Comparison of Magnetic Resonance Angiography, Conventional Angiography, and Duplex Scanning

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Background and Purpose: To determine the accuracy of magnetic resonance angiography in assessing patients with cerebrovascular disease, we performed a study comparing the results of conventional cerebral angiography, duplex scanning, and magnetic resonance angiography.

Methods: From 42 patients, a total of 25 carotid arteries were evaluated by all three techniques. The studies were independently read and sorted into five categories according to the degree of stenosis: 0-15%, normal; 16-49%, mild; 50-79%, moderate; 80-99%, severe; and totally occluded.

Results: Magnetic resonance angiography correlated exactly with conventional angiography in 39 arteries (52%); duplex scanning correlated with conventional angiography in 49 cases (65%). Compared with conventional angiography, both magnetic resonance angiography and duplex scanning tended to overread the degree of stenosis. The most critical errors associated with magnetic resonance angiography were three readings of total occlusion in vessels found to be patent on conventional angiograms.

Conclusions: Although magnetic resonance angiography offers great hope of providing high-quality imaging of the carotid artery with no risk and at less cost, data from this study suggest that misreading the degree of stenosis, or misinterpreting a stenosis for an occlusion, could lead to errors in clinical decisions. Guidelines for use of magnetic resonance angiography in a clinical setting are offered.

KEY WORDS • angiography • carotid artery diseases • endarterectomy • tomography. x-ray computed magnetic resonance angiography

Magnetic resonance angiography is a relatively new, noninvasive technique of imaging the extracranial carotid arteries. Its high-quality images offer promise that magnetic resonance angiography may replace conventional contrast cerebral angiography for preoperative assessment of patients with carotid bifurcation disease. Magnetic resonance angiography offers several important advantages over conventional angiography, in that there is no risk of stroke, arterial injury, or contrast reaction. Furthermore, because the technique is noninvasive, the study can be performed on an outpatient basis and, therefore, at less cost (Figure 1).

To determine the accuracy of magnetic resonance angiography and its role in the assessment of patients with carotid disease, this prospective, blinded study was performed to compare the results of conventional and magnetic resonance angiography. In addition, all patients had duplex scanning of their carotid arteries to determine whether magnetic resonance angiography was more accurate than duplex scanning and whether the combination of magnetic resonance angiography and duplex scanning was more accurate than either technique alone.

Subjects and Methods

From March 1989 to March 1990, 42 patients were evaluated by duplex scanning, cerebral angiography, and magnetic resonance angiography at our institution. These patients had been referred for either symptoms referable to the carotid distribution or asymptomatic stenosis of >80%, as determined by duplex scan. The patients, 22 men and 20 women, ranged in age from 44 to 87 (mean 68) years. The three studies were performed within 2 weeks in 23 patients, within 1 month in eight patients, and between 1 and 7 months (>4 months in only one patient) in 11 patients.

Duplex scans were performed and read by an experienced nurse-technician with a pulsed-wave Doppler with a 7.5-MHz probe (Advanced Technical Laboratories, Inc.). Degree of stenosis was determined by measuring the peak systolic velocity, the diastolic velocity, and the degree of spectral broadening. The bifurcation lesions were divided into five categories based on the following determinations: 0–15%, normal; 16–49%, mild; 50–79%, moderate; 80–99%, severe; and totally occluded.1

Cerebral angiography was performed through femoral artery catheterization with selective carotid artery injections in 39 patients. In three patients, retrograde

right brachial injections were performed, assessing only the right carotid and vertebral. Biplane views of the carotids were obtained using either film-screen or digital subtraction technique. The region of stenosis was measured on the view that showed it to be most severe. The percent diameter reduction was calculated using the formula \(1 - \left(\frac{\text{diameter of vessel at lesion}}{\text{diameter of outflow vessel}}\right) \times 100\). After calculating the percent stenosis, we assigned vessels to one of the five categories identical to those used for the duplex scans.

Magnetic resonance angiograms were performed on a 1.5-T Philips Gyroscan S15 with 10 mT/m gradients and a standard head/neck coil. The images were obtained using a two-dimensional time-of-flight technique described by Keller et al.\(^2\) These images, seen in 16 different views, were viewed on film as well as on a computer console, permitting the viewer to see them in a three-dimensional fashion. The estimate of the severity of stenosis was made by experienced neuroradiologists using the same categories as those for duplex scans and contrast arteriograms. The three studies were initially read independently by separate teams. A final review by the combined teams was required for several problem cases. At the final review, however, the observers were focused on the specific study and were not aware of the results of the other two studies on the same patient.

Thirty-four patients eventually underwent carotid surgery. Thirty-two patients had carotid endarterectomy, one had a carotid-to-subclavian bypass for subclavian artery stenosis, and one had a common carotid aneurysmectomy. There were no major operative complications. There were three complications attributable to angiography: two strokes and one transient ischemic attack.

Results

Of the 42 patients studied, three had retrograde right brachial angiograms resulting in visualization of only the right carotid arteries. One conventional angiogram could not be measured on either side for technical reasons. In one patient, internal carotid artery occlusion occurred before all three studies could be performed. Three patients had unilateral carotid endarterectomies before magnetic resonance angiography was performed. In all, complete studies were available for both carotid arteries in 34 patients and only one carotid artery in seven patients, which left a total of 75 carotid arteries available for review.

Based on the measurements of the conventional contrast angiograms, six bifurcations had 0–15% stenosis, 19 had 16–49% stenosis, 25 had 50–79% stenosis, 20 had 80–99% stenosis, and five were totally occluded.

The magnetic resonance angiogram correlated precisely with the conventional study in 39 cases (52%). In another 33 cases, the magnetic resonance reading indicated that a vessel was more stenotic than it appeared on conventional angiography. In 30 of these cases, the difference between the two readings was a matter of a single category; in three the magnetic resonance study was at variance to the conventional angiogram by two categories (Table 1). The most critical errors occurred in three patients who were read as having severe stenosis on the magnetic resonance angiogram, but who were, in fact, found to have total occlusion of the internal carotid artery on the conventional study (Figure 2).

The duplex scans correlated with the conventional angiograms in 49 cases (65%) (Table 2). Of the variations between duplex scanning and conventional angiography, one was overread or underread by more than
TABLE 1. Comparison of Readings of Degree of Stenosis at Carotid Bifurcation by Conventional Contrast Angiography and Magnetic Resonance Angiography

<table>
<thead>
<tr>
<th>Magnetic resonance angiography</th>
<th>Conventional contrast angiography</th>
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</thead>
<tbody>
<tr>
<td>Normal (0-15% stenosis)</td>
<td>0-15% stenosis</td>
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<tr>
<td>Mild (16-49%)</td>
<td>16-49%</td>
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<tr>
<td>Moderate (50-79%)</td>
<td>50-79%</td>
</tr>
<tr>
<td>Severe (80-99%)</td>
<td>80-99%</td>
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<tr>
<td>Occluded</td>
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one category. Also, none of the duplex overreadings were in the severe stenosis or total occlusion categories.

Duplex scanning and magnetic resonance angiography correlated in 49 cases (65%). When these two studies agreed, conventional angiography also agreed in 33 cases (67%). In the 16 cases in which duplex scanning and magnetic resonance angiography correlated but differed from the conventional study, ultrasound and magnetic resonance angiography estimated the degree of stenosis to be greater than that measured by conventional angiography (Table 3). In none of the cases did the noninvasive studies, when they agreed with each other, call a vessel occluded when it was patent or patent when it was occluded.

Discussion

Since the advent of carotid endarterectomy in the 1950s, cerebral angiography through catheterization of the arterial tree has been the principle diagnostic tool for preoperative evaluation. The major risks of conventional cerebral angiography are stroke and death, with the incidence reported to be from 1.2% to 5.2%. In this small series, two patients experienced cerebral infarcts as a result of angiography. Despite the vast experience and improved technology, conventional angiography still remains one of the more hazardous diagnostic tests in medicine.

Magnetic resonance imaging has been one of the major developments in the past decade. Technical advances have now led to vascular imaging, or magnetic resonance angiography. There are a few small studies that have compared conventional angiograms with magnetic resonance angiography of the carotid bifurcation, although the magnetic resonance techniques have varied. The purpose of the present study was to determine the role of magnetic resonance angiography in the evaluation of patients being considered for carotid endarterectomy.

In the present study, magnetic resonance and conventional angiography correlated precisely in only 52% of the cases (n=29). When magnetic resonance and conventional angiography did not agree, the difference was usually on overreading of the magnetic resonance angiogram by one category. There are several explanations for these differences. First, magnetic resonance software is programmed to detect movement of blood in a

FIGURE 2. Left panel: Magnetic resonance angiogram interpreted as showing a “string sign,” or severe stenosis of the internal carotid artery (arrow). Right panel: Conventional angiogram shows an occluded internal carotid artery.
considerably more plaque is usually present than estimated by the conventional angiographic findings. Because the bulb is generally larger than the more distal internal carotid artery, considerably more plaque is usually present than estimated when one measures only the residual lumen. Moreover, the categorization of stenosis on the magnetic resonance angiograms were based on an estimate of the normal luminal diameter including the bulb, thus increasing the amount of "stenosis" compared with the distal vessel measured on the contrast study. Finally, as acknowledged by Baker et al., it is impossible to achieve exact correlations when comparing anatomic measurements to physiological measurements of stenosis. To a certain extent, the magnetic resonance images are derived from the physiology of the blood flow through the carotid artery. The duplex scan measurements are based entirely on physiology rather than on direct anatomic measurement.

The most critical interpretation errors in this study occurred in three cases in which the magnetic resonance angiogram led to the diagnosis of severe stenosis of the internal carotid artery, although the conventional study showed total occlusion. Surgeons and neurologists generally do not advise surgery if the internal carotid artery is totally occluded. In the present study, had the decision for surgery been based solely on magnetic resonance readings, the surgeon would have been expecting in these three cases to find a high-grade stenosis but instead would have found a vessel unsuitable for reconstruction. Surgery was not performed on these patients because of the conventional angiographic findings.

To a lesser degree, the magnetic resonance angiography-based diagnoses in 19 patients of 80-99% stenosis, but which were found to be 50-79% stenosis by contrast study, were misreadings that may have misguided our clinical decisions. If the patient has focal neurological symptoms of the ipsilateral hemisphere, the difference in interpretation is not of great consequence; surgery would be advised in either case. In our practice, if the patient is asymptomatic, accurate measurement of the degree of stenosis is of greater importance in deciding whether surgery is worthwhile. Based on the natural history studies of asymptomatic stenosis, we have advised prophylactic carotid endarterectomy for patients with ≥80% reduction in the diameter of the internal carotid bifurcation. In this study, had magnetic resonance angiography rather than conventional contrast angiography been used as the only diagnostic test for patient selection, it is likely that more asymptomatic patients would have undergone surgery.

Compared to the magnetic resonance angiograms, the duplex scans had a higher percentage of correlations with the conventional angiograms than did the magnetic resonance studies (65% versus 52%). Eleven patients judged to have 80-99% stenosis on duplex had, in fact, only moderate stenosis. Three patients with moderate stenosis on the duplex scan had severe stenosis on the contrast angiogram. As previously discussed, these 14 misreadings in the moderate-to-severe categories are of importance mainly in the selection of patients for surgery if they are asymptomatic. There was no instance in which duplex scanning failed to distinguish between a total occlusion and a severe stenosis.

The use of duplex scanning as the sole diagnostic test for the selection of patients for carotid surgery has been widely discussed. Although it may be argued that no critical errors would have occurred had decisions been based on duplex scanning alone, we continue to have reservations regarding this practice. Recent data from the Asymptomatic Carotid Artery Stenosis Study confirmed specific direction and at a specific range in velocity. As the blood passes through an area of stenosis, there is a change in velocity and vector. As a result, some of the blood, particularly in regions of severe stenosis, is not captured by the magnetic resonance angiograms when one measures only the residual lumen.

The duplex scans had a higher percentage of correlations with the conventional angiograms than did the magnetic resonance studies. This is not surprising, given the differences in the methods of measurement. The duplex scans are based on the physiology of the blood flow through the carotid artery, whereas the magnetic resonance angiograms are based on an estimate of the normal luminal diameter including the bulb. This results in an increased amount of "stenosis" compared with the distal vessel measured on the contrast study. Finally, as acknowledged by Baker et al., it is impossible to achieve exact correlations when comparing anatomic measurements to physiological measurements of stenosis. To a certain extent, the magnetic resonance images are derived from the physiology of the blood flow through the carotid artery. The duplex scan measurements are based entirely on physiology rather than on direct anatomic measurement.

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firm our impression that there is a wide variability among vascular laboratories. Few of the laboratories that perform duplex scans have made an effort to validate their results and, therefore, do not know their accuracy in diagnosing carotid stenosis. Finally, there is always some unease in undertaking the risks of carotid surgery solely on the basis of a technician-performed test that does not provide a hard-copy image of the carotid bifurcation.

Part of the purpose of this study was to determine whether conventional angiography was necessary or helpful if there was agreement between the reading of the magnetic resonance angiogram and the duplex scan. Of the 49 cases in which magnetic resonance and duplex did agree, the two agreed with the contrast study in only 33 cases (67%). We reviewed the 16 cases in which duplex scanning and magnetic resonance angiography correlated but conventional angiography did not. In three instances the magnetic resonance and duplex scan read mild stenosis, but the contrast study was interpreted as normal. In two cases the magnetic resonance and duplex were interpreted as moderate, but the contrast study showed 16–49% stenosis. In each of these five cases, the patient was asymptomatic, and the variance in the readings was not of clinical significance. In 11 cases, the magnetic resonance angiogram and duplex scan determined a vessel to be severely stenosed, whereas it measured 50–79% stenosis by conventional study. A review of these angiograms showed that they were mostly on the moderate-to-severe borderline. Management of these patients would have been altered had angiography not been performed only if the evaluation was for asymptomatic disease. In fact, each of these vessels was associated with ipsilateral carotid territory symptoms and, therefore, the differences in reading were not of clinical significance.

To answer the question of whether information from magnetic resonance angiography can be relied on when it correlates with duplex scanning, the data from this study suggest that both noninvasive studies tend to overread the degree of stenosis. Judgment must be used to determine whether an overreading would change the clinical decision for a given patient. In our practice, overreading would not change the decision if the patient had appropriate neurological symptoms, but it might if the patient were asymptomatic. If one limits surgery to >80% stenosis for this group, the information needed is a precise measurement of the degree of stenosis at the bifurcation. Caution must be used when relying on the magnetic resonance angiography information in the asymptomatic patient, as overreadings will lead to some unnecessary operations.

At present we feel one must be selective in using magnetic resonance angiography as the sole diagnostic tool before performing carotid endarterectomy. If the patient has hemispheric symptoms and a duplex scan shows an ipsilateral carotid stenosis, magnetic resonance angiography may be performed to confirm the duplex finding before surgery and to assess the contralateral carotid. For patients with repetitive symptoms and minimal stenosis on the duplex scan and patients with unusual neurological symptoms, a conventional contrast angiogram is the procedure of choice. In these cases high-resolution films are needed to detect luminal surface irregularities or intracranial lesions that may be responsible for the symptoms.

Although rapid improvements in magnetic resonance angiography are taking place, the technique has several inherent drawbacks. Patients with pacemakers or other metallic implant devices cannot be studied by magnetic resonance angiography because of the effect of the strong magnetic field on these objects. The images can be significantly degraded by patient motion. Poor cardiac output may also contribute to poor quality of images. Finally, the high-velocity blood flow and turbulence at areas of severe stenosis can distort the image and may lead to misreadings regarding the degree of stenosis.

Magnetic resonance angiography is an exciting development that is already having an impact on the diagnosis and treatment of vascular disease. As our experience increases and the technology advances, it is likely that angiography by percutaneously placed arterial catheters will become a relic of the past. At present, however, there are limitations to the technique, and we must be cautious when relying on information from these studies to make clinical decisions. To establish the role of magnetic resonance angiography in selecting patients for carotid surgery, more validation studies comparing magnetic resonance angiography with conventional contrast angiography are needed.

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Comparison of magnetic resonance angiography, conventional angiography, and duplex scanning.

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