Intracranial Aneurysms: Evaluation by MR Angiography

Jeffrey S. Ross[1,2]
Thomas J. Masaryk[1,2]
Michael T. Modic[1,2]
Paul M. Ruggieri[1,2]
E. Mark Haacke[1]
Warren R. Selman[3]

The purpose of this study was to compare the accuracy of a volume gradient-echo MR angiography (MRA) technique with that of intraarterial digital subtraction angiography (IA DSA) in the identification of intracranial aneurysms. The intracranial vasculature was examined in 47 patients by MRA and compared with IA DSA findings in 19 of these patients who had saccular or giant intracranial aneurysms. The remaining 28 patients, in whom no aneurysm was found, served as a control group. MRA was performed with the use of a velocity-compensated gradient-echo sequence (TR = 40–50/TE = 7–15) with a 15° flip angle. The sensitivity and specificity were calculated for the evaluation of the cine 3D reconstructions (cine MRA) only, cine MRA + inspection of the individual partitions, and cine MRA + individual partitions + spin-echo studies. Of 21 aneurysms, of which three were missed in two patients, the sensitivity varied from 67% for cine MRA only to 86% for the cine MRA + partitions + spin-echo studies; of the 19 patients, among whom it was assumed that the diagnosis of any one aneurysm in a patient would lead to angiography and detection of additional aneurysms, the sensitivity varied from 73% for the cine MRA only to 95% for the cine MRA + partitions + spin-echo studies.

The results of this study suggest that MRA can define the circle of Willis sufficiently to allow detection of intracranial aneurysms as small as 3–4 mm. MRA holds promise as a truly noninvasive screening examination of intracranial vasculature in patients at risk for aneurysms.

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Previous reports have demonstrated that MR angiography (MRA) using a three-dimensional gradient-echo sequence is capable of producing an accurate anatomic depiction of intracranial vasculature and vascular pathology [1–3]. This technique can be used in addition to routine MR imaging of the brain parenchyma with an increase in overall examination time of 12–20 min. Our initial study of the intracranial vasculature was designed to demonstrate the feasibility of the methodology without using a direct comparison of MRA with intraarterial angiography [2]. Before more widespread application of the technique can occur, its sensitivity and specificity must be assessed to enable comparison with more conventional techniques. The purpose of this study was to compare the clinical accuracy of a volume gradient-echo MRA technique with that of intraarterial digital subtraction angiography (IA DSA) in the identification of intracranial aneurysms, with the hypothesis that the technique has sufficient sensitivity and specificity to allow more widespread vascular screening of populations at particular risk, such as patients with a family history of aneurysm or polycystic kidney disease (PCKD). Toward that end, the intracranial vasculature was examined in 47 patients by MRA, and compared with IA DSA findings in the 19 patients who had saccular or giant intracranial aneurysms.

Materials and Methods

The retrospectively reviewed study group consisted of two populations: The first group comprised 19 patients referred for MR imaging of the brain in whom aneurysms were known

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[1] Department of Radiology, University Hospitals of Cleveland/Case Western Reserve University, 2074 Abington Rd., Cleveland, OH 44106.

[2] Present address: Division of Radiology, Cleveland Clinic Foundation, Cleveland, OH 44195. Address reprint requests to J. S. Ross.

[3] Department of Neurosurgery, University Hospitals of Cleveland/Case Western Reserve University, Cleveland, OH 44106.

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and who had undergone intraarterial angiography. Eleven of these patients have been described previously [2]. The aneurysm population consisted of 12 females and seven males 14–76 years old (mean, 48). The second group, 28 patients referred for MR imaging of the brain in whom there was no clinical suspicion of aneurysm, served as a control group. This population consisted of 18 females and 10 males 10 months to 76 years old (mean, 32). Fourteen of the 28 control patients had had contrast-enhanced CT studies within 2 years of the MR study. All patients signed informed consent forms that explained the procedure. After routine MR imaging, all the patients underwent MRA.

MR imaging was performed with a 1.5-T system (Magnetom, Siemens, Iselin, NJ) with a 10-mT/m gradient capability. Studies were performed with either a circularly or linearly polarized head coil that operated in both the transmit and receive modes.

Routine spin-echo (SE) MR imaging of the brain was performed with multiecho T2-weighted axial, 2000–2500/15–90 (TR/TE), and T1-weighted sagittal pulse sequences. T2-weighted imaging was performed with one excitation, 5-mm slice thickness with 50% interslice gap, 23-cm field of view, and 256 × 256 matrix. Gradient refocusing for velocity was used in the read and slice-select directions. The examination time was 10.7 min. Sagittal T1-weighted images were obtained with a 500/17 pulse sequence, two excitations, 5-mm slice thickness, and 256 × 256 matrix. The examination time for the T1-weighted study was 4.3 min.

MRA was performed as previously described [2]. Briefly, the technique involves a gradient-echo fast imaging with steady precession sequence (40–50/7–15) with a 15° flip angle. Velocity compensation was performed in the read and section-select directions. The volume slab was oriented axially to cover the circle of Willis. Imaging volumes ranged from 32 to 150 mm in thickness, with 32 to 64 partitions ranging in thickness from 1.0 to 1.25 mm. The partition thickness was kept relatively fixed, although the imaging volume chosen varied with the neurologic status of the patient, and the patient's ability to remain motionless for the examination. Imaging time was 6.4 or 12.8 min for 32 and 64 partitions, respectively. Data sets were reconstructed on a Vax 750 computer (Digital Equipment, Marlboro, MA) by means of a ray tracing technique, which incorporates a maximum-intensity projection that has been described in more detail previously [1]. Cine loops of the MRA projections were displayed on a Pixar imaging computer and placed on a videotape for later viewing.

Correlation with IA DSA was available in all 19 aneurysm patients. IA DSA was performed within 1 week of MR imaging. All DSA studies included anteroposterior, lateral, and oblique views. Studies were obtained with a 0.3-mm focal spot and 11-in. (28-cm) cesium iodide image-intensifying tube (Polytron, Siemens). Images were displayed and photographed with a 1024 × 1024 matrix.

The videotaped MRA and SE studies of all 47 patients (aneurysm and control groups) were randomized, then independently interpreted by two neuroradiologists without knowledge of clinical history or results of other imaging studies. Additionally, the hard copies of the individual partitions of the volume MRA studies were examined.

The MRA studies were evaluated in two separate fashions. First, the MRA images were divided into four groups: In diagnostic group 1, the images were inadequate for diagnosis because of technical factors including patient motion. In group 2, the intracranial circulation was visualized, but the images were not useful for diagnosis in terms of helping to confirm or exclude aneurysms. In group 3, the images were useful, but had the potential for diagnostic error owing to the limited field of view or persistent filling defects within the intracranial vessels. In group 4, the images were useful with a high degree of observer confidence. Then, the MRA images were viewed in a forced-choice method as to the presence or absence of aneurysms and location. The SE studies were evaluated in a forced-choice fashion as to whether aneurysms were or were not identified. Additionally, the SE images were evaluated for the presence of hemorrhage, infarction, and ventricular dilatation. The results for the presence or absence of aneurysms were then combined for the MRA images (both cine 3D reconstructions and individual partitions) and the parenchymal MR examinations for a final diagnosis. The key was then broken, and the results compared with the IA DSA–correlated aneurysm group and the control group for calculation of sensitivity and specificity.

Aneurysm size was measured on the IA DSA and MRA studies in the following manner: Since no measurement scale was present on the IA DSA studies, a ratio was obtained of the aneurysm size in three dimensions (length, width, height) to the size of the supraclinoid internal carotid artery using calipers. A similar ratio was calculated on the MRA study. Both sets of ratios were then converted to millimeters using the centimeter scale on the MRA study. These three measurements were then averaged to give one number reflecting the aneurysm size on both MRA and IA DSA.

Results

The results are summarized in Table 1. Twenty-one aneurysms in 19 patients were defined by IA DSA. The aneurysms were located in the anterior communicating artery (two),

TABLE 1: Summary of Findings in Aneurysm Patients

Location of Aneurysm/Case No.	Cine MRA	MR Imaging	Size (mm)	
			MRA	IA DSA
Anterior communicating artery				
1	+	–	5	5
2	–[a]	+	10	17
Basilar artery				
3	+	NA	7	11
4	+	+	12	14
5	+	+	7	9
Middle cerebral artery				
6	+	+	10	10
7	–	+	–	47
8	+	+	9	9
9	+	–	7	8
Internal carotid artery				
10	+	+	9	15
11	+	+	14	28
12	+	–	12	17
13	+	NA	6	5
14[b]	–[a]	–	–	8
			4	9
15[b]	+	–	6	5
			6	5
Posterior communicating artery				
16	–	–	–	3
17	+	–	5	4
18	+	NA	6	7
Superior cerebellar artery				
19	–[a]	–	7	7

Note.—MRA = MR angiography; IA DSA = intraarterial digital subtraction angiography; NA = not available.

[a] Aneurysm visible only on MRA individual partitions.

[b] Two aneurysms.

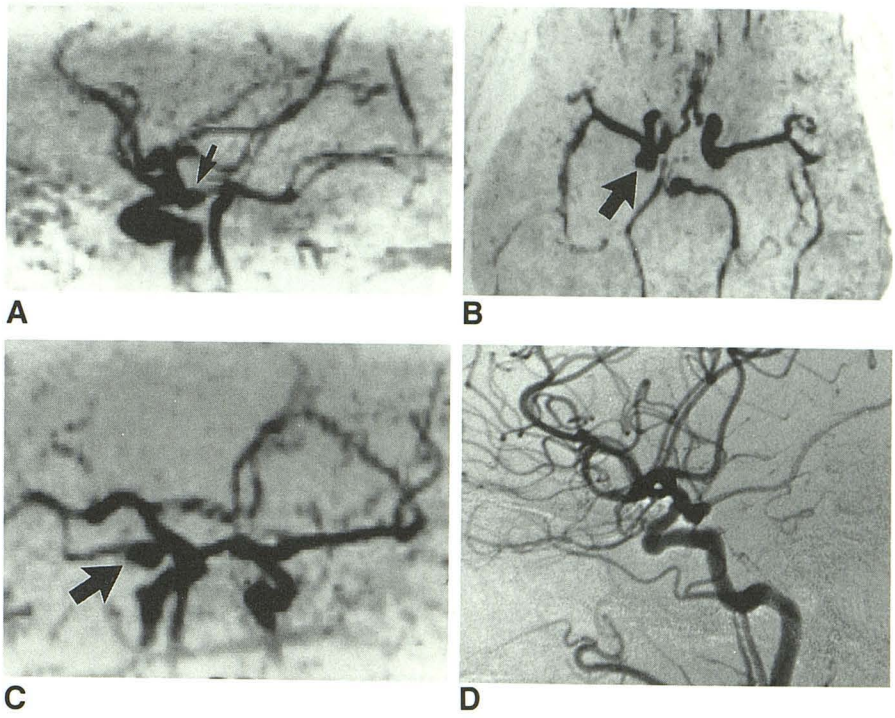

Fig. 1.—Posterior communicating artery aneurysm (case 18).

***A–C*, Lateral (*A*), base (*B*), and right anterior oblique (*C*) views of 3D MR angiogram show 6-mm right posterior communicating artery aneurysm (*arrows*) with good visualization of intracranial circulation (group 4).**

***D*, Lateral view from intraarterial digital subtraction angiogram also shows aneurysm, which measures 7 mm.**

posterior communicating artery (three), basilar artery (three), middle cerebral artery (four), internal carotid artery (eight), and superior cerebellar artery (one). Three of the aneurysms were giant: one of the internal carotid, one of the middle cerebral, and one of the basilar. The remainder of the aneurysms were 1 cm or less in diameter.

In the aneurysm group, the MRA images were considered of diagnostic quality (groups 3 and 4) in 16 (84%) of 19. Eleven of 19 images were considered of good quality (group 4). (Fig. 1); five (26%) of 19 were considered to have the potential for diagnostic error (group 3) (Fig. 2). The images of two patients (11%) were not considered useful for diagnosis (group 2), and in one patient (5%) the MRA image was uninterpretable (group 1) because of poor vessel definition owing to patient motion. MR images of the brain parenchyma were available in 16 of 19 patients.

In the control group, 18 (64%) of 28 were in group 4 and eight (29%) of 28 were in group 3. Two (7%) of 28 were rated as group 1 or 2. Overall, there were 47 MRA studies, 42 (89%) of which were rated as group 3 or 4. MR images of the brain parenchyma were available in all 28 patients.

Sensitivity and specificity were calculated for the evaluation of the cine 3D reconstructions (cine MRA) only, cine MRA + inspection of the individual partitions, and cine MRA + individual partitions + SE studies (Table 2). For the 21 aneurysms, of which three were missed in two patients, the sensitivity varied from 67% for cine MRA only to 86% for the cine MRA + partitions + SE studies. For the 19 patients in whom it was assumed that the diagnosis of any one aneurysm in a patient would lead to angiography and the detection of any additional aneurysms, the sensitivity varied from 73% for cine MRA only to 95% for the cine MRA + partitions + SE studies.

The sensitivities increased from 67% to 81% and from 73% to 89% for aneurysms and patients, respectively, if the individual image partitions were evaluated along with the cine reconstructions (Figs. 3–5). For example, one patient (case 14) had bilateral internal carotid aneurysms, and no abnormality was identified on the cine MRA image. However, on the individual partitions, the right carotid was definitely abnormal with an aneurysm projecting medially off of the siphon (Fig. 3).

Parenchymal SE studies identified the aneurysms in eight (50%) of 16 cases. Other abnormalities identified in the aneurysm group included infarcts in two and surrounding edema in one. In the control group, abnormalities identified on the SE studies included infarcts in six, encephalomalacia in two, and cyst in one.

The relative sizes of the aneurysms on MRA and IA DSA are given in Table 1. In general, the smaller aneurysms (less than 8 mm) were represented accurately on MRA studies. The size of larger aneurysms tended to be underestimated on MRA. The general relationship of the aneurysm to the parent vessel was easily visualized on MRA, while the precise aneurysm neck often was not recognizable.

Discussion

The utility of any technique in the evaluation of aneurysms depends on the natural history of asymptomatic aneurysms; that is, does an asymptomatic aneurysm have a significant chance of rupture, thus requiring surgery? In the United States, approximately 20,000 aneurysms rupture each year; 8% of these patients die before reaching a hospital [4, 5].

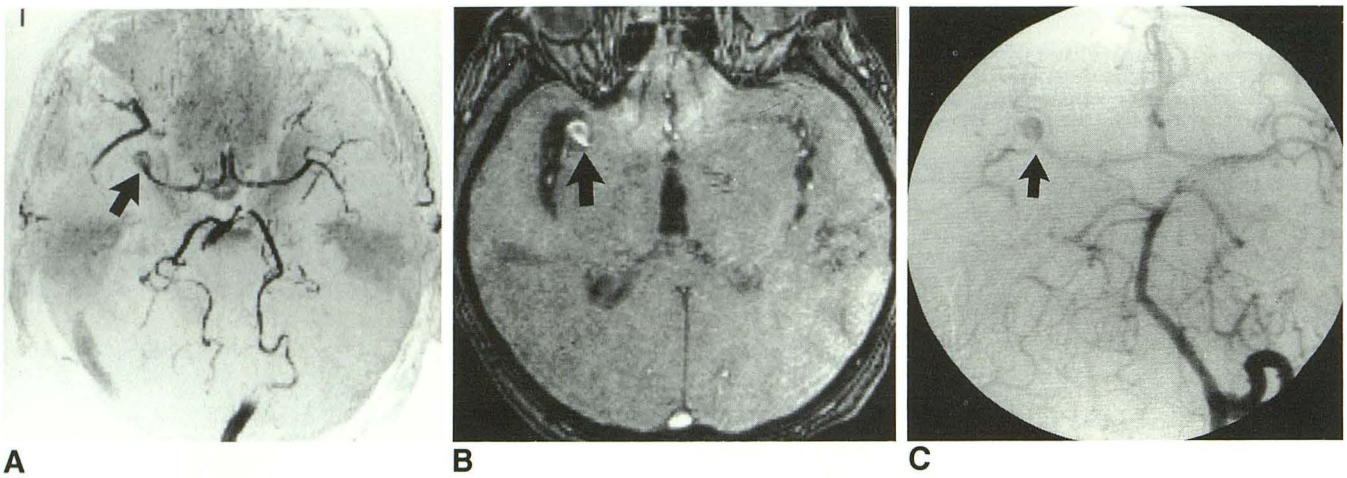

Fig. 2.—Right middle cerebral artery aneurysm in patient with occlusion of both internal carotid arteries (case 9).
A, Base view from 3D MR angiogram shows 7-mm spherical area of increased signal at right middle cerebral artery bifurcation (*arrow*), despite relatively slow flow caused by collateral flow. There is nonvisualization of right middle cerebral branches owing to previous infarction. Carotid siphons are not seen.
B, Individual partition from MR angiogram also shows aneurysm (*arrow*).
C, Base view from intraarterial digital subtraction angiogram (left vertebral artery injection) shows 8-mm right middle cerebral artery aneurysm (*arrow*).

TABLE 2: Results of MR Angiography in the Detection of Aneurysms

Measure	Aneurysms (n = 21)	Patients (n = 19)
True positive[a]	14/17/18	14/17/18
False negative[a]	7/4/3	5/2/1
False positive	0	0
True negative	28	28
% Sensitivity[a]	67/81/86	73/89/95
% Specificity	100	100

[a] Cine MR angiography only/cine MR angiography + individual partitions/cine MR angiography + partitions + spin-echo studies.

Fifty percent of patients will die within the first 30 days after rupture. The prevalence of incidental aneurysms in autopsy series is extremely variable and inconsistent, ranging from 1.3% to 7.9% [6, 7]. Studies quoting a small number of autopsy series with a high prevalence of aneurysms would suggest that aneurysms are abundant in the population as a whole, and only a small number go on to rupture, making the role of surgical management of an incidentally discovered aneurysm unclear. However, a recent report found that the prevalence of asymptomatic aneurysms of the anterior circulation was much closer to 1%, making their identification of major clinical significance [8]. That is, the decreased prevalence of aneurysms coupled with the known rate of life-threatening subarachnoid hemorrhage dramatically increases the risk of having an asymptomatic aneurysm that may rupture.

Although conventional arteriography remains the gold standard in the diagnostic workup of intracranial aneurysms, it is not performed unless the patient is symptomatic or an additional imaging study has been suspicious for an aneurysm. Additional, less invasive imaging studies that potentially could act as a screening examination include CT, IV DSA, and MRA. The ability of CT to define asymptomatic aneurysms is difficult to determine owing to the wide variety of techniques and studies; reports have varied, from detection of 14 (16%) of 85 aneurysms in one series to none [8, 9]. The resolution of the system, timing since injection of contrast material, and aneurysm size all affect the detection rate. The relatively poor spatial resolution of IV DSA, with the overlap of multiple vessels and limited viewing angles, allows for false negatives [10]. Both these techniques are invasive in the sense of needing large amounts of IV contrast material to define the vascular system.

The rationale for this MRA technique involves two aspects of flow imaging:

1. Flow-related enhancement is maximized when using the appropriate orientation of the imaging volume, TR, and flip angle. The axially oriented volume not only enables visualization of the entire circle of Willis and major branches, but permits blood arriving into the area of interest to be unsaturated. Sagittal or coronal volumes allow blood flowing into the lower margin of the volume to become saturated prior to reaching the area of interest, with a resultant loss of signal. The best TR and flip angle to provide maximum contrast between vessel and parenchyma are related to flow velocity, the characteristics of this gradient-echo sequence, and the T1 relaxation time of brain and blood. The low flip angle gives CSF and the brain parenchyma similar signal intensities, which are lower than that of moving blood. This permits increased contrast between the vasculature and surrounding tissues.

2. Signal loss secondary to phase dispersion is minimized by a short TE, refocusing pulses, and the volume technique (allowing a small voxel element). First-order motion compensation in the read and slice-select directions coupled with the shortest available TE is an effective method of reducing motion-induced phase shifts [1].

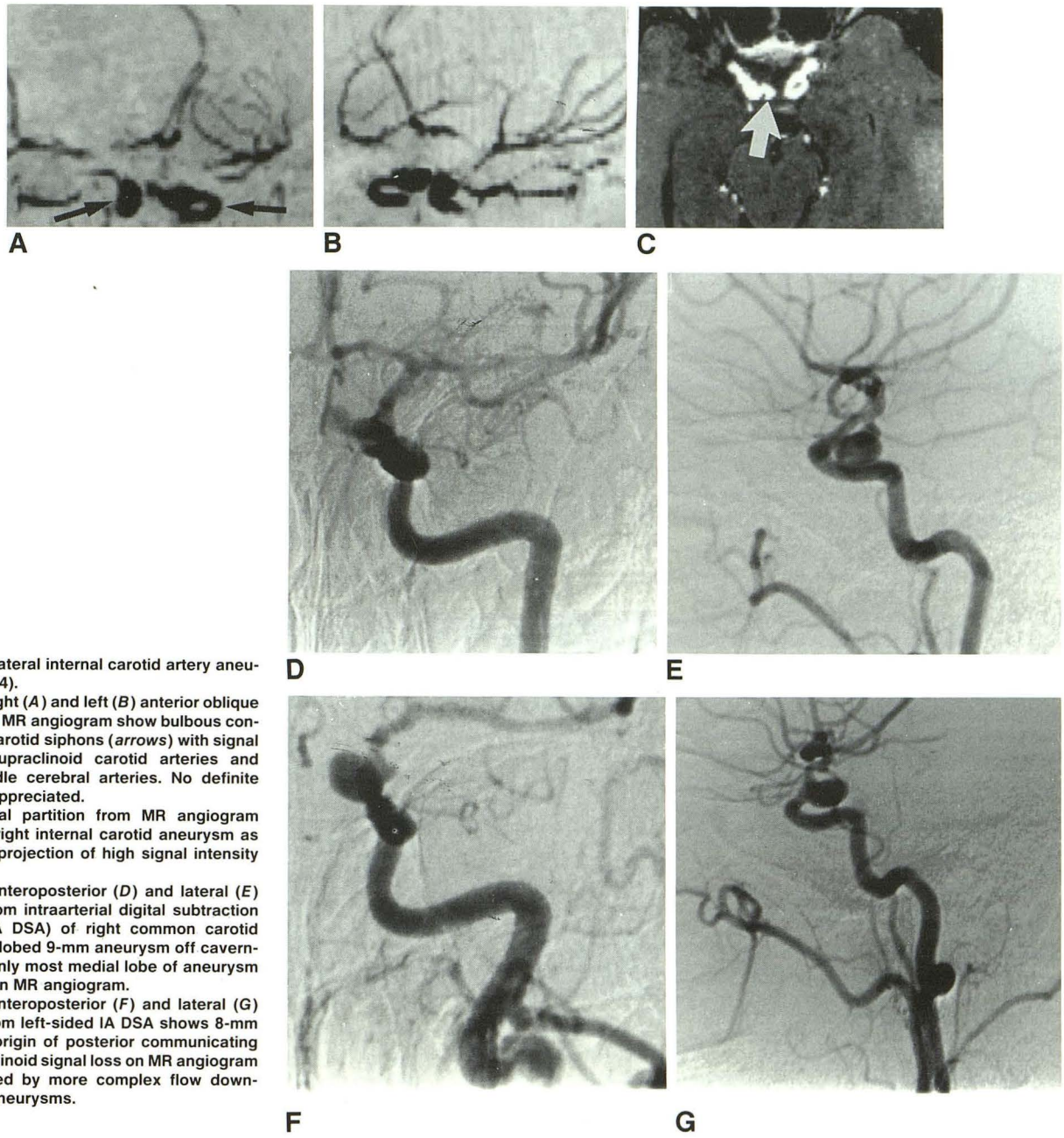

Fig. 3.—Bilateral internal carotid artery aneurysms (case 14).

***A* and *B*, Right (*A*) and left (*B*) anterior oblique views from 3D MR angiogram show bulbous configuration to carotid siphons (*arrows*) with signal dropout of supraclinoid carotid arteries and proximal middle cerebral arteries. No definite aneurysm is appreciated.**

***C*, Individual partition from MR angiogram study shows right internal carotid aneurysm as 4-mm medial projection of high signal intensity (*arrow*).**

***D* and *E*, Anteroposterior (*D*) and lateral (*E*) projections from intraarterial digital subtraction angiogram (IA DSA) of right common carotid artery show bilobed 9-mm aneurysm off cavernous carotid. Only most medial lobe of aneurysm is visualized on MR angiogram.**

***F* and *G*, Anteroposterior (*F*) and lateral (*G*) projections from left-sided IA DSA shows 8-mm aneurysm at origin of posterior communicating artery. Supraclinoid signal loss on MR angiogram may be caused by more complex flow downstream from aneurysms.**

While the resolution of 3D gradient-echo MRA does not approach that of conventional arteriography, this does not appear to be a critical shortcoming since studies suggest that the aneurysms that are most likely to rupture are of a size that may be imaged with MRA. In particular, Locksley [11], and McCormick and Acosta-Rua [12] found no hemorrhages from aneurysms smaller than 3 mm. Our current MRA technique is capable of identifying aneurysms in that size range, with an in-plane resolution of the gradient-echo technique of less than 1 mm. The utility of MRA is increased by coupling the technique to conventional MR imaging of the brain parenchyma, adding 12–20 min to the examination time. In our series, MRA plus SE parenchymal imaging demonstrated a sensitivity of 95% and specificity of 100% for detecting at least one intracranial aneurysm in a patient.

The limitations of this preliminary study and technique need to be emphasized. First, the study population was biased to those patients with angiographically confirmed aneurysms. A large population of normal subjects has not been imaged to determine the sensitivity of the technique. This critical variable must be addressed. Second, the volume gradient-echo technique provides a limited region of interest for intracranial imaging. Imaging the vasculature of the entire head requires at least 128 partitions covering 120–150 mm. Even with very short TRs, the examination lasts approximately 20 min. However, this limited field is not a significant problem for the

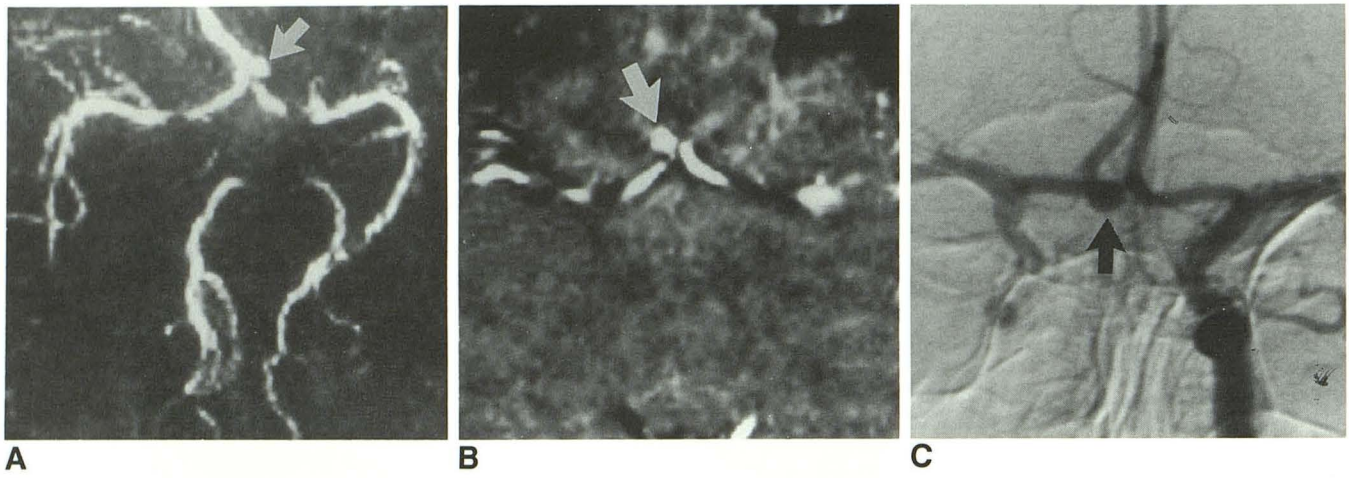

Fig. 4.—Anterior communicating artery aneurysm (case 1).
A, Oblique view from MR angiogram shows 5-mm aneurysm in region of anterior communicating artery (*arrow*).
B, Individual partition from MR angiogram also shows focal area of increased signal (*arrow*).
C, Anteroposterior view from left internal carotid intraarterial digital subtraction angiogram (with compression of contralateral carotid) shows 5-mm aneurysm (*arrow*).

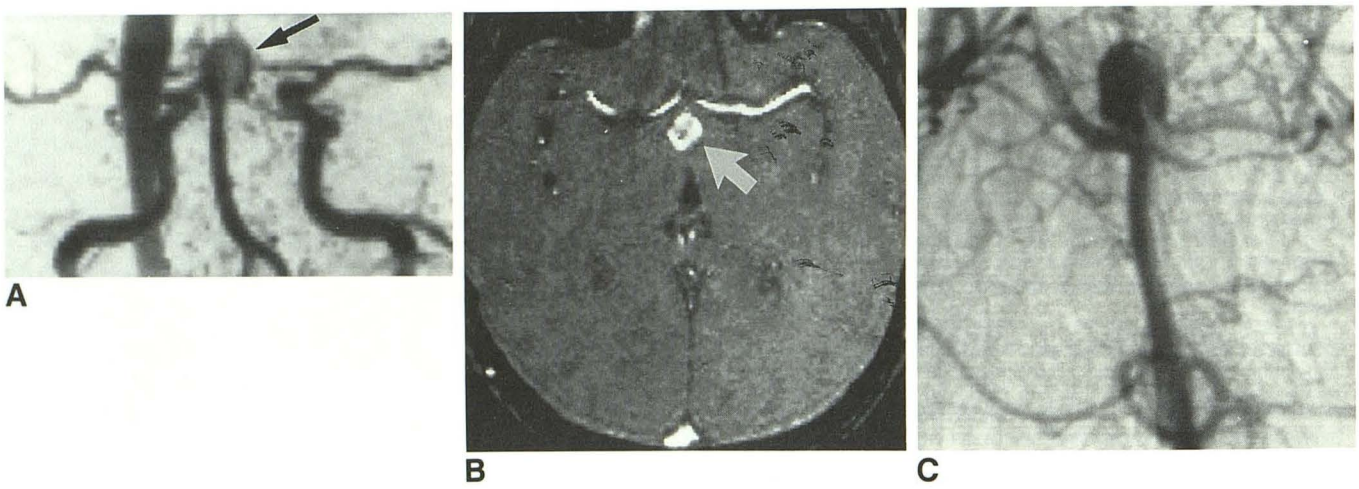

Fig. 5.—Basilar tip aneurysm (case 5).
A, Slightly right anterior oblique view from MR angiogram shows 7-mm aneurysm at basilar tip (*arrow*).
B, Individual partition from MR angiogram study confirms cine study (*arrow*).
C, Anteroposterior view from intraarterial digital subtraction angiogram shows 9-mm aneurysm at basilar tip.

evaluation of aneurysms, of which the vast majority are centered about the circle of Willis. Locksley [11] found that approximately 10% of single aneurysms involved with subarachnoid hemorrhage were in more peripheral branches or within the cerebellar vessels. The entire circle is easily encompassed by a limited transverse volume. Third, the volume technique is dependent on flow-related enhancement for vessel contrast. Thus, slow-flow lesions such as giant intracranial aneurysms are poorly visualized owing to saturation of the moving spins residing for too long within the excited volume. For a similar reason, MRA consistently underestimated the size of the larger aneurysms. However, these larger, slow-flow lesions are most likely to be detected on the accompanying conventional MR image of the brain parenchyma, and the size of the smaller aneurysms on MRA closely correlated with the size on IA DSA. Fourth, the precise aneurysm neck often could not be appreciated on the MRA study, although the general relationship of the aneurysm to the parent vessel could be delineated. This failure to visualize the necks was most pronounced for the internal carotid artery aneurysms, and less of a problem with basilar tip and middle cerebral artery aneurysms. Finally, our control group is not perfect since there is a small chance that an aneurysm was present but was missed. The contrast-enhanced CT scans and brain

MR images without evidence of vascular disease reduce the likelihood of this possibility.

The inadequate studies (groups 1 and 2) in the aneurysm and control groups were 16% and 7%, respectively. This difference is attributable to the poorer clinical condition of the aneurysm group, with increased motion artifacts. The number of inadequate studies should no doubt be closer to that of the control group figure for screening of an asymptomatic population.

The ability to define carotid siphon disease is easily the most significant problem with the current technique for the evaluation of aneurysms. The anterior communicating artery, middle cerebral artery bifurcation, and basilar tip were generally well defined. Signal dropout was a ubiquitous finding within the carotid siphon. This, coupled with the anatomic variations of the siphon course, accounted for the three missed aneurysms. In particular, if the cephalocaudal height of the siphon was small, then the loops tended to merge into one another on MRA, and the distinction between normal and aneurysmal dilatation was not possible. Further reductions in TE and slice thickness may be necessary to correct these signal voids.

The cine MRA and the hard-copy images of the individual partitions played complementary roles in this study. The individual partitions allowed detection of three aneurysms that were not seen on the cine studies. The partitions were especially useful to detect the siphon aneurysm that projected medially in case 14. Inspection of the individual partitions is time-consuming owing to their sheer numbers, and more difficult to interpret for aneurysms that project superiorly or inferiorly. They do appear useful for aneurysms that project within the partition plane and that might be obscured on the cine studies owing to overlap of the signal within both carotid siphons.

Certain populations, particularly patients with PCKD, are logical candidates for a screening examination for intracranial aneurysms. However, previously published analysis has shown that conventional angiography should not be carried out on a routine basis in this population because there are not significant benefits unless the prevalence of aneurysm exceeds 30%, the surgical complication rate is 1% or less, and the patient is under 25 years of age [13]. Levey et al. [13] did state that this might change: If "newer noninvasive tests . . . prove to identify reliably patients who are highly likely to have a cerebral aneurysm, routine screening with these tests will be warranted in patients with polycystic kidney disease." They further projected that if the sensitivity and specificity of a new test were 80% and 85%, respectively, then the benefit of arteriography and surgery in a 20-year-old patient would be significant; these criteria for MRA were met in this study. Future studies are needed to further define the role of MRA in groups at high risk for intracranial aneurysms (family history, PCKD, coarctation, fibromuscular disease, collagen vascular disorders), with the hope that the ease of use and noninvasive nature of the examination will make more widespread screening feasible [14].

While the statistics concerning intracranial aneurysms and the risks of surgery in patients with PCKD are fairly straightforward, the ease of use, safety, and accuracy of MRA raise a more difficult set of questions concerning widespread cerebrovascular screening in patients presenting with headaches (such as might have been seen with a sentinel leak of an aneurysm) or other CNS symptoms. The MRA technique and its short acquisition time make the possibility of a cranial MRA study coupled to every parenchymal head examination a very real one.

One drawback to the use of MR imaging and MRA in the diagnosis of aneurysms is the insensitivity of the techniques to subarachnoid hemorrhage [15]. However, the technique's greatest use is presumably in asymptomatic high-risk patients, before the development of subarachnoid hemorrhage. Once there is a suspicion of hemorrhage, then CT and conventional IA DSA are the more appropriate diagnostic studies.

Although our study population was small, our results suggest that MRA can define the circle of Willis sufficiently to allow detection of intracranial aneurysms as small as 3–4 mm. MRA holds promise as a truly noninvasive intracranial vasculature screening examination in patients at risk for aneurysms.

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