Carotid Imaging: A Cardiologist's Perspective

BY RAJESH M. DAVE, MD

Cerebrovascular disease is the third leading cause of death in the US. Approximately 600,000 people in the US experience a stroke annually, costing $30 billion in treatment and lost productivity. Carotid artery disease is responsible for up to 25% of these strokes. Traditionally, carotid endarterectomy (CEA) has been the gold standard for treating carotid artery stenosis. Several landmark trials using interventional carotid artery stenting (CAS) have shown at least equivalent and even improved early outcomes with internal carotid artery (ICA) stenting versus surgery, challenging gold standard CEA as the best treatment for ICA disease.[1,2] We predict that in the next few years, more than 90% of ICA disease will be treated with CAS.

Recent FDA approval of CAS for high-risk patients has generated great enthusiasm among physicians in many specialties to learn this technique. Optimal imaging for CAS requires more detailed and comprehensive information on the aortic arch and the entire extra- and intracranial carotid artery system than is currently required for CEA. In our opinion, digital subtraction angiography (DSA) is the method of choice to evaluate and treat carotid artery stenosis using stent-supported angioplasty. In this article, we discuss different modalities used in the management of carotid artery disease.

DIAGNOSIS OF ICA STENOSIS

Duplex ultrasound is a quick, noninvasive technique to screen patients with high-grade carotid stenoses. The advantages of duplex ultrasound, which include absence of com-

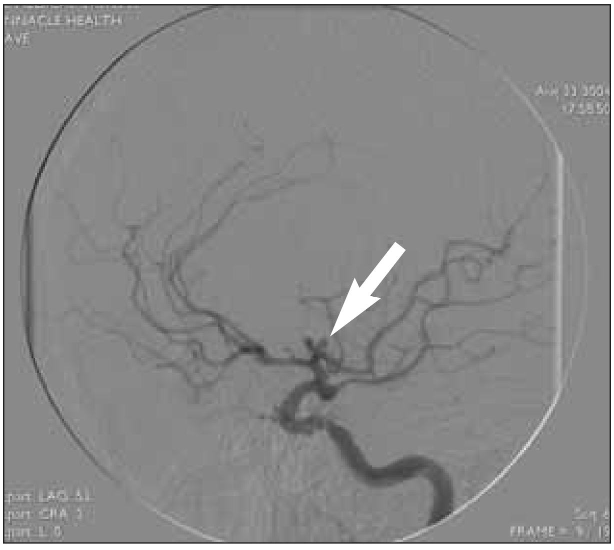

Figure 1. Upon intracranial angiography, this elderly patient with severe carotid stenosis was found to have bilobed MCA aneurysm, a current contraindication to CAS.

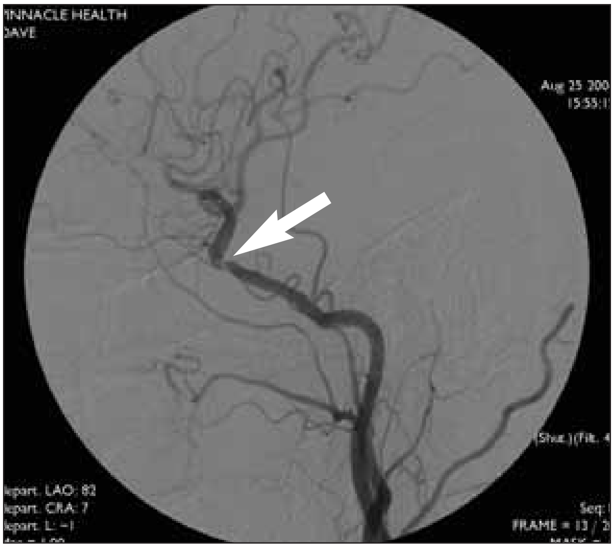

Figure 2. This patient with recurrent TIAs but a negative duplex ultrasound examination was found to have an intracranial ICA lesion.

plications, low cost, and widespread availability, are weakened by the lack of standardization for quantifying the degree of stenosis. Although duplex ultrasound tends to lead to an overestimation of angiographic grade, this noninvasive examination can be confidently applied to screen for high-grade stenoses with negative predictive value of up to 98%.[3] However, outside of selected centers and clinical trials, duplex ultrasound has been challenged as a sole diagnostic test prior to CEA and/or CAS. In a recent prospective study of 130 patients by Qureshi et al,[4] the positive predictive value (PPV) of duplex ultrasound for identifying appropriate symptomatic candidates (angiographic >50%) for carotid intervention was 80%, with a false-positive value (FPV) of 20%. The PPV of duplex ultrasound for asymptomatic (>60%) stenoses was 59%, with an FPV of 41%. Only 46% (60 of 130) patients underwent CEA or CAS.[4] In our current clinical practice, we have noticed a similar trend. Also, duplex ultrasound is operator-dependent and moderately time consuming, and provides limited information on the distal ICA, with no information on intracranial and arch vessels. As a general practice, duplex ultrasound is not justified as the sole technique to determine candidacy for CEA or CAS.

HOW CAN WE BEST EVALUATE THESE PATIENTS WITHOUT SUBJECTING EVERY PATIENT TO DSA?

Multidetector computed tomographic angiography (CTA) has undergone a remarkable evolution in recent years and can be a very useful tool to supplement accurate diagnosis of carotid artery stenosis. Many studies have now evaluated the utility of magnetic resonance imaging (MRI), CTA, and duplex ultrasound in a comparative fashion.[5,6] Several reports have shown the diagnostic accuracy of carotid CTA for 70% to 99% ICA stenosis to have a sensitivity of 100%, and a specificity of 84% to 100%.[7,8]

A distinct advantage of CTA is its ability to provide multiple views and identify lesions that can potentially be underestimated by DSA. DSA has been shown to underestimate the degree of ICA stenosis when results were compared with cross-sectional lumens of surgical specimens.[9] Elgersma et al identified an additional 16% of ICA lesions suitable for CEA compared to DSA.[10] Although limited information is available in evaluating intracranial vessels by CTA in comparison to DSA, a recent study by Herzig et al demonstrated specificity of 84% and PPV of 82% in detecting severe ICA stenosis when duplex ultrasound and CTA were combined.[5]

Other advantages of CTA worth mentioning include its office-based application, speed, less contrast use, less radiation exposure, fewer clinical risks such as access complications and stroke, and accuracy in imaging highly calcified vessels. At present, however, this emerging technique is not widely available and the capital expense for equipment is substantial.

Figure 3. This patient was shown to have a TIA and severe stenosis by duplex ultrasound. DSA shows a large thrombus burden, which is an absolute contraindication for CAS and extremely high risk for CEA.

Elliptic, contrast-enhanced MR angiography is yet another tool to aid in accurate diagnosis of severe ICA stenosis. Currently, the most frequently used techniques are two-dimensional and three-dimensional time-of-flight sequences. The advantage of MRA is its ability to image circulation from the aortic arch through intracranial vessels. Good correlation of elliptic MRA with conventional DSA has been reported. These studies indicate sensitivity of 93% to 100% and specificity of 85% to 100% (average, 75%) for detecting carotid stenosis of greater than 70% severity.[12-16] The vast majority of inaccurate MRA readings represent overcalls, which is not surprising because MRA is most accurate in areas of laminar flow that are perpendicular to the imaging plane. When blood flow is slow or turbulent, such as in carotid bulb or stenosis, bright-blood MRA techniques are subject to areas of flow void or signal dropout where no signal is generated from the flowing blood because it is either moving too slowly or moving in a different direction. Because such an area appears dark in the processed image, the MRA scan tends to overestimate the stenosis where flow is typically highly turbulent.

The differentiation of near-total and total occlusion of the carotid artery is a very important diagnosis. The distinction is critical because there are important implications for therapeutic management and clinical outcome. In a study by Elsaden et al of 548 ICAs, DSA depicted 37 total occlusions and 21 near-total occlusions. Duplex ultrasound depicted all total occlusions and MRA depicted 34 (92%), whereas duplex ultrasound depicted 18 of 21 (86%) near occlusions (another three were called occluded) and MRA depicted all. This suggests that by relying only on duplex ultrasound, there is a chance of calling a near occlusion complete. In our opinion, MRA can aid greatly in differentiating this particular condition.[17] There are disadvantages of the MRA technique, such as motion artifact, stent artifact (especially important during follow-up of CAS patients), and inability to perform a study due to claustrophobia or the presence of an implanted metallic device.

In summary, our opinion is that duplex ultrasound imaging should be aided by either CTA or MRA for accurate diagnosis of severe carotid artery stenosis.

DSA AND CAS

Expert diagnostic cervicocerebral angiography is the foundation for safe and successful cervicocerebral endovascular intervention, including CAS and embolization of cerebral aneurysms, epistaxis, and vascular malformations. In a patient undergoing CAS, the utilization of cervicocerebral angiography and techniques associated with that procedure are absolutely essential. Reported risks associated with carotid angiography include neurological deficits, access site complications, arterial dissections, thrombosis, false aneurysms, and others. In the literature, complications occur in an average of 1% to 2% of cases. In one review of more than 5,000 cerebral angiographic procedures, the overall risk of neurologic sequelae was 0.9%. In a recent study by Qureshi et al[4] of 94 patients with carotid angiography, no complications due to diagnostic angiography were reported. In the author's experience with more than 200 cervicocerebral angiographies, no complications were determined to be due to diagnostic angiography. It is our opinion that in experienced hands, the minimal complication rate related to diagnostic angiography should not deter the operator from performing this very important evaluation of patients undergoing CAS.

The information obtained by diagnostic angiography should include a detailed assessment of four-vessel angiography, including intracranial circulation, patency of the circle of Willis, collateral supply, anomalous vessels, aneurysms, AV malformation, and, of course, an evaluation of arch anatomy with aorto-ostial segments, which greatly impact management decisions. The technical skills involved in cervicocerebral angiography, such as catheter and guidewire manipulations, can be directly applied to techniques in placing the guiding catheter or sheath placement in the common carotid artery, the critical step in the CAS procedure. The importance of this fact cannot be underestimated in the management of the carotid disease patient.

To perform cervicocerebral angiography, we utilize single-plane angiographic equipment with 6-, 9-, and 12-inch image magnification. The equipment should have roadmapping and digital subtraction capability to allow detailed examination of intracranial vessels and minimize contrast load. With the newest flat-panel DSA equipment, patient exposure to radiation is also reduced by 20%. In addition, we only use 50% contrast material mixed with saline to achieve superb image quality and minimal contrast load to the patient. In our opinion, systems for cardiac imaging without subtraction or C-arms are largely inadequate for this evaluation. Also, we must not forget that, in the rare event of distal embolization (after stenting), subtraction capability is essential in recognizing the appropriate embolized vessel and/or to perform a neurorescue procedure.

The flow characteristics and presence of thrombus in the carotid arteries can be evaluated accurately by angiography. Depicted are some examples of findings that may substantially impact management in the CAS patient. Figures 1 through 7 are examples of how DSA is beneficial in CAS.

Figure 4. Duplex ultrasound showed this patient's severe carotid stenosis; the patient was also found to have severe tortuosity of the CCA, which may make sheath placement into the CCA extremely difficult.

Figure 5. Despite significant tortuosity of the CCA, the sheath placement proximal to the bend allowed navigation of the distal protection and stent device to complete the procedure.

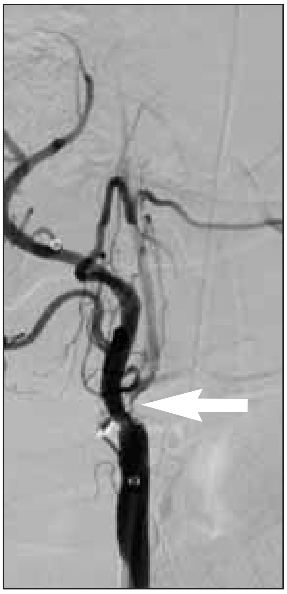

Figure 6. Patient with total occlusion of carotid by duplex ultrasound, but found to have persistent flow through the occlusion in ICA, which allowed intervention using a distal protection device, resulting in a successful outcome after stenting.

FOLLOW-UP OF THE CAROTID STENT PATIENT

Duplex scanning is an easily available, cheap, and noninvasive method of following CAS patients, although some pitfalls are worth mentioning. Blood flow velocity has been demonstrated to be changed by stent implantation after CAS, which may cause duplex scanning to depict falsely increased velocities within the stented segment. Ringer et al, in a follow-up study of carotid stent patients, demonstrated that strict blood flow velocity criteria for restenosis after carotid stenting are less reliable and result in overcalls. Hence, an immediate (or within 30 days) after stenting Doppler study must be conducted to serve as a reference value for future follow-up.[19,20] At the author's institution, we perform Doppler either immediately or within 30 days, and then at 6 months to 12 months and yearly thereafter. In addition, we also supplement this evaluation by CTA or DSA in cases in which significant restenosis is suspected.

Figure 7. A patient post-CAS with now unrestricted flow in ICA through a stent.

CREDENTIALING AND TRAINING

Currently, approximately 300 physicians in the US are trained to perform CAS. We anticipate that in the future, many more physicians will have to be trained to perform this procedure to keep up with growing demand. It is imperative that proper credentialing and training criteria be established to train future operators. Detailed study of neuroangiography cannot be underestimated as an essential element in this process. Industry-sponsored training, formal fellowship training, and simulator-based training will all be very important in increasing the ranks of trained physicians.

The SCAI/ SVMB/SVS writing committee has now published its consensus statement on clinical competence on carotid interventions. The committee recommends 30 diagnostic cervicocerebral angiographies and 25 carotid stents as primary operator as the minimum numbers to achieve competence in these techniques.[21]

CONCLUSION

We have no doubt that rapid adoption of CAS by the medical community is inevitable. With the development of multidetector CTA and MRA, our ability to detect severe carotid lesions with excellent accuracy will be greatly enhanced. Duplex scanning will continue to remain a basic tool in detection of carotid stenosis and follow-up of CAS patients.

In coming years, DSA, techniques used to perform carotid angiography, in-depth knowledge of carotid artery disease, and extensive training in carotid stenting techniques will remain important focal points for vascular medicine. ■

Rajesh M. Dave, MD, is Chairman, Endovascular Section, Pinnacle Health at Harrisburg Hospital, and Director, Central Pennsylvania Cardiovascular Research Institute, Harrisburg, Pennsylvania. Dr. Dave may be reached at (717) 920-4400; rdintervention@comcast.net.

1. Yadav J. Protected carotid artery stenting versus endarterectomy in high risk patients. N Engl J Med. 2004;351:1493-1501.
2. Wholey MH. The ARCHER Trial prospective clinical trial for carotid stenting in high risk patients-preliminary 30 day results. Presented at ACC annual meeting. March, 2003;1347-1355.
3. Sabeti S, Schillinger M, Mlekusch W, et al. Quantification of internal carotid artery stenosis with duplex US: comparative analysis of different flow velocity. Radiology. 2004;232:431-439.
4. Qureshi AI, Suri MF, Ali Z, et al. Role of conventional angiography in evaluation of patients with carotid artery stenosis demonstrated by Doppler ultrasound in general practice. Stroke. 2001;32:2287-2291.
5. Herzig R, Burval S, Krupka B, et al. Comparison of ultrasonography, CT angiography, and digital subtraction angiography in severe carotid stenosis. Eur J Neurol. 2004;11:774-781.
6. Alvarez-Linera J, Benito-Leon J, Escribano J, et al. Prospective evaluation of carotid artery stenosis: elliptic centric contrast enhanced MR angiography and spiral CT angiography compared with digital subtraction angiography. Am J Neuro Radiol. 2003;24:1012-1019.
7. Leclerc X, Godefroy O, Lucas C, et al. Internal carotid artery stenosis: CT angiography with volume recording. Radiology. 1999;210:673-682.
8. Link J, Brossman J, Penselin V, et al. Carotid artery bifurcation: preliminary results of CT angiography and color coded duplex sonography compared with digital subtraction angiography Am J Roentgenol. 1997;168:361-365.
9. Pan XM, Saloner D, Reilly LM, et al. Assessment of carotid artery stenosis by ultrasonography, conventional angiography and magnetic resonance angiography: correlation with ex vivo measurement of plaque stenosis. J Vasc Surg. 1995;21:82-89.
10. Elgersma OE, Buijs PC, Wust AF, et al. Maximal internal carotid artery stenosis: assessment with rotational angiography versus conventional intra arterial digital subtraction. Radiology. 1999:213:777-783.
11. Scarabino T, Carriero A, Giannatempo GM, et al. Contrast enhanced MR angiography in the study of the carotid stenosis: comparison with digital subtraction angiography. J Neuroradiology. 1999:26:87-91.
12. Huston J III, Fain SB, Wald JT, et al. Carotid artery: elliptic centric contrast enhanced MR angiography compared with conventional angiography. Radiology. 2001;218:138-143.
13. Carr JC, Shaibani A, Russell E, et al. Contrast enhanced MR angiography of the carotid circulation. Top Magn Reson Imaging. 2001;12:349-357.
14. Randoux B, Marro B, Koskas F, et al. Carotid artery stenosis: prospective comparison of CT, tree dimensional gadolinium-enhanced MR, and conventional angiography. Radiology. 2001;220:179-185.
15. Remonda L, Senn P, Barth A, et al. Contrast enhanced 3D MR angiography of the carotid artery:comparison with conventional digital subtraction angiography. Am J Neuro Radiol. 2002;23:213-219.
16. Korosec FR, Frayne R, Grist TM, et al. Time resolved contrast enhanced 3D MR angiography. Magn Reson Imag. 1996;36:345-351.
17. El-Saden SM, Grant EG, Hathout GM, et al. Imaging of the internal carotid artery: the dilemma of total versus near total occlusion. Radiology. 2001;221:301-308.
18. Mani RL, Eisenberg RL, McDonald EJ Jr, et al. Complications of catheter cerebral angiography: analysis of 5000 procedures. Am J Roentgenol. 1978;131:861-865.
19. Robbin ML, JJ Vitek, GS Roubin, et al. Carotid artery stents: early and intermediate follow up with Doppler US. Radiology. 1997;205:749-756.
20. Ringer AJ, German JW, Guterman LR, et al. Follow up of stented carotid arteries by Doppler ultrasound. Neurosurgery. 2002;51:639-643.
21. Clinical competence statement on carotid stenting. Catheter Cardiovasc Interv. 2005;64:1-11.