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Intracranial MR Angiography: Its Role in the Integrated Approach to Brain Infarction

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PURPOSE: To determine the contribution of cranial MR angiography (MRA) for the evaluation of patients with acute and subacute brain infarction. **METHODS:** MR and MRA studies performed on 78 adult patients with acute and subacute stroke were retrospectively reviewed and correlated with the clinical records. **RESULTS:** There were 50 acute and 28 subacute infarctions in our series. Five of 78 MRA exams (6%) were nondiagnostic. Sixty examinations (80%) were positive for stenosis or occlusion. The distribution of stenotic or occlusive vascular lesions correlated with the location of infarction in 56 of the 60 positive cases (93%). MRA provided information not obtained from the MR images in 40 cases (55%). One hundred four individual vessels in 8 patients who underwent conventional cerebral angiography were compared with the MRA appearance. The MRA interpretations correlated with the conventional angiographic evaluations for 90 vessels (87%). **CONCLUSIONS:** Vascular lesions demonstrated on intracranial MRA show a high correlation with infarct distribution. MRA provides information adjunctive to conventional MR in a majority of cases. We conclude that MRA is an important component of the complete evaluation of brain infarction.

Index terms: Magnetic resonance angiography (MRA); Brain, infarction; Brain, magnetic resonance

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The cost of brain infarction to society in terms of morbidity, mortality, and economics is profound. Stroke is the third most common cause of death in the United States (1, 2) and has devastating sequelae for survivors and their families. In certain countries in the Far East, it is the most common cause of death (3). Heightened interest in the early diagnosis and treatment of acute stroke challenges neuroimagers to optimize available modalities and to develop new techniques for the evaluation of cerebrovascular disease. Magnetic resonance (MR) provides accurate anatomic information regarding the distribution and characteristics of early infarction. MR angiography (MRA) complements the cross-sectional parenchymal imaging modalities, providing a noninvasive means for assessing cerebrovascular structures. Our goal in this investigation was to evaluate the role of MRA in the diagnostic evaluation of patients who present with acute and subacute stroke. We correlated the distribution of infarction on conventional MR with the distribution of cerebrovascular disease depicted on MRA and sought additional information provided by MRA that could not be derived from conventional MR alone.

Methods

Patients

We retrospectively reviewed the clinical records and imaging studies of 78 consecutive patients who presented to our institution between August 30, 1991, and January 14, 1993, with acute or subacute stroke with positive MR findings, and underwent MRA. Clinical records were interrogated for information regarding symptoms and time of onset.

Imaging

Conventional spin-echo MR was performed on 1.5-T systems. T1-weighted, spin-echo axial and sagittal 600/

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20/1 (repetition time/echo time/excitations), and long-repetition-time dual-echo axial sequences (2500/30,90/1) were performed.

Various forms of three-dimensional time-of-flight MRA were used during this investigation. Improved protocols were implemented as they became available. Twenty-nine of 78 examinations were conducted with the unmodified pulse sequence supplied by the vendor, or with the local addition of magnetization transfer binomial radio-frequency pulses (4). The MRA parameters included: 50/4.9/1, 25° flip angle, 19-cm field of view, 64 partitions 0.7 mm thick, 256 × 256 matrix, first moment flow compensation on the section- and frequency-encoding axes, radio-frequency phase-spoiled acquisition, and scan time of 13.6 minutes. When magnetization transfer was used, parameters were the same with the exception of the repetition time (30 msec) and acquisition time (8.3 minutes).

The remaining 49 patients were evaluated using multiple overlapped thin-slab acquisition (MOTSA) (5), a technique in which multiple thin 3-D slabs are sequentially acquired. The slabs in this case consisted of 16 0.75-mm-thick sections, and the slab locations overlapped each other by 50%. Other relevant scan parameters were: 31/5.3/1 (early versions required longer echo times, up to 7 msec), 30° flip angle, 11 slabs, 16- to 14-cm field of view, 256 × 128 matrix, first moment flow compensation, and scan time of 11.9 minutes.

Axial source images were printed, and a maximum intensity pixel algorithm was used to generate subvolume projections of the anterior and posterior circulations. The entire maximum intensity pixel volume set was also reviewed in a single base-view projection. The anterior and posterior circulation projection images were printed at 18° increments, rotated in a counterclockwise fashion over 180°.

Image Analysis

All imaging studies were reviewed by two neuroradiologists (J.E.H. and B.A.J.) who were blinded to the clinical information, MR results, and conventional angiographic findings. The source images and projection MRA images were reviewed first. The intracranial vessels were individually graded as normal, stenotic, or occluded on the MRA examinations. A stenotic lesion consisted of focal signal attenuation of 50% diameter or greater or a signal void with distal reconstitution of intravascular signal (Fig 1). An occlusion was interpreted when there was no distal reconstitution of signal. The readers then documented the location, size, and signal characteristics of the infarction based on the conventional MR study. A consensus opinion was formed at the time of image interpretation. A computerized spreadsheet was generated during the evaluation of the films for recording the results of the MR and MRA interpretations.

The vascular distribution of infarction as depicted on MR was then compared with the MRA findings to assess for correlations. MRA findings were considered to correlate with the MR if a stenotic or occlusive lesion occurred in the vascular distribution of the infarction (Fig 1). MRA was considered to provide additional information if it: 1) defined a pattern of collateral flow to the compromised territory; 2) diagnosed a branch occlusion rather than a suspected major vessel occlusion based on the MR (eg, internal carotid artery or middle cerebral artery); 3) diagnosed a major vessel occlusion rather than a suspected branch occlusion on MR; or 4) demonstrated patency in a suspected vascular occlusion.

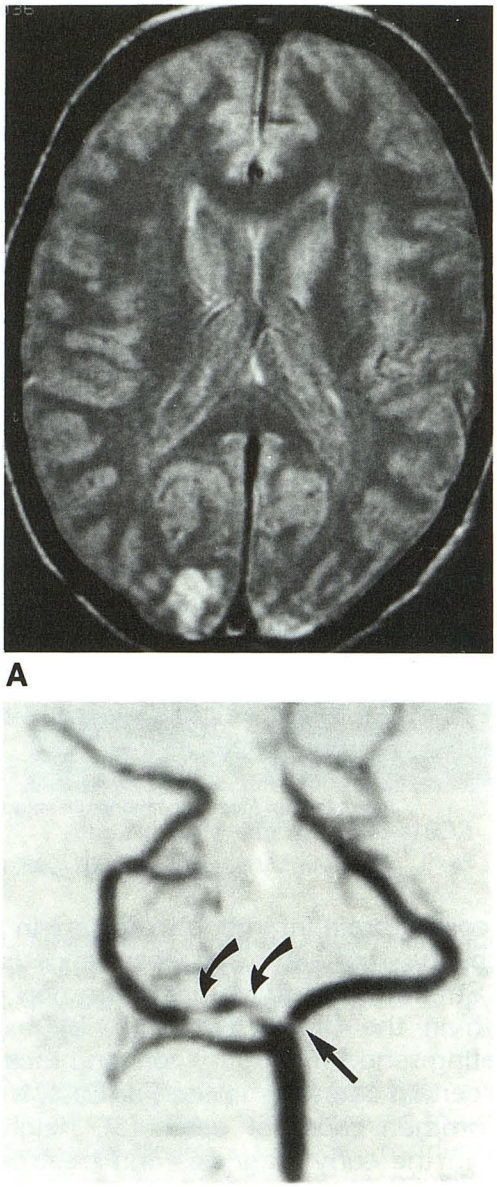

Fig. 1. *A,* Intermediate-weighted image demonstrates small bilateral occipital cortical infarcts.

B, MRA projection image of the posterior circulation shows tandem stenotic lesions in the proximal right posterior cerebral artery (*curved arrows*) and a single focus of stenosis at the origin of the left posterior cerebral artery (*straight arrow*). The superior cerebellar artery is not visualized, although there was no infarction in the superior cerebellar distribution.

Data for the MOTSA and 3-D time-of-flight MRA were compared by computing the normal deviate z derived from the χ^2 statistic assuming independent samples. A correction was applied for continuity (6).

Conventional cerebral angiography was performed on 8 of 78 patients (11%). All but one angiogram was obtained within 1 week of the MR study. Individual vessels were assessed by both readers for stenosis or occlusion. On each study, the internal carotid, anterior cerebral, middle cerebral, posterior cerebral, vertebral, basilar, and superior cerebellar arteries were evaluated. We read the conventional angiograms while blinded to the MRA results and subsequently compared them with the results of the MRA for correspondence of the interpretation for each of 104 vessels.

Results

The cohort comprised 40 men and 38 women, 26 to 87 years of age (mean, 67 years). There were 50 acute (<48-hour) and 28 subacute (3- to 14-day) infarctions in our series. The interval between ictus and imaging ranged from 0 to 14 days (mean, 3.2 days). Five (6%) of the MRAs were considered nondiagnostic because of patient motion and were excluded from further statistical analysis. Clinical data were available for all but 7 patients; imaging criteria were used to categorize the lesions as acute or subacute infarction in these individuals. Only 13 of the 73 diagnostic MRA findings (18%) were normal. The remaining 60 patients (82%) demonstrated a stenotic or occlusive vascular lesion on MRA. The vascular occlusion or stenosis correlated with the distribution of infarction in 56 of the 60 positive cases (93%). Twenty-six patients with stenoses and 30 patients with occlusive lesions were in this category. Table 1 shows the distribution of infarction in each patient and the status of the corresponding vessels as evaluated by MRA.

TABLE 1: MR distribution of infarctions versus MRA findings

Vascular Distribution of Infarct on MR	MRA Findings		
	Normal	Stenosed	Occluded
Internal carotid artery	1	2	1
Anterior cerebral artery	1	2	0
Middle cerebral artery	4	14	19
Posterior cerebral artery	2	3	7
Superior cerebellar artery	2	1	0
Posterior inferior cerebellar artery	1	0	1
Vertebral and basilar arteries	0	0	1
Brain stem	4	3	0
Basal ganglia and thalamus	2	2	1
Total	17	26	30

The MOTSA MRA technique was used in 48 of 73 cases (66%). Forty of the MOTSA studies (83%) had findings that correlated with the distribution of infarction, versus 15 of 25 (60%) of the studies that antedated our use of MOTSA. This difference in results was marginally significant ($P = .054$). The mean age of patients studied with the MOTSA technique was 67 years, with a mean of 2 days between ictus and imaging. The mean age for the other group was 66 years, with a mean of 2 days between ictus and imaging. The clinical presentations for these groups were comparable as well.

There was no significant difference in results between patients with acute infarction and those with subacute infarction. The MRA findings correlated with the distribution of infarction in 34 of 46 (74%) patients with acute infarcts and in 21 of 27 (78%) patients with subacute infarcts. However, of the patients with clinical records documenting an event occurring 24 hours or less before scanning, 14 of 26 (54%) had occlusions in the vascular distribution of the infarction, versus 14 of 40 (35%) of those who presented after 24 hours.

The size of the infarct correlated with the MRA findings. Of 14 patients with infarcts smaller than 2 cm, 9 had MRA findings that correlated with the vascular distribution (64%). Forty-six of 59 patients (78%) with infarcts 2 cm or larger had correlative MRA findings.

Using the criteria described in the previous section, we determined that MRA provided information that could not be derived directly from the MR images in 40 patients (55%). This included cases in which collateral circulation was demonstrated on MRA (Fig 2). Other examples include cases in which conventional MR suggested compromise or patency of a major vessel or a branch, and MRA demonstrated otherwise. Such cases met this criterion only if the information obtained from MRA could not be gleaned from the conventional MR alone.

One hundred four individual vessels in 8 patients who underwent conventional angiography were evaluated. The same grading scheme used for analyzing the MRA exams was used to evaluate the contrast angiograms; individual vessels were graded as normal, stenotic, or occluded. The MRA readings correlated with the conventional angiographic findings in 90 vessels (87%) (Table 2). Two that appeared normal on conventional angiography were read as occluded on MRA. Both were posterior cerebral arteries. In

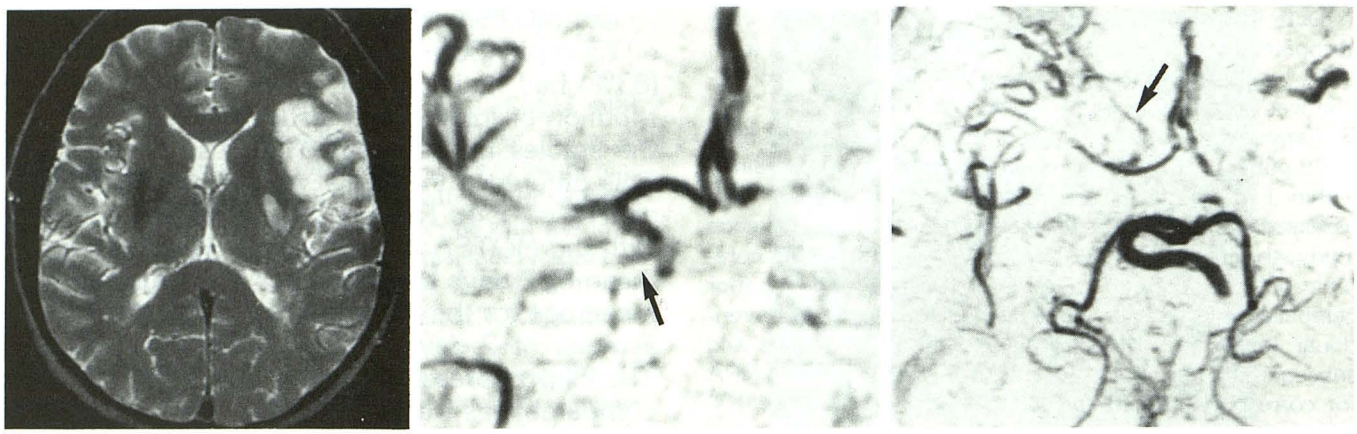

Fig. 2. *A*, T2-weighted image shows a large infarction in the left middle cerebral artery distribution with lenticulostriate territory involvement, which suggests proximal MCA occlusion.

B, Coronal projection and *C*, base-view MRA images show bilateral internal carotid artery occlusions. A potential collateral pathway is suggested by the prominent right external carotid and ophthalmic arteries (*arrow*).

TABLE 2: Conventional angiography versus MRA findings

	Conventional Angiography		
	Normal	Stenosed	Occluded
MRA			
Normal	73	5	0
Stenosed	7	10	0
Occluded	2	0	7

one case, the angiogram was performed 6 days after the MRA, and recanalization was apparent in the distribution of infarction. In the second case, more than 1 week elapsed (after the MRA) before the angiogram was performed. Both patients had posterior cerebral artery distribution infarcts. Vessels that were read as normal on MRA and stenotic on contrast angiography (or vice versa) were as follows: superior cerebellar artery (5 vessels), anterior cerebral artery (3 vessels), vertebral artery (2 vessels), internal carotid artery (1 vessel), and posterior cerebral artery (1 vessel).

None of the discordant interpretations of stenotic vessels was in the distribution of infarction.

Discussion

Stroke Evaluation

Existing and potential therapeutic regimens for cerebrovascular disease provide motivation for early and accurate assessment of cerebrovascular disease (7). MR is an excellent tool for evaluating cerebral infarction, and it affords the ability to diagnose stroke early in the course of the disease (8, 9). However, MR and other cross-sectional imaging modalities alone are insufficient for the comprehensive evaluation of cerebrovascular disease because they fail to delineate the complex cerebrovascular anatomy adequately. This information is significant because prognosis correlates with the location and magnitude of intravascular disease (10) and with the presence of collateral channels or early recanalization (11). Information regarding the severity, location, and number of cerebrovascular lesions may help clinicians select the appropriate therapy for cerebrovascular disease (12–14). The lack of correlation between initial clinical presentation and angiographic findings (10) further justifies obtaining appropriate vascular imaging studies to exclude clinically unsuspected abnormalities.

Contrast Angiography

Selective catheter angiography has traditionally been used for the assessment of patients with stroke symptoms because it complements cross-sectional imaging modalities (15). Previous workers have shown that a majority of patients studied during the acute phase of ischemic symptoms had occluded vessels and that a significant number of these were intracranial (12). Information obtained from the angiogram can help guide therapy and predict outcome, because there is probably a correlation between the extent of vascular disease and poor patient prognosis (16). A correlation between the site of cerebrovascular occlusion and subsequent development of hemorrhagic infarction is also likely (17). This asso-

ciation may provide important prognostic information and may significantly affect the decision to anticoagulate or institute thrombolytic therapy. Evaluation of the cerebral vasculature should be performed in a timely fashion, because thromboembolic disease is a dynamic process, and vascular imaging findings are time dependent (12, 16, 18–20).

Risks of Angiography

Tempering the valuable information provided by conventional cerebral arteriography is the small but significant risk associated with this invasive procedure (21, 22). The risk is further increased in patients with cerebrovascular disease (23). The risk/benefit considerations are especially important in patients with transient ischemic attacks. Because as many as 50% of such patients will subsequently suffer a stroke (24), vascular evaluation is important. The yield of angiography is low in these patients (16), yet the risk of the procedure is still present. Thus performing an angiogram may be more difficult to justify in this setting, whereas a noninvasive screening modality is certainly warranted.

MRA

MRA is effective for the evaluation of carotid bifurcation disease (25–28) and intracranial aneurysms (29, 30). Limited clinical trials evaluating the clinical efficacy of intracranial MRA in acute or subacute stroke are available (7), although excellent correlation with cerebral angiography has already been demonstrated for the diagnosis of intracerebral vascular occlusion (31). The utility of this important technology has also been demonstrated in large-vessel cerebral occlusive disease in the pediatric and adult populations (32). Warach et al (33) correlated MR, dynamic contrast-enhanced MR, and time-of-flight MRA in the evaluation of patients presenting with cerebral ischemia. In their series, there was a high correlation between stenosis and occlusion as demonstrated by MRA and reduction in blood volume and delayed transit time assessed by dynamic enhanced MR.

In our series, there was a high correlation between the vascular distribution of infarction and abnormalities on MRA. In addition, patterns of flow and the presence or absence of vascular disease that was not suspected or inapparent on conventional MR was demonstrated on MRA in 55% of cases. Although vascular stenosis or occlusion may often be inferred based on the MR exam alone (Fig 3A), vascular imaging provides the location and degree of vascular compromise and may reveal collateral pathways or unsuspected vascular disease at other locations. Stroke neurologists previously sought this information with an invasive procedure, so MRA appeals to those with this prior standard of practice. The MRA and cross-sectional brain images complete the diagnostic imaging evaluation of patients who have had strokes, directing the clinician to the specific location (or absence) of vascular abnormalities. As thrombolytic regimens and other early intervention protocols mature, such timely information will be even more important. In addition, serial examinations provide a noninvasive means for following the evolution of vascular compromise (Fig 3).

Correlation with Conventional Angiography

We compared our MRA interpretations against the standard of conventional angiography to verify the accuracy of the MRA readings. The high correlation between MRA and conventional angiography (87%) in our series (Table 2) is in agreement with previous results of Heiserman et al (31). A stronger correlation was demonstrated with normal and occluded vessels than with stenotic arteries, which is also in agreement with prior series. Although intracranial MRA may not correlate with angiography as well for stenotic lesions as for complete vascular occlusions, this shortcoming is mitigated by the fact that distal vessel disease in patients studied angiographically for cerebrovascular disease tends to be occlusive rather than stenotic (16).

Two vessels in our series were read as occluded on MRA and as patent with conventional angiography. In the first case, a patient with a left posterior cerebral artery distribution infarct had a nonvisualized posterior cerebral artery on MRA. The conventional angiogram performed 6 days later showed a patent vessel. It is presumed that this vessel recanalized in the interim, given the large caliber of this vessel on the subsequent study. The second case in which MRA suggested vascular occlusion and the conventional angiogram revealed a patent vessel was also a left posterior cerebral artery occlusion on the MRA. In this case the conventional angiogram was performed more than 1 week after the MRA. This discrepancy may also be attributable to recanali-

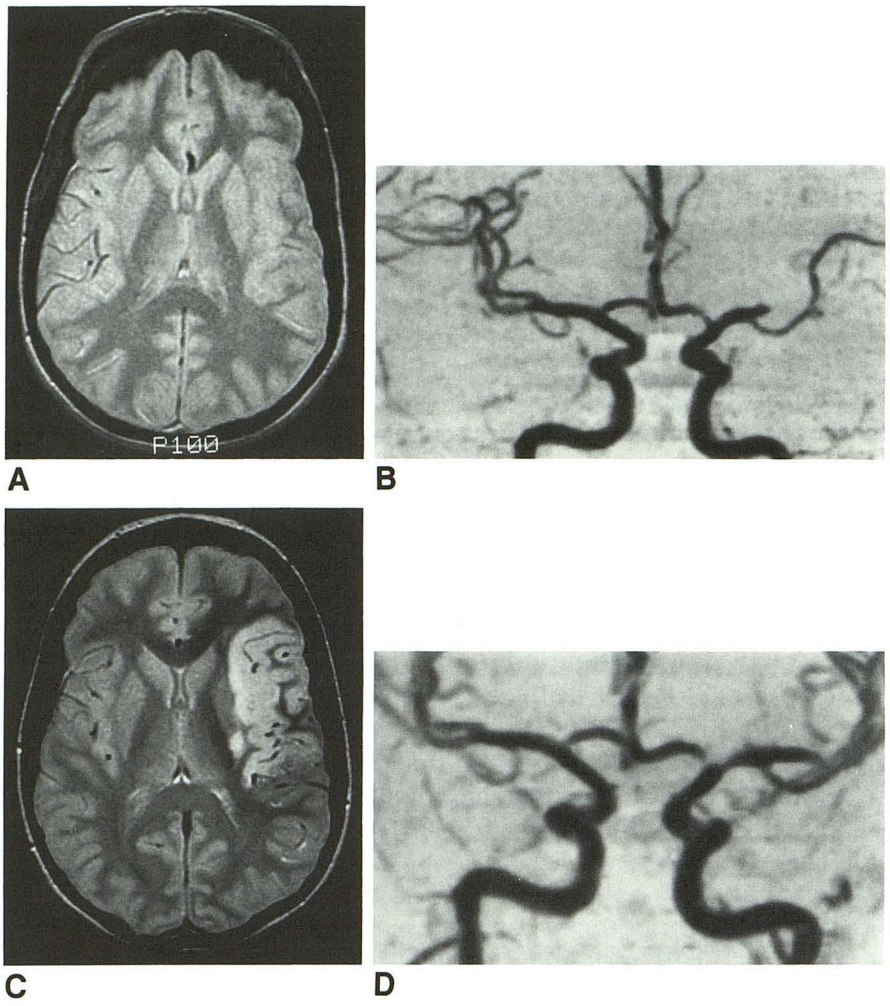

Fig. 3. *A,* Intermediate-weighted image obtained 6 hours after the onset of speech difficulties and right-sided weakness shows subtle swelling of the left insular cortex. There is also absence of flow void within the opercular branches of the middle cerebral artery, implying slow or no flow.

B, Coronal projection MRA image obtained at the same time demonstrates occlusion of a proximal middle cerebral artery branch with a paucity of distal vessel filling.

C, Intermediate-weighted image 3 days later shows a large high-signal-intensity infarct in the left middle cerebral artery territory.

D, MRA demonstrates partial recanalization of the occluded vessel with increased perfusion of multiple distal branches. The distribution of infarction is similar to that seen in Figure 2, despite significant differences in the distribution of vascular compromise.

zation, although technical limitations of MRA must be considered as well. Turbulent dephasing or very slow flow within a patent vessel can cause signal loss. Ideally, MRA/conventional angiogram comparisons should be made in studies performed within 24 hours of each other to limit discrepancies caused by the natural history of thrombosis.

Limitations of MRA

Some MRA pitfalls occur because this method is not simply an anatomic exam. Problems with focal signal loss caused by complex flow phenomenon initially jaded reader confidence (34); however, limiting the echo delay time to minimize phase shifts and turbulent dephasing, which contribute to intravascular signal loss, has produced significant improvements (31).

A second problem encountered with 3-D time-of-flight MRA occurs as a result of saturation effects at the margins of the volume or slab (35). Using thin overlapping slabs, the degree of spin saturation is significantly reduced (36). Overlapping the slabs allows the peripheral partitions within the slab to be discarded because the corresponding anatomic information is available from the adjacent slab. In the current study, the MRA exams obtained with overlapping slabs showed a higher correlation with the distribution of infarction (83%) than did the other exams (60%).

A third problem encountered in MR is limitation of spatial resolution. Warach et al showed occlusive or severe stenotic lesions of major vessels in the distribution of cerebral infarction in 16 of 24 patients but found MR unreliable in infarcts smaller than 2 cm (33). In our series infarcts smaller than 2 cm also showed a lower incidence of correlative MRA findings (64%) than did infarcts 2 cm and larger (78%). The lower correlation with smaller infarcts may result from limitations in spatial resolution, preventing visualization of occluded distal branch vessels with small diameter. Diminished inflow into small peripheral vessels also hinders visualization on MRA.

A fourth potential problem with MRA results from the projection algorithm used to reconstruct vascular anatomic images from the source data. Low-intensity features of vessels may be lost on maximum intensity pixel images, contributing to artifactual narrowing of vessel caliber (37). MRA pulse sequences that maximize flow signal and minimize background signal provide the best compensation for such artifacts. Further refinements in MRA techniques will address the limited spatial resolution, saturation effects from recirculation, and signal loss from higher-order motion (38, 39). Such improvements will further improve the utility of MRA in the evaluation of cerebrovascular disease.

Limitations of Study

A variable was introduced into this trial as a result of evolving MRA techniques. A marginally significant difference between results with MOTSA studies and those that antedated them was noted. Because the MOTSA studies showed a higher correlation between MRA abnormalities and the distribution of infarction, inclusion of the older studies likely results in an underestimation of the utility of MRA for the evaluation of stroke.

This trial was not randomized to determine whether the information obtained from the MRA studies contributed to or affected patient management. Our goal was not outcome analysis, although such studies are warranted to evaluate further the clinical utility of this important technology.

It is also important to be aware that although we compared MRA with conventional angiography when the latter was available, a limited number of these comparative cases were available. The purpose of this study was not to compare the two modalities, but rather to determine the incidence of positive MRA studies in individuals with acute and subacute infarction.

Summary

Vascular lesions demonstrated on intracranial MRA show a high correlation with infarct distribution. In a majority of cases, this noninvasive modality provides information that cannot be acquired from cross-sectional MR alone. As early intervention for stroke therapy continues to evolve, the expeditious and complete evaluation of such patients becomes even more critical. Combining MR and MRA provides a more comprehensive means of evaluating intravascular disease. MRA could be used to screen potential candidates for thrombolytic therapy or surgical intervention, and to provide information that helps prescribe and monitor less invasive therapy. Although it may not currently serve as a replacement for conventional angiography, we conclude that MRA is useful for selecting patients who warrant the more invasive examination and for screening those who do not.

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