MR Angiography in Acute Cerebral Ischemia of the Anterior Circulation: A Preliminary Report

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PURPOSE: To determine the prevalence of major vessel occlusion in cases of acute cerebral ischemia of the anterior circulation by using MR angiography and to assess the frequency of spontaneous thrombolysis. METHODS: Thirty patients with an initial clinical diagnosis of possible acute stroke of the anterior circulation made within 24 hours of the event were studied with conventional T2-weighted MR imaging and with two-dimensional and three-dimensional time-of-flight MR angiography. Studies were repeated if the initial study showed partial or complete occlusion. RESULTS: Of the 30 patients studied, six (20%) had a final diagnosis of a transient ischemic attack and 24 (80%) had a stroke of the anterior circulation as confirmed by T2 abnormalities and persistence of clinical symptoms. Twelve (50%) of the stroke patients had a major vessel abnormality, either partial or complete occlusion, at MR angiography. Of these 12 patients, nine subsequently had follow-up MR angiography, and only two of these had a change in the findings. One patient with diminished flow signal had progression of the occlusion and another patient had flow signal in a vessel where no flow was seen initially. CONCLUSION: MR angiography can show patients with acute cerebral ischemia and major vascular occlusive disease. Of those with partial or complete occlusion, progression of thrombus or spontaneous recanalization occurs infrequently.

Index terms: Arteries, stenosis and occlusion; Brain, ischemia; Magnetic resonance angiography

Stroke (1) is a significant cause of morbidity and mortality in industrialized populations (2). Only 43% to 80% of survivors are able to return to their previous lifestyle (3–7), and long-term care for those who are disabled is expensive (8). The majority of acute focal cerebral ischemic events are embolic (31%) (9, 10) or due to in situ thrombosis (53%) (11). A smaller proportion are watershed infarcts resulting from a hypotensive episode or from occlusion on the internal carotid artery (ICA) (12–14). Tandem occlusion of the ICA and middle cerebral artery

(MCA) (15) is said to occur in 22% (16) to 57% (17) of cases of thromboembolism of the cerebral circulation.

Recently, the use of magnetic resonance (MR) angiography has been advocated in the acute stroke setting (18). Warach et al (19) performed MR angiography in 34 patients imaged 2 to 48 hours after stroke onset. In 24 patients with a T2 abnormality, 16 (67%) had MR angiographic evidence of a major vascular occlusion.

The aims of this study were to determine the prevalence of major vessel occlusion in acute cerebral ischemia of the anterior circulation with the use of MR angiography and to assess the frequency of spontaneous recanalization.

Patients and Methods

Thirty patients in whom an initial clinical diagnosis of possible acute stroke of the anterior circulation was made within 24 hours of the event were studied prospectively.

Patients were examined clinically and assigned a score on the Canadian Neurological Scale (20).

MR imaging and MR angiography were performed at 1.5 T. Four series were obtained as follows. Sagittal T1 localizer images were acquired with parameters of 500/20/1 (repetition time/echo time/excitations), a 24-cm field of view (FOV), and a 256 × 256 matrix. Oblique axial double-echo spin-density T2-weighted (3000/30,100/0.75) images were obtained with 5-mm-thick sections, no gap, a 24-cm FOV, and a 256 × 192 matrix parallel to the line of the anteroposterior commissure. Axial two-dimensional time-of-flight (TOF) MR angiograms of the carotid bifurcations were obtained with parameters of 45/6.9/1, a section thickness of 1.5 mm, a flip angle of 60°, a 20-cm FOV, and a 256 × 192 matrix, for a total of 32 sections. Both source images and maximum intensity projection (MIP) renderings were acquired. Axial three-dimensional TOF MR angiograms of the circle of Willis were obtained with parameters of 40/6.9/1, a section thickness of 0.9 mm, a flip angle of 20°, a 20-cm FOV, and a 256 × 192 matrix, for a total of 60 sections. Both source images and MIP renderings were acquired. If possible, all sequences were repeated 72 hours after stroke onset.

A completed stroke was defined as persistence of a neurologic deficit for more than 24 hours and the presence of clinically appropriate spin-density T2-weighted MR evidence of stroke on day 1 and/or day 3. A transient ischemic attack (TIA) was defined as the resolution of the acute neurologic deficit by 24 hours after ictus with no spin-density T2-weighted MR changes in the affected territory.

Three readers independently reviewed each MR angiogram and a consensus was obtained for final analysis. Both the source and MIP images were used in the evaluation of the MR angiograms. The signal from flow in each common carotid artery, ICA (extracranial and intracranial), M1 segment of the MCA, and A1 segment of the anterior cerebral artery (ACA) were graded as normal, partially occluded (reduced signal intensity; ie, narrowed lumen or slowed flow), or occluded (absent signal). The quality of the MR angiograms was rated as excellent, good, adequate, or poor/inadequate (nondiagnostic).

Ethical approval was obtained from the Joint Committee for Clinical Investigation of the Johns Hopkins Hospital. Informed consent was obtained from each subject (or from a close relative) before a patient was included in the study.

Results

The 30 patients studied were 14 women and 16 men ranging in age from 34 to 84 years (mean, 64 years). Twenty-four (80%) had a history of hypertension, 13 (43%) a history of diabetes, five (17%) a history of clinical stroke, and six (21%) a history of a TIA. Twenty-four (80%) of the patients had a stroke of the anterior circulation as confirmed by T2 abnormalities on day 1 and/or day 3, and persistence of clinical symptoms. Twelve (50%) of the stroke patients had a major vessel abnormality, either partial or complete occlusion, at MR angiography.

Six (20%) of the patients had a final diagnosis of TIA. Five of the TIA patients had normal MR angiographic findings, while one had bilateral partial occlusion of the ICA in the neck.

The times of presentation, imaging, and results of initial and follow-up MR angiographic studies for those patients with major vascular occlusion (complete or partial) are shown in the Table. Patient 11 was imaged at 2 hours, 24 hours, 8 days, 3 weeks, and 5 months from stroke onset. All other patients who were reimaged had the repeat study performed on day 3.

One patient with total occlusion of the left ICA, MCA, and ACA died less than 72 hours after the stroke, and two patients with stroke and abnormal MR angiographic findings declined follow-up MR studies. The rest of the patients with abnormal MR angiographic studies on day 1 had follow-up examinations. Only the two patients with a partially occluded vessel had a change in the MR angiographic findings: one had progression with a further reduction in distal flow signal and the other had flow signal in a vessel that previously showed no flow.

Of the 12 stroke patients who had normal MR angiographic findings, four had normal findings at follow-up MR angiography, four declined follow-up imaging, two were unable to complete the study and had T1- and T2-weighted MR imaging only, one was discharged before day 3, and the remaining patient could not be reimaged because of profound clinical instability consequent to the stroke.

Only three (25%) of the 12 stroke patients who had abnormal findings at MR angiography presented within 6 hours of stroke onset. Of the 12 stroke patients who had normal MR angiographic findings, six (50%) presented within 6 hours of stroke onset ($P = .23$, Student's t test). The median time of presentation for those patients with a major vascular occlusion (partial or complete) was 10 hours, and that for patients with normal MR angiographic findings was 5 hours.

Four stroke patients with abnormal MR angiographic findings had these findings confirmed with conventional angiography. One stroke patient with normal MR angiographic findings and the one TIA patient with abnormal MR angiographic findings also underwent con-

MR angiographic changes occurring in patients with stroke secondary to complete or partial occlusion of a major cerebral artery

Patient	Time from Stroke Onset to Presentation, h	Time from Stroke Onset to Imaging	MR Angiographic Findings at Day 1		Follow-up Changes
			Carotid Bifurcation	Circle of Willis	
1	19	27	Normal	R ACA occlusion	None
2*	4	7	Normal	R MCA occlusion	None
3	2	18	Normal	L MCA partial occlusion	Not done
4*	8.5	13	Not done	R ICA occlusion, R MCA and ACA partial occlusion	Not done
5	6	7	R ICA occlusion	R ICA occlusion	None
6	18	19.5	L ICA occlusion	L ICA, MCA, and ACA occlusion	Flow signal seen in L ACA
7	7	9.5	L ICA partial occlusion	Normal	None
8	14.8	21	L ICA occlusion	L ICA, MCA, and ACA occlusion	Died on day 3
9	11	15	Bilateral ICA partial occlusion	L ACA, MCA, and ICA occlusion	None
10	<24	24	Normal	L ICA partial occlusion	None
11*	1	2	R ICA occlusion	R ICA occlusion, R MCA partial occlusion	Progression of R MCA partial occlusion
12*	18	22.5	R ICA occlusion	R ICA and MCA occlusion, R ACA partial occlusion	None

* Confirmed by conventional angiography.

Note.—ACA indicates anterior cerebral artery; MCA, middle cerebral artery; and ICA, internal carotid artery.

ventional angiography, which confirmed the MR angiographic findings.

Typical cases are illustrated in the figures. In Figure 1 (patient 3), the MIP rendering and source images of the 3-D TOF MR angiogram of the circle of Willis show decreased signal intensity in the M1 and M2 segments of the left MCA, which was graded as partial occlusion. Figure 2 depicts the findings in the only patient (patient 11) in whom partial occlusion was seen to progress. Figure 3 shows a complete right MCA occlusion (patient 2).

Discussion

The recent development of experimental protocols for thrombolysis in acute stroke (21–23) necessitates the accurate identification of those patients who are likely to benefit from these interventions because of the cost and associated risks of the treatment. Not only does one need to identify vascular occlusive disease, but more understanding of its natural course is needed. While spontaneous recanalization of thrombosed intracranial and extracranial arteries is known to occur, there is little detailed information on the frequency and temporal course of these events (17, 24–42). Previous studies have generally used conventional X-ray angiography, although there are now reports of

the use of transcranial Doppler sonography (43, 44) to identify recanalization and positron emission tomography (45) to show reperfusion.

Of the 30 patients in our study, all treated within 24 hours of the onset of their neurologic deficit, only 13 (43%) had evidence of partial or complete major vascular occlusion. Twelve of these had a final diagnosis of stroke, the other had a TIA, most likely resulting from long-standing carotid artery stenosis. It is possible that the MR angiographic sequence used failed to depict more peripheral vascular disease within the FOV (eg, in the M3 segment) or that a smaller vessel occlusion was situated outside the FOV. Thus, an apparently normal MR angiographic result might be falsely reassuring in patients with distal emboli or thrombi.

Of the two principle studies of the use of MR angiography in acute stroke to date, Warach et al (19) prospectively showed a major vessel occlusion rate of 67% (16 of 24) within 48 hours, and Johnson et al (18) retrospectively demonstrated an occlusion rate of 82% (60 of 73) in patients imaged within 14 days of stroke onset. These differences may be partly due to the timing of the studies. Initial MR angiography was performed less than 24 hours from stroke onset in our study, so patients with TIAs and reversible ischemic neurologic deficits are more likely to have been included in the study population. Such patients would be less common in
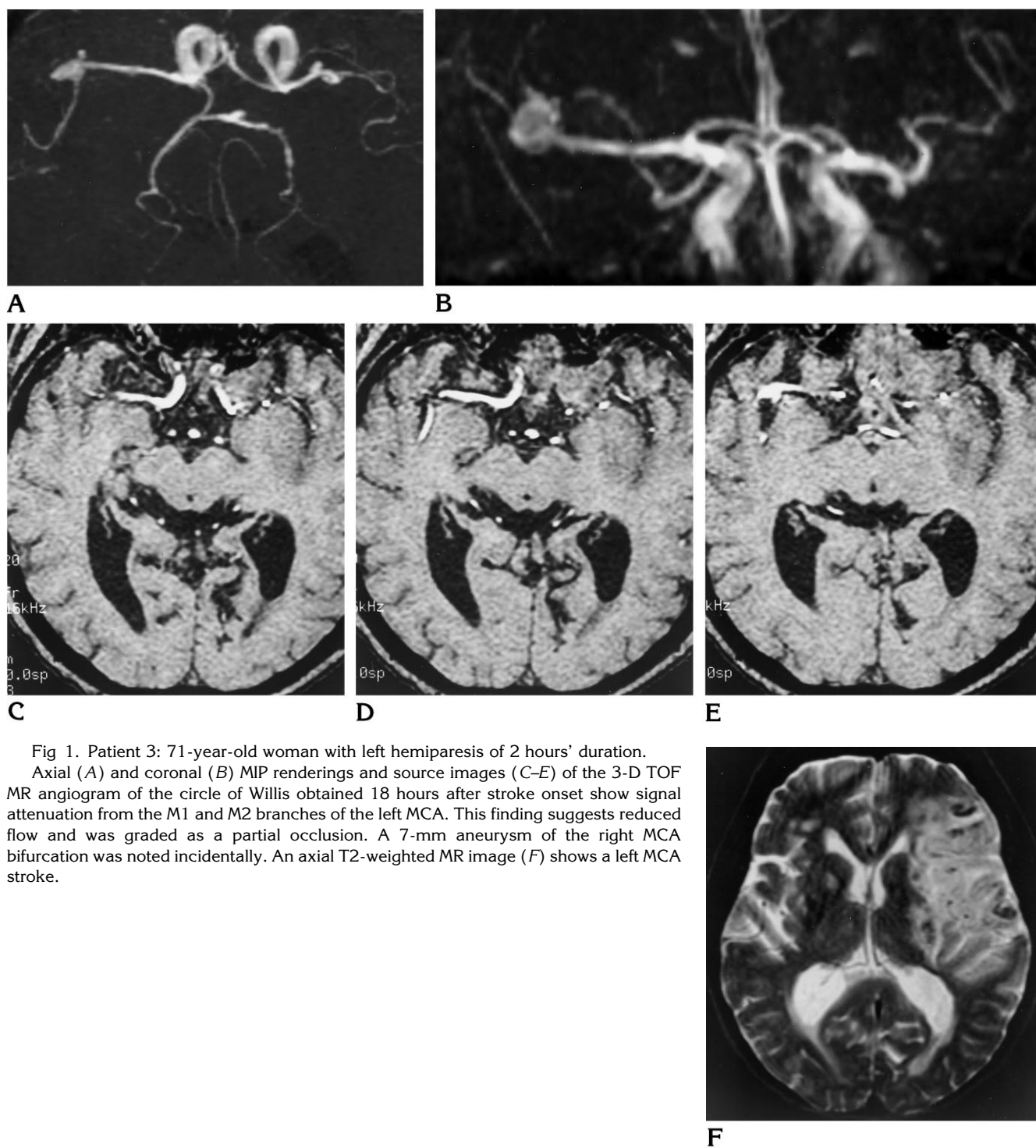
Fig 1. Patient 3: 71-year-old woman with left hemiparesis of 2 hours' duration.

Axial (*A*) and coronal (*B*) MIP renderings and source images (*C–E*) of the 3-D TOF MR angiogram of the circle of Willis obtained 18 hours after stroke onset show signal attenuation from the M1 and M2 branches of the left MCA. This finding suggests reduced flow and was graded as a partial occlusion. A 7-mm aneurysm of the right MCA bifurcation was noted incidentally. An axial T2-weighted MR image (*F*) shows a left MCA stroke.
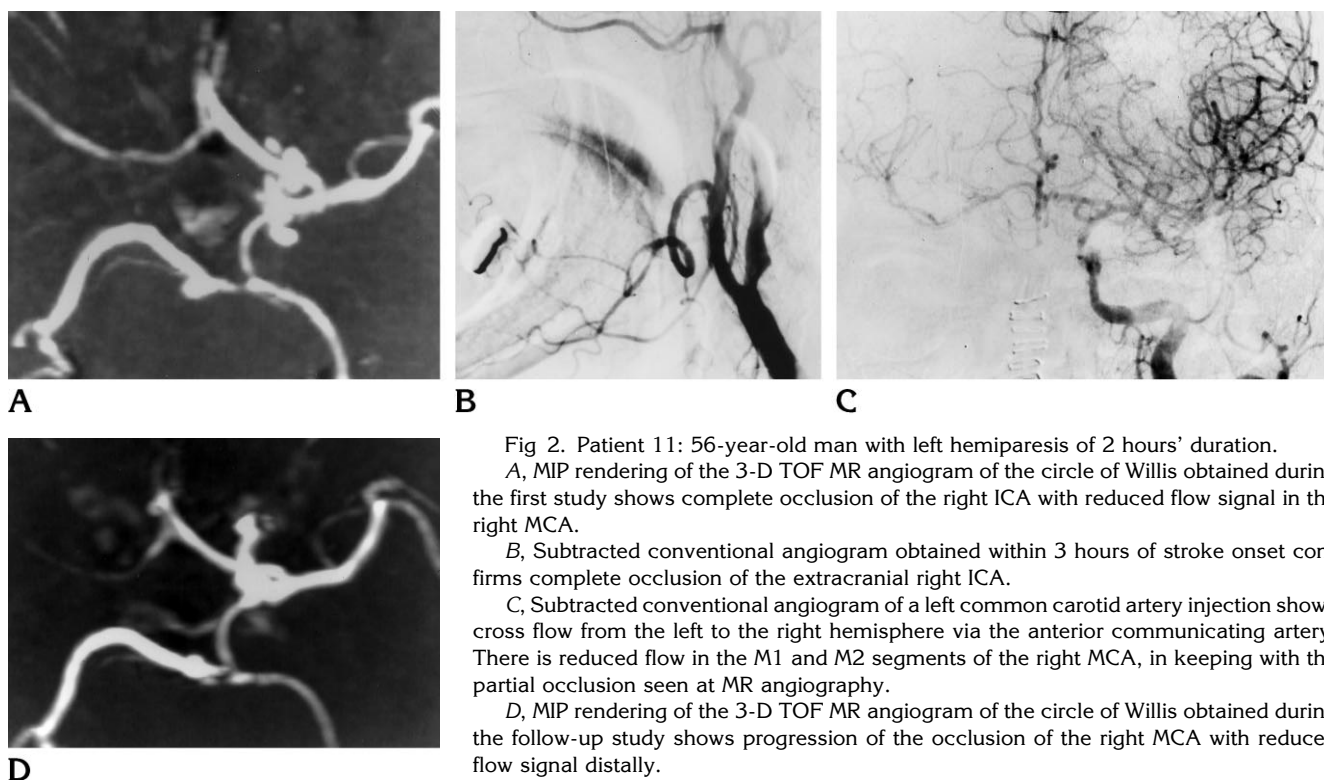
Fig 2. Patient 11: 56-year-old man with left hemiparesis of 2 hours' duration.

A, MIP rendering of the 3-D TOF MR angiogram of the circle of Willis obtained during the first study shows complete occlusion of the right ICA with reduced flow signal in the right MCA.

B, Subtracted conventional angiogram obtained within 3 hours of stroke onset confirms complete occlusion of the extracranial right ICA.

C, Subtracted conventional angiogram of a left common carotid artery injection shows cross flow from the left to the right hemisphere via the anterior communicating artery. There is reduced flow in the M1 and M2 segments of the right MCA, in keeping with the partial occlusion seen at MR angiography.

D, MIP rendering of the 3-D TOF MR angiogram of the circle of Willis obtained during the follow-up study shows progression of the occlusion of the right MCA with reduced flow signal distally.

the other two series. It is difficult to assess the true prevalence of major vascular occlusion from prior studies. The data from diagnostic conventional angiographic studies suggests an occlusion rate of about 40% to 60% (17, 40), but these studies generally were not performed within 24 hours of stroke onset. They included, therefore, patients who had a partial occlusion that completely occluded later and excluded patients in whom thrombolysis occurred spontaneously before angiography. In addition, the prevalence of ICA occlusion or high-grade stenosis in our study—seven (29%) of 24 patients ultimately had a stroke—compares well with the rate of 18% reported in autopsy studies (46).

The use of MR angiography to identify normal major vessels should reduce the number of patients who are considered for conventional angiography and possible thrombolysis (47). In the future, this technique may also be used to identify those occluded vessels that may be more amenable to successful thrombolytic intervention than other regions of occlusion. This is of particular significance when one considers the potential risks and expense of thrombolysis.

Two important questions to consider in treating acute thromboembolic stroke are: What proportion of cases spontaneously reperfuse and over what time frame? and What proportion of patients have demonstrable collateral circulation with which to reduce or ameliorate the acute vascular insult? In some studies, persistent occlusion without evidence of collaterals has been associated with poor outcome (4). Although MR angiography may be able to show major vascular occlusion, it is relatively poor at defining collateral circulation. MR perfusion imaging may be a more effective methodology in defining such flow (B. J. Soher et al, "Identification of the Perfusion Penumbra in Acute Middle Cerebral Artery Stroke by Gadolinium-DTPA MRI," presented at the 20th International Joint Conference on Stroke and Cerebral Circulation, Charleston, SC, February 1995).

A review of the literature reveals how difficult it is to assess the true prevalence of major arterial occlusion at the time of ictus in patients who present with acute thromboembolic stroke (17, 24, 28, 29, 31–40, 42). There is even less information concerning the number of persons in whom occluded vessels reperfuse spontane-

Fig 3. Patient 2: 69-year-old woman with left hemiparesis of 4 hours' duration.

Axial (*A*) and coronal (*B*) MIP renderings show a proximal right MCA occlusion. The posteroanterior conventional angiogram (*C*) confirms the MR angiographic findings, and the T2-weighted study (*D*) shows an area of hyperintensity in the basal ganglia. The midline shift seen in *C* is caused by an incidental anterior falcine meningioma.
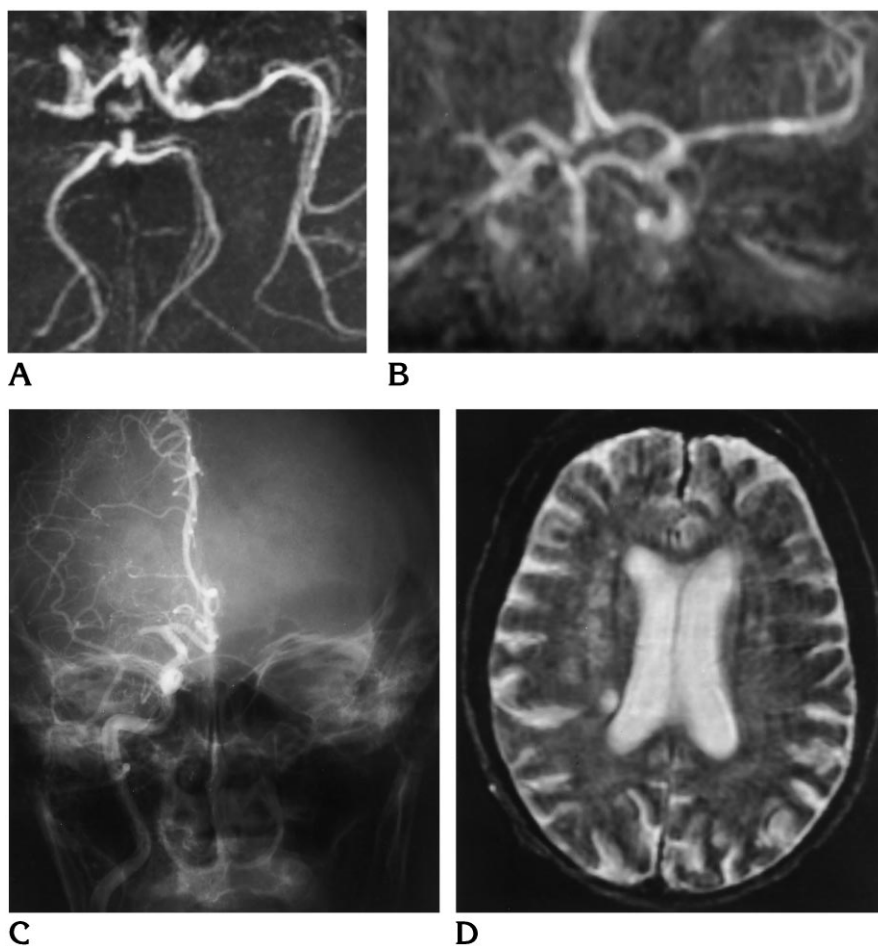
ously after ictus. Only a few investigators have studied the frequency with which recanalization occurs in the first 24 hours after stroke onset (25, 30, 43, 44), and even fewer have reported findings in the first 6 hours or less (26).

In view of the variable selection criteria and the timing of sequential studies used to assess spontaneous thrombolysis in acute stroke, it is difficult to extrapolate an average rate of spontaneous thrombolysis in cases of thromboembolic stroke in the anterior circulation. If thrombolysis is to have a chance of salvaging tissue in the ischemic penumbra (48–52), it is imperative that it be done quickly. The late recanalization times described in the studies mentioned above are unlikely to result in a significant recovery of function. In our study, patient 6 had a degree of recanalization that was thought to be real. It would seem reasonable to surmise that the patients with normal MR angiographic findings either had macrovascular occlusive disease, possibly embolic, that thrombolysed

spontaneously or microvascular perfusion deficits below the spatial resolution of current MR angiographic techniques (53). These latter patients have been shown to have significant MR susceptibility-weighted perfusion abnormalities (Soher et al, "Identification . . ."). In view of the present limitations of spatial resolution, it is unlikely that progression from complete occlusion to recanalization with a persistent high level of stenosis (eg, 90%) could be assessed by means of MR angiography. It is, therefore, impossible to be sure that a small degree of recanalization occurred over the 3-day interval. Comparison with Doppler sonographic studies for cervical disease might be helpful.

Difficulties in assessing patients expeditiously after stroke onset are well known (54) and it is perhaps not surprising that those with major vascular occlusion presented later in this series. The duration of the imaging sequences in acutely ill and possibly disorientated patients is a real problem. Motion artifacts degraded the

images in a number of patients, but only the 2-D TOF study in patient 26 was classified as poor/inadequate (nondiagnostic). Faster imaging sequences may be of benefit for some of these patients. There will always be those patients in whom MR imaging is contraindicated.

Although there was some variability in the initial interpretations of the three readers, a consensus generally was readily achieved with further review of the studies. This is probably a reflection of the simple classification scheme (normal, partially occluded, or completely occluded) used. Only in patient 6 was there a genuine variance in opinion as to whether there was true recanalization of the A1 segment. An assessment of interobserver variability in interpreting MR angiograms was not itself an objective of this study and, therefore, a reproducibility calculation was not prospectively performed. Since MR angiography is known to overestimate the degree of vascular stenosis (18, 55–59), these classification terms, as used specifically in this study, relate only to the MR angiographic appearances and are not intended to be equivalent to conventional angiographic findings. MR angiography may be useful as a screening investigation to identify patients who should have conventional angiography or who might benefit from medical thrombolytic intervention.

The ability to identify noninvasively patients with major vascular occlusion in the setting of acute stroke with MR angiography may prove to be a powerful tool for use in selecting patients in whom therapies to facilitate recanalization should be considered. However, public and professional stroke education may now be more important than methodological details. Only nine (30%) of 30 patients in this study presented for examination within 6 hours of ictus, a common cut-off time for acute stroke therapies. Only three patients (10%) would have been appropriate for most current thrombolytic clinical trials (MCA occlusion within 6 hours of ictus). On the other hand, MR angiography might have spared many patients the risks of conventional angiography and/or thrombolytic therapy. MR angiography could play a critical role in acute stroke management, which requires early identification of patients who do not have major vessel disease, including the 20% of patients with TIA.

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