper than 4 to 5 cm is, however, limited with the equipment design now commercially available.

Key Words • Doppler ultrasound • aneurysm • intraoperative imaging • arteriovenous malformation

Technological improvements and innovations continue to reduce the morbidity and mortality associated with resection of arteriovenous malformations (AVM’s) and giant aneurysms. In this paper, the use of intraoperative color-flow Doppler sonography of AVM’s and aneurysms is described. With a color-flow Doppler ultrasound unit, a two-dimensional color-encoded intraoperative image of a vascular lesion can be obtained in which an ultrasonic shift is measured in every pixel in the image. Flow is encoded in color, with red being assigned to flows in one direction and blue to flows in the other direction. Locations with no measurable flow are imaged on the gray scale as with any other ultrasound scanner.

We have found this technology useful in the surgical management of vascular lesions in 10 patients. Vessels feeding into and draining from AVM’s could be identified intraoperatively. This technique was particularly useful in localizing an intramedullary AVM and, with improvements in equipment design, it could prove valuable in localizing deep cerebral AVM’s. In one case, intraoperative color-flow imaging demonstrated residual AVM after the surgeons were confident that a complete resection had been obtained. This technique can also demonstrate obliteration of flow in giant aneurysms without rupture of the aneurysm wall, and patency of flow in the parent vessel after aneurysm clipping.

Materials and Methods

At the time of this communication, intraoperative color-flow imaging has been applied to 10 surgical cases: eight cerebral AVM’s, one spinal intramedullary AVM, and one giant aneurysm. An Angiodynograph 1* was utilized for this technique. Scans were performed with a 7.5-MHz linear array transducer. The maximum width of the scanning head was 6.9 cm and the width of the active element was 5.8 cm. The scanning head contained 92 piezoelectric elements providing an in-plane resolution of 0.6 mm. All scans were performed with an 18° wedge attached to the face of the scanning head in order to generate a sonography angle of less than 90° for structures running parallel to the cortex (such as vessels running along the surface). Scanning was usually attempted in two orthogonal directions through the craniotomy; however, the size of the scanning head face (2.2 x 6.2 cm) not infrequently made scanning impossible in more than one plane. In addition, difficulties occurred because of poor contact between the flat scanning head face and the curved surface of the cerebral cortex. We were generally able to image to a depth of 6 cm beneath the cerebral cortex, although ultrasound Doppler signals could only be obtained to a depth of 4 to 5 cm.

*Angiodynograph 1 manufactured by Quantum Medical Systems, Inc., Issaquah, Washington.
The scanning head was covered with a sterile latex glove, and the cord was draped with a stockinet as described previously.1,4 The findings were recorded on digital tape for review and photography at a later time. A summary of illustrative cases follows.

**Illustrative Cases**

**Case 1**

This 44-year-old left-handed man came to the University of Michigan Hospitals complaining of the acute onset of headache and perseveration of speech. A computerized tomography scan before and after administration of intravenous contrast material revealed a small acute hematoma in the left lateral ventricle and a left temporoparietal lesion consistent with an AVM. Cerebral angiography demonstrated a left temporoparietal AVM supplied primarily via the left middle cerebral and posterior cerebral arteries, and drained through the vein of Labbé and basal vein of Rosenthal (Fig. 1). Preoperative Wada testing was consistent with speech localization on the left.

A left temporoparietal craniotomy was performed and intraoperative Doppler color-flow imaging before resection demonstrated the AVM as well as the feeding and draining vessels (Fig. 2). After the surgeons were confident that a complete resection had been obtained and no abnormal vessels could be appreciated in the area of resection by visual inspection, post-resection intraoperative Doppler color-flow imaging revealed residual AVM deep to the area of prior resection (Fig. 3 left). The remaining AVM was then excised. A second post-resection color-flow image demonstrated no further residual malformation (Fig. 3 right). This was confirmed by postoperative cerebral angiography (Fig. 4). The patient did well postoperatively except for occasional perseveration of speech, which gradually resolved.

**Case 2**

This 72-year-old right-handed woman presented to the University of Michigan Hospitals with a Grade II subarachnoid hemorrhage (Hunt and Hess grading system)3 from a ruptured left middle cerebral artery aneurysm. Two years earlier, one giant and two smaller left middle cerebral artery bifurcation aneurysms had been noted incidentally on cerebral angiography during a workup for right hemispheric transient ischemic attacks. Elective aneurysm clipping had not been recommended at that time because of the patient’s age. Repeat cerebral angiography (Fig. 5) revealed no change in the middle cerebral artery bifurcation aneurysms.

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**Fig. 1. Case 1. Left internal carotid angiogram, lateral view, showing a left posterior temporal lobe arteriovenous malformation with drainage in part via the vein of Labbé (arrow). Deep drainage and feeding vessels from the middle and posterior cerebral arteries are not shown.**

**Fig. 2. Case 1. Left: Color-flow ultrasound image demonstrating the arteriovenous malformation (AVM) with multidirectional flow depicted by adjacent areas of red and blue. A large draining vein (arrows) is seen coursing away from the malformation; this could be tracked for a considerable distance. Right: Color-flow Doppler ultrasound image showing the AVM and a feeding vessel flowing toward the malformation (arrows).**
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Parent middle cerebral artery could be demonstrated with color-flow imaging (Fig. 6 left). A post-clipping color-flow image demonstrated obliteration of flow in the aneurysm and patency of the parent vessel (Fig. 6 right). Postoperatively, the patient had no neurological defects and angiography demonstrated adequate clipping of the aneurysm (Fig. 7).

Case 3

This 24-year-old man had the acute onset of back pain concurrently with hypalgesia below the T-10 level, marked bilateral lower-extremity weakness, and loss of bowel and bladder control while doing aerobic exercises. A myelogram and magnetic resonance image revealed an intramedullary lesion suggestive of an AVM. A vascular malformation was demonstrated with spinal angiography (Fig. 8). A thoracic laminectomy was performed and the malformation could not be visualized on the dorsal surface of the spinal cord; however, intraoperative color-flow imaging easily localized the intramedullary AVM (Fig. 9), which was resected through a dorsal myelotomy. Postoperatively,
FIG. 6. Color-flow Doppler ultrasound images in Case 2.  *Left:* Image obtained before clipping showing swirling flow in the large aneurysm. Red depicts flow toward the scanning head in this case, and blue denotes flow away. The *three arrows* within the aneurysm represent a possible flow path. There is an area running vertically through the aneurysm (*curved arrow*) that contains no color. The blood in this portion of the aneurysm is moving parallel to the face of the scanning head and therefore produces no ultrasound shift. The portion of the middle cerebral artery carrying blood away from the aneurysm is seen in blue deep to the aneurysm (*large arrow*). The two smaller aneurysms are not seen in this view.  *Right:* Post-clipping image showing the aneurysm (*A*) containing no flow. The margins of a shadow generated by the clip across the neck of the aneurysm are marked by the *solid arrows*. The middle cerebral artery (*open arrows*) is seen deep to the aneurysm with persistent flow.

FIG. 7. Case 2. *Left:* Internal carotid angiogram, oblique view, showing adequate clipping of all three aneurysms.

*Discussion*

Intraoperative Doppler color-flow imaging shows great promise as an adjunct in the surgical management of AVM's and aneurysms. Malformations and aneurysms are rapidly localized in real time, which is beneficial in the resection of AVM's not presenting on the surface or for the superior temporal gyrus approach to a distal middle cerebral artery aneurysm. This imaging technology was particularly valuable in the intraoperative localization of an intramedullary spinal cord AVM which could not be identified from the surface. Arteries feeding and veins draining a malformation are also quickly located. The scanning head can be positioned and flows can be assigned such that vessels flowing toward the scanning head or AVM appear red and vessels flowing away from the scanning head or AVM appear blue. Tortuous vessels will turn in multiple directions, however, and therefore a single vessel may appear both red and blue as its direction changes.

In our experience, perhaps the most important application of intraoperative Doppler color-flow sonography may be its ability to accurately demonstrate any residual AVM after resection and prior to closure of the craniotomy. Even in this small series, residual AVM was demonstrated in one case by intraoperative color-flow imaging after the surgeons were confident that a complete resection had been performed and no abnormal vessels could be appreciated in the area of resection by visual inspection. It was then possible to achieve complete resection during one operation. A large draining vein or feeding artery remaining after resection can be distinguished from the AVM by the intervening brain tissue and the presence of flow primarily in one direction. As more experience is gained with color-flow imaging, the need for postoperative angiography may decrease. Although there were no complicating hematomas in this series, gray-scale, B-mode ultrasonography which is performed concurrently with Doppler color-flow imaging would also be useful in localizing any hematomas that may occur during the resection.23

Intraoperative Doppler color-flow imaging can also be applied to aneurysm surgery. Obliteration of flow in an aneurysm after clipping can be demonstrated, elim-
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Intraoperative color-flow Doppler imaging has several limitations. Although range-gated Doppler techniques and standard gray-scale, B-mode ultrasonography have been employed during operations on AVM's, they are both severely limited in their applications. Range-gated Doppler scanning presents the extremely difficult problem of interrogating complex three-dimensional objects with a small localized sampling volume, while it is difficult to image feeding arteries, draining veins, and many AVM's at all using gray-scale ultrasonography. In addition, it is unlikely that duplex-Doppler ultrasonography (a combination of range-gated Doppler scanning and gray-scale ultrasonography) will add significantly to its parent techniques.

Doppler color-flow imaging itself has some shortcomings. Although the 7.5-MHz linear array transducer produced high-quality scans to a depth of 4 to 5 cm, color-flow images could not be obtained deeper than this, thus limiting the ability of the current technology to localize very deep AVM's. A 5-MHz transducer which is available with the device and which could certainly aid in depicting deeper AVM's is too large to fit into most craniotomies. The 7.5-MHz scanning head is itself large compared to the sector head usually employed in intraoperative scanning, sometimes making it difficult to manipulate even this scanning head within a craniotomy. Clearly, a scanning head with a smaller contact area and a lower frequency would improve this imaging technique. Despite the current limitations, intraoperative Doppler color-flow imaging is a promising new adjunct in the surgical treatment of AVM's and aneurysms.

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