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Assessment of MR Angiography versus Arteriography for Evaluation of Cervical Carotid Bifurcation Disease

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PURPOSE: To assess the accuracy of MR angiography alone in screening for vascular stenosis of the common carotid bifurcation. **METHODS:** Two hundred two common carotid bifurcations in 101 patients were evaluated with MR angiography and selective contrast arteriography. A two-dimensional time-of-flight pulse sequence was used to obtain sequential transverse images through the common carotid bifurcations. These images were reprojected with a maximum intensity pixel ray-tracing algorithm. Both examinations were blindly graded as either normal or mildly stenotic (0%-29%), moderately stenotic (30%-69%), severely stenotic (70%-99%), or occluded. **RESULTS:** Of the 202 common carotid bifurcations, 119 were classified as normal-mild stenosis by contrast arteriography. In this category, MR angiography correctly identified 114 of these as normal to mild stenosis. Among 21 common carotid bifurcations graded as moderate stenosis by arteriography, 15 were correctly graded as moderate by MR angiography. Among 45 common carotid bifurcations graded as severe stenosis by arteriography, 41 of these were correctly graded as severe by MR angiography. There were 17 complete occlusions which were all correctly graded by MR angiography. **CONCLUSION:** MR angiography with its high rate of agreement with contrast arteriography can be regarded as an accurate screening method of the common carotid bifurcation.

Index terms: Arteries, carotid (common); Magnetic resonance angiography (MRA); Angiography, comparative studies; Arteries, abnormalities and anomalies

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Atherosclerotic disease of the common carotid bifurcation (CCB) is a major cause of stroke (1) which is a leading cause of death in the United States. Inasmuch as the extracranial carotid artery is a common location for surgically correctable atherosclerotic disease, accurate, safe and reliable methods of diagnosing problems are desirable. Duplex carotid sonography and, recently, duplex sonography with color Doppler capabilities, has emerged as the major screening technique in this country (2). Despite the addition of color Doppler flow, duplex sonography is relatively time consuming and remains operator-dependent.

We report results using magnetic resonance angiography (MRA) with a two-dimensional time-of-flight (2DTOF) (3, 4) pulse sequence as a primary screening method for evaluating the CCB. MRA is noninvasive and has no radiation hazard. It is a quick procedure (6.5 minutes scan time) and is less operator-dependent than Doppler ultrasound. The purpose of this study was to evaluate the accuracy of MRA versus carotid angiography for screening of carotid vascular disease.

Methods

One hundred one patients (202 CCBs) were studied with both MRA and selective carotid contrast arteriography over an 8-month period. The study group consisted of 101 sequential patients age 37 to 83 years referred from neurology and the neurosurgery departments for contrast arteriography for evaluation of symptoms related to cerebrovascular disease. The study was conducted under a patient participation investigational review board at two separate hospitals. The MRA was performed on a General Electric 1.5-T Signa MR System (Milwaukee, WI).

A two-dimensional technique with a spoiled gradient-echo pulse sequence was used to obtain 64 sequential

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Fig. 1. Normal left carotid artery demonstrated with selective contrast arteriogram (*A*), and 2DTOF MRA (*B*).

contiguous thin (1.5 mm) transverse sections. The pulse sequence used first-order flow compensation in both the section-selection and read-out directions. The stacked volume produced bright vessels based on time-of-flight phenomena (5). A presaturation pulse was applied cephalad to each transverse section to suppress signal from venous flow. The volume data were then analyzed using a maximum intensity pixel (MIP) ray-tracing projection program, which retrospectively yielded multiple arbitrary projection angles rotating through any plane (6). This program (which was the precursor to General Electric's Interactive Vascular Imaging Program) also allowed selective volume editing (targeting) to separate right and left carotids.

The imaging parameters for the first 10 patients were 50/10.5/1 (TR/TE/excitations) using a 50° flip angle. With software changes, the parameters were changed to 45/8.7/1 with a 60° flip angle for the final 91 patients. A 256 × 128 matrix with a 20-cm field of view was used for all patients. Scan time for a volume of 64 images was 6 minutes, 27 seconds. Images were obtained using either an anterior neck surface coil (General Electric Medical) or a volume neck coil (Medical Advances, Milwaukee, WI). Image quality and coverage with both coils were comparable.

MIP postprocessing of transverse images was performed on the Signa system. The reprojections were completed as a background batch job requiring 15 minutes. There were

18 MIP images (Fig. 1) for each case that rotated through 180°. These images could then be reviewed as a cine loop or filmed on transparency.

Selective common carotid arteriography was performed via a transfemoral approach with cut film or digital subtraction recording. At least three views of the CCB were available in each case.

A forced choice grading of the stenosis for the contrast arteriogram and the MRA into normal-mild (0%-29%), moderate (30%-69%), severe (70%-99%), or occluded (100%) category was performed. Degree of stenosis on contrast arteriography was determined by the radiologist performing the study by measuring the degree of stenosis in three planes. The arterial lumen was measured perpendicular to the vessel axis. The degree of stenosis was calculated with the following formula: percentage of stenosis $= 1 - (\text{Dsten}^2/\text{Dnorm}^2) \times 100$, where Dnorm is the mean diameter of the undiseased prestenotic vessel and Dsten is the average stenotic diameter. The greatest stenosis was used as the correct value.

Because the study was performed at two separate hospitals, grading of each MRA was performed by one of the radiologists from the other hospital. Each of the neuroradiologists grading the MRAs (R.E.L. and J.D.A.) are experienced in MR interpretation. The reader of the MRA was blinded as to the result of the arteriogram. An MRA was graded normal-mild (0%-29%) if the vessel had a normal size and contour or a very minimal irregularity of its contour. An MRA was graded moderate (30%-69%) if there was an apparently more significant vessel narrowing or stenosis but there was no segmental signal void associated with this narrowing. The MRA was graded as severe (70%-99%) if there was a segment of signal void present with proximal and distal segments present. An MRA was graded as occluded if no signal could be seen in the expected course of the distal vessel. The MRA was then compared with contrast arteriography, which represented the gold standard for this study.

Results

The study demonstrates excellent agreement of MRA stenosis grading with intraarterial selective CCB contrast arteriography (Table 1). Of the 202 CCBs studied with both techniques, 119 were classified as normal-mild stenosis (0%-29%) by contrast arteriography. In this category, MR angiograms were correctly interpreted in 114. Four MR angiograms were incorrectly graded moderate and one was not imaged because of artifacts created by vascular clips from previous endarterectomy.

In the category of moderate stenosis (30%-69%), 21 CCBs were diagnosed by contrast arteriography. Fifteen of these were correctly classified by MRA. Of the remaining six, four were graded severe and one mild with MRA. One CCB was not adequately demonstrated.

In the category of severe stenosis (70%-99%), 45 CCBs were detected by contrast arteriography. Forty-one of these were correctly classified by MRA. Of the remaining four, two were graded moderate and one occluded by MRA. One CCB was incompletely evaluated secondary to a combination of high bifurcation and low placement of MRA imaging data set.

Seventeen occlusions were diagnosed with contrast arteriography. All 17 were correctly diagnosed by MRA. One required review of individual 2-D image sections for correct grading as a complete occlusion.

Discussion

Within the normal-mild stenosis category, the MRA agreement with arteriography was straightforward. The vessels demonstrated with MRA show normal or near-normal morphology (Fig. 1). Because the vessel under study can be rotated through 180° or "targeted" for selective reprojection, the MRA study provided a greater level of confidence than the three views obtained by contrast arteriography. In this category of disease, similar results have been documented by Masaryk et al (7) using 3DTOF gradient-echo techniques, and Litt et al using 2DTOF (8).

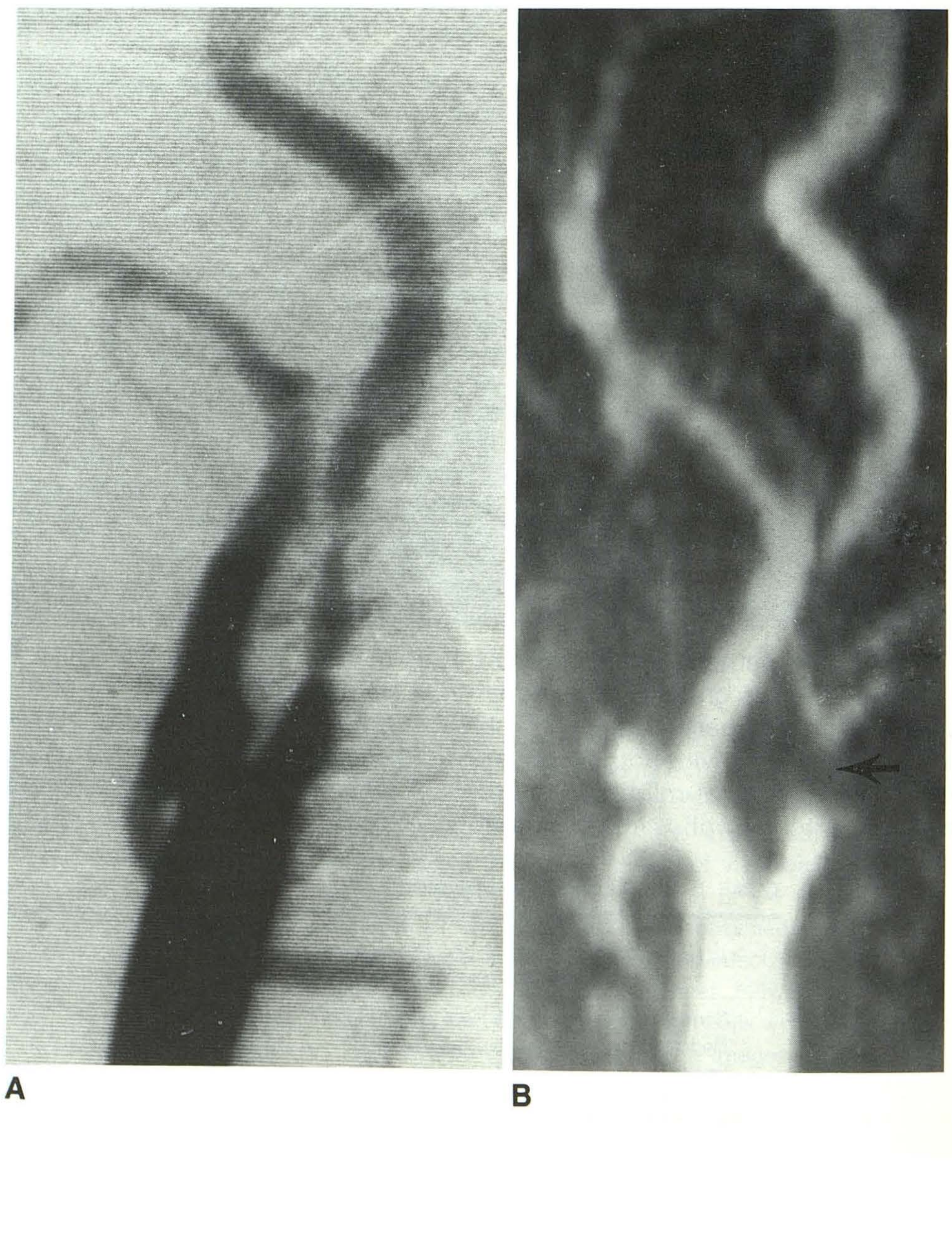
The severe stenosis category was in good agreement with arteriography. The severe stenoses on MRA showed a segment of signal void within the course of the internal carotid or at the

TABLE 1: MRA vs contrast arteriography

Angiography	MRA				
	Normal-Mild	Moderate	Severe	Occluded	No Classification
Normal-mild	114	4	0	0	1
Moderate	1	15	4	0	1
Severe	0	2	41	1	1
Occluded	0	0	0	17	0

level of the CCB (Fig. 2). Litt et al (8) also described this discontinuity in the vessel with clearly defined proximal and distal segments. The signal loss occurs secondary to intravoxel spin-phase dispersion, also called intravoxel incoherence or spin-phase coherence loss. Spin-phase dispersion occurs whenever either a wide spectrum of flow velocities exists within the imaging volume, higher orders of motion such as acceleration and jerk are not compensated, or magnetic susceptibility effects are present. A severely narrowed vessel causes loss of laminar flow, increase in velocity, and turbulence. Each of these contribute to signal loss or intravoxel spin-phase dispersion. The presence of hemorrhagic plaque could result in magnetic susceptibility effects and cause signal loss. In the moderate category, one CCB was inadequately visualized with no obvious reason. It was speculated this could be caused by magnetic susceptibility effects from hemorrhagic plaque. Therefore, segmental signal void secondary to intravoxel spin-phase dispersion correlates well with contrast arteriographic severe stenosis.

The MRA diagnosis of occlusion was in excellent agreement with contrast arteriography, but adequate coverage, cine loop review, and evaluation of the original 2-D sections proved important. The diagnosis of occlusion with MRA depends on complete signal loss with no evidence of signal in the distal internal carotid (Fig. 3). In our study, 17 of 17 (100%) of the total occlusions identified by arteriography were correctly graded as occluded by MRA. In a recent study by Litt et al (8), also using a 2DTOF, there was a poor



A B

Fig. 2. Severe stenosis proximal internal carotid demonstrated with contrast arteriogram (*A*) and MRA (*B*). The MRA demonstrates a segment of signal void (*arrow*) corresponding to segment of vessel stenosis.

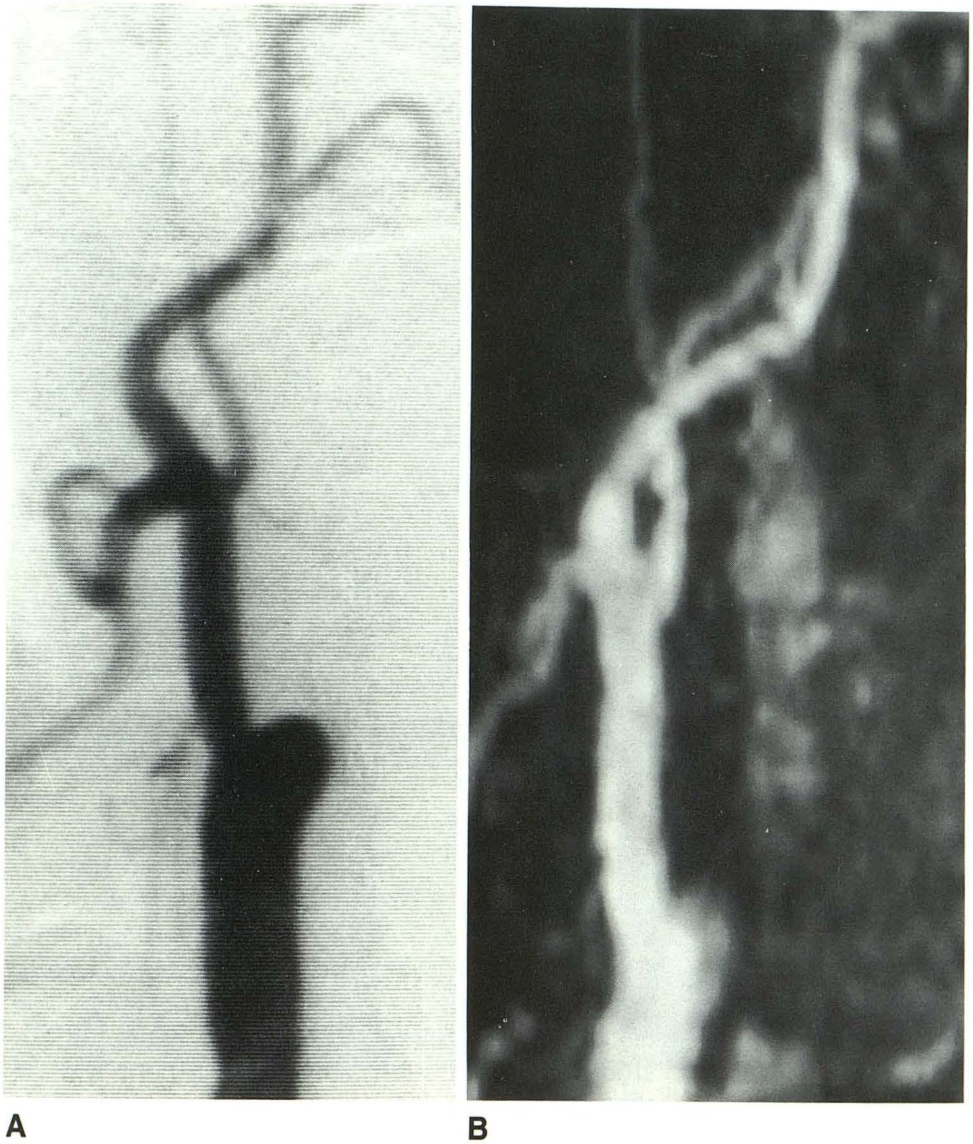


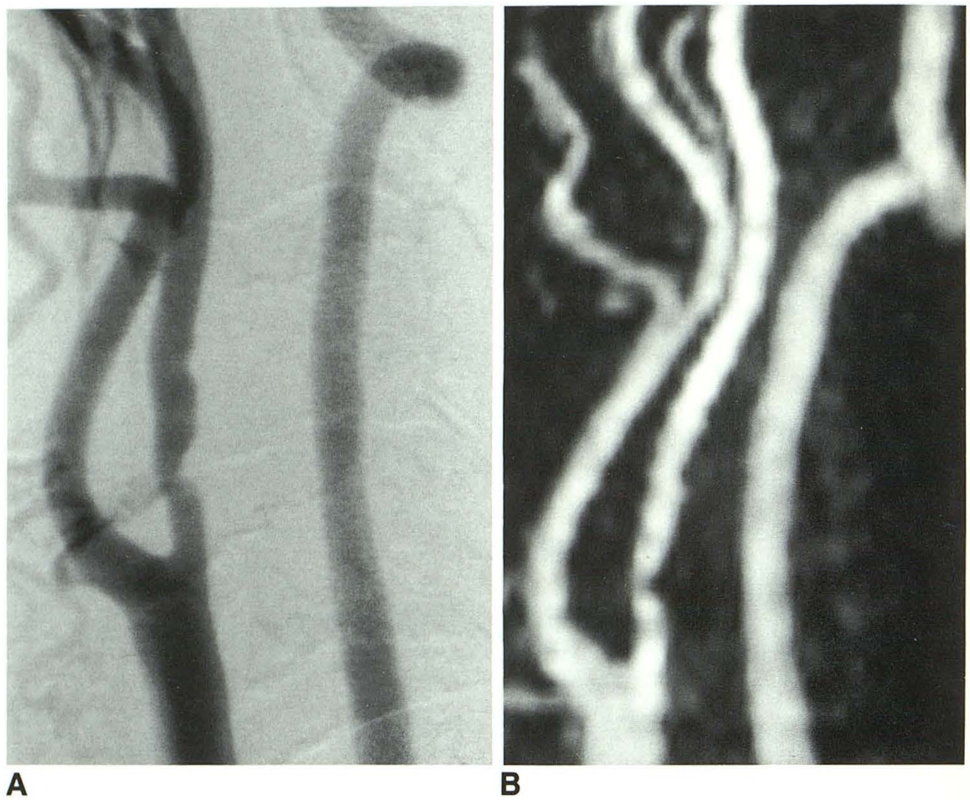
Fig. 3. Complete occlusion internal carotid is shown with arteriogram (*A*) and MRA (*B*). No signal, indicating no flow, is seen in the distal internal carotid on the MIP images. Accuracy is increased by review of the cine loop of reprojected images and review of the axial partitions (data not shown).

agreement in the category of total occlusions. This discrepancy could be related to the length of coverage. It is important to have adequate coverage of the distal internal carotid artery to determine whether there is flow in the distal internal carotid artery. Our protocol provided over 9 cm of craniocaudal coverage, and used a shorter TE, which minimizes intravoxel spin-phase dispersion or intravoxel incoherence. Extremely slow flow accounted for the one false-positive diagnosis of occlusion. Our results suggest that the diagnosis of occlusion may be made by MRA, although extremely slow flow may cause a false-positive interpretation.

The poorest agreement was in the moderate stenosis category. An MRA stenosis was called moderate when the stenosis occurred without segmental signal void (Fig. 4). The general mistake was overestimation of the degree of stenosis. The MIP projection algorithm causes a decrease in vessel diameter as well as an artificial lengthening of the stenotic portion (9). This alone may account for the overestimation of stenosis in most of the moderate categories. This MIP decrease in vessel lumen size may be partially corrected by interpreter experience and purposeful underestimation of the MRA stenosis in this category.

Of the 202 carotids evaluated, three CCBs were not satisfactorily imaged. These three cases could cause misinterpretation and deserve discussion. One carotid was inadequately covered. Upgrades since this study now allows us to obtain routinely 128 sections in 13 minutes. This should correct coverage limitations. Two CCBs showed a large

Fig. 4. Moderate stenosis right internal carotid. Contrast arteriogram (*A*) shows moderate stenosis which is demonstrated with MRA (*B*).



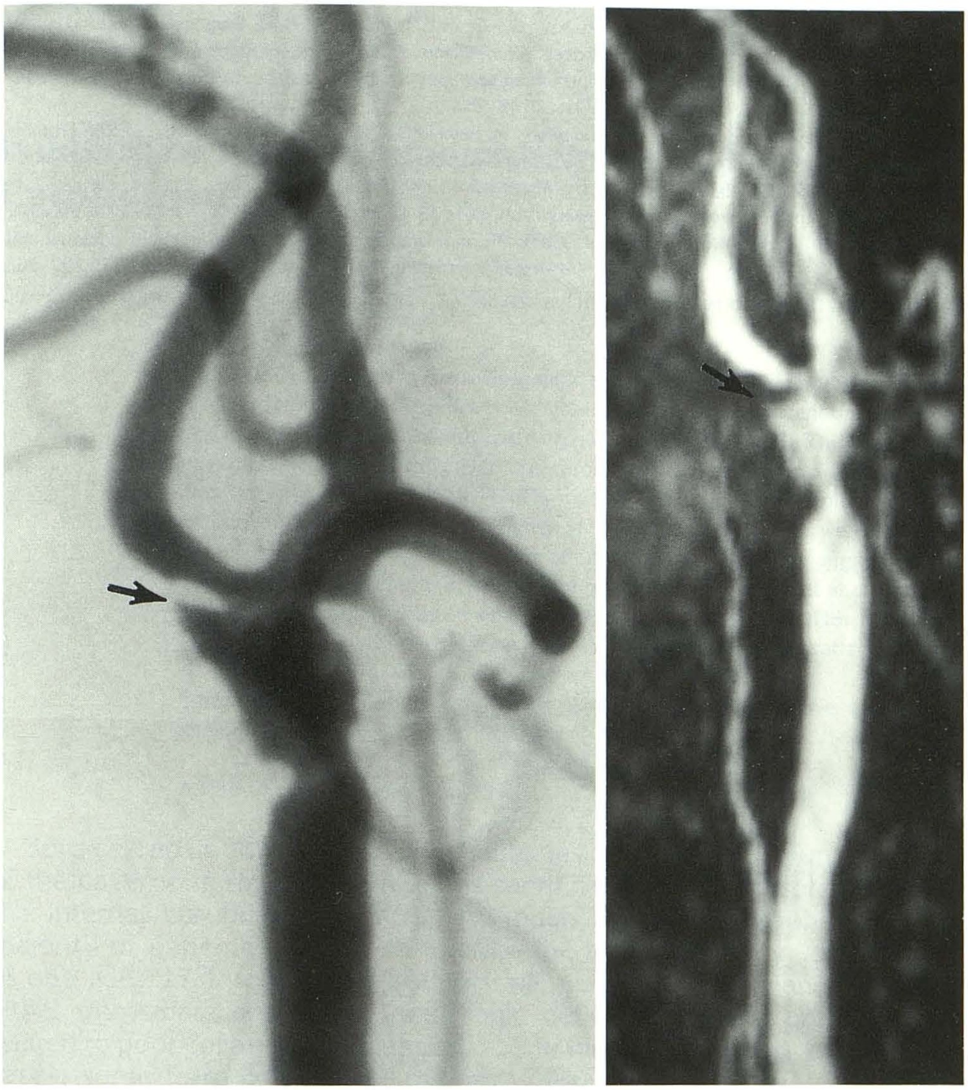
area of signal loss like that associated with magnetic susceptibility artifact. One was secondary to vascular clips from previous endarterectomy. The other was of unknown etiology. A possible cause is hemorrhage into plaque. The degree of stenosis with arteriography was not sufficient to warrant surgical intervention. Of the 202 carotids, 12 were incorrectly classified by MRA. Each of these differed from the contrast arteriogram by only one category. In all but three, the stenosis was overestimated. In two of the three, underestimation could have changed clinical management (MRA moderate vs severe arteriographic). Both cases were in the advanced moderate range (60%-69%). This group may require the addition of duplex sonography for verification, although this was not addressed by the current study.

The 2DTOF technique has several advantages over 3-D techniques. The ability to obtain 64 sections (1.5-mm thickness) gives almost 10 cm of coverage. Since the 2DTOF acquires each section individually, there is no spin saturation, which is a widely recognized problem with 3DTOF techniques, especially when considering this length of coverage.

Because each section is individually acquired, patient motion artifacts will not degrade the study as easily as with 3-D techniques. Several of our cases exhibited patient motion artifacts secondary to swallowing or inadvertent movement. However, this movement usually affected only one or two sections. This did not affect the diagnostic accuracy of the individual case. No patient in our study exhibited such significant patient motion that the MRA was felt to be nondiagnostic. This was partially because of patient selection: the fact that the patients were part of a research protocol and had to give informed consent biased the population to a more motivated group. However, the main reason is the 2-D acquisition technique.

The 2DTOF technique obtains its MIP images from axial sections, allowing adequate coverage of tortuous vessels and branches of the external carotid. This was a problem with the limited coverage using a sagittal 3DTOF technique described by Masaryk et al (10). The 2DTOF technique is also sensitive to slow flow. Theoretically flow would have to be slower than 3.5 cm/second to go undetected by our technique (section thickness/repetition time).

During the course of the study there were several observations of note. Arteriography demonstrated three cases of fibromuscular dysplasia, whereas MRA demonstrated only one of these.



A B

Fig. 5. Contrast arteriogram (*A*) reveals severe stenosis at level of CCB and at level of distal common carotid artery. An ulcer is also seen (*arrow*). MRA (*B*) demonstrates areas of stenosis as well as demonstration of signal from flow within the ulcer (*arrow*).

There were two cases of carotid dissection that were not well demonstrated by 2DTOF-MRA.

A surprising strength of MRA was its ability to detect large ulcerations (Fig. 5). Arteriography demonstrated at least nine large ulcerations. Seven of these were demonstrated with MRA. However, with this small number, no statistical accuracy could be made.

In conclusion, this study demonstrates excellent agreement of MRA with intraarterial contrast arteriography. MRA accuracy is sufficient to be used alone or with color flow duplex sonography in screening for carotid vascular disease. MRA could be especially useful in patients who have routine MR examination for evaluation of stroke symptoms. These patients could receive quick and safe screening of the CCB with a single additional sequence. This would seem to be a more complete evaluation of the patient with stroke symptoms.

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