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Blinded Prospective Evaluation of Sensitivity of MR Angiography to Known Intracranial Aneurysms: Importance of Aneurysm Size

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PURPOSE: To determine the sensitivity of time-of-flight and phase-contrast MR angiography for the detection of intracranial aneurysms. **METHODS:** Sixteen patients with 27 intracranial aneurysms previously identified with conventional angiography and 19 control patients were examined with three-dimensional time-of-flight, three-dimensional phase-contrast MR angiography, and standard MR imaging. Subvolumes of the carotid and posterior circulations, source images, and standard MR images were blindly interpreted by three experienced neuroradiologists. **RESULTS:** Detection of an aneurysm by a given sequence was defined as at least two of the three blinded readers identifying the aneurysm. The sensitivities of the sequences based on all 27 aneurysms were: transaxial T1, 25.9%; T2, 48.1%; PC, 44.4%; and TF, 55.6%. Two of 3 aneurysms detected with T2 but not MR angiography had adjacent blood products. Five millimeters appeared to be a critical size; the sensitivities for aneurysms greater than or equal to 5 mm were: T1, 37.5%; T2, 62.5%; PC, 75%; and TF, 87.5%. **CONCLUSIONS:** Three-dimensional time-of-flight MR with 512 × 256 matrix is more sensitive than three-dimensional phase-contrast or standard MR imaging for detection of aneurysms. Retrospectively, aneurysms 3 mm or larger can be identified with MR angiography; however, prospectively, 5 mm is the critical size for detection.

Index terms: Aneurysm, intracranial; Aneurysm, magnetic resonance; Magnetic resonance angiography (MRA); Efficacy studies

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The frequency of intracranial aneurysms is unknown but has been estimated to be as high as 5% in the general population (1). Conventional angiography has been the only technique available to identify and characterize aneurysms reliably. Recently, magnetic resonance (MR) angiography (MRA) has emerged as a noninvasive technique to image the intracranial circulation (2–5). Previous retrospective work has suggested that MRA could show aneurysms 3 mm or greater in size (6–8). If accurate, MRA offers several advantages over conventional angiography including its noninvasive nature and lack of need for contrast agents. The purpose of this investigation was to determine the sensitivity of transaxial T1- and T2-weighted standard MR images as well as time-of-flight (TF) and phase-contrast (PC) MRA by performing a blinded prospective study including patients with angiographically proved intracranial aneurysms. Our hypothesis was that MRA would prospectively show all aneurysms greater than or equal to 3 mm in size.

Methods

Sixteen patients with 27 intracranial aneurysms previously identified with conventional angiography were examined with a 1.5-T superconducting imaging system. The study group included 14 women and 2 men ranging in age from 30 to 85 years, with an average age of 53 years. Nineteen additional patients underwent the same standard and vascular MR imaging to serve as controls but did not have conventional angiograms to confirm the absence of aneurysms. These patients included 14 women and 5 men

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ranging in age from 35 to 79 years, with an average age of 52 years. Although the patients were not consecutive, the only selection criteria were the ability of the principle investigator to obtain informed consent and the availability of MR scanning time.

Standard MR head imaging was performed with sagittal T1-weighted (500/20/2 [repetition time/echo time/excitations]) and transaxial T2-weighted (2300/30,80/1) sequences. The T2-weighted sequence included 5-mm-thick sections with a 2.5-mm skip. In addition a transaxial T1-weighted (500/20/2) sequence was obtained using 4-mm-thick sections with no skip.

A coronal two-dimensional PC scout image with 30 cm/s maximum velocity encoding was obtained to locate the circle of Willis for 3-D TF and 3-D PC imaging. Then 3-D PC imaging was performed (26/8.6/1, 256 × 128 matrix; 15° flip angle, 18-cm field of view, 30 cm/s maximum velocity encoding) with use of 60 0.7-mm-thick axial sections. Additionally 3-D TF imaging was performed (43/6/1, 512 × 256 matrix, 20° flip angle, 18-cm field of view) with use of 60 0.7-mm-thick axial sections. The 3-D PC technique required 14 minutes 15 seconds, and the 3-D TF required 11 minutes 46 seconds.

To isolate both of the carotid and posterior circulations, postprocessing subvolumes were obtained. These subvolumes were selected from the maximum intensity projection image along the axial imaging plane (collapse image) of both the 3-D TF and 3-D PC series. A trace function was used to select the carotid distributions, with care taken to include the anterior communicating artery in both carotid volumes (9). A circle or trace function was used to isolate the posterior circulation. The subvolumes, separated by location, were transferred onto optical disks.

The 35 exams (16 patients with proved aneurysms and 19 control subjects) were presented to three experienced neuroradiologists in a randomized and blinded fashion. The readers were blinded to knowledge of MR, MRA, and conventional angiogram results as well as to patient's identification, age, gender, and medical history. The readers categorized the aneurysms by 1 of 11 locations including the carotid siphon (proximal to the ophthalmic artery), ophthalmic artery, posterior communicating artery, supraclinoid internal carotid artery, internal carotid artery bifurcation, middle cerebral artery (including the trifurcation), anterior cerebral artery, anterior communicating artery, basilar artery, superior cerebellar artery, and posterior cerebral artery.

To account for differences in definitions of locations, some grouping was performed. For instance, an ophthalmic aneurysm that was categorized as a supraclinoid aneurysm was defined as match. However, a supraclinoid aneurysm was not defined as a match with a middle cerebral artery aneurysm. The transaxial T2-weighted exams were first presented to the neuroradiologists. A forced-choice decision about the presence of aneurysms was made individually by the three blinded readers. In a similar manner, the T1-weighted transaxial exams were randomized and blindly reviewed. The MRA subvolumes were loaded onto an independent workstation and viewed in a cine loop to enhance the perception of the 3-D relationship of the vessels. First, the PC left carotid circulations were reviewed for all 35 patients. The source images were used to correlate with the maximum intensity projection images. A forced-choice decision regarding the presence or absence of aneurysms was made. Next the PC right carotid subvolumes and source images were randomly reviewed. In a similar manner, the PC posterior circulation and the 3 TF subvolumes were reviewed.

Results

For a given sequence, an aneurysm was defined to be present if detected by at least two of the three blinded readers in the same location. Sensitivities were calculated for each sequence based on the 27 aneurysms previously demonstrated by conventional angiography. The location and size based on the conventional angiograms and number of reviewers detecting the aneurysms, according to the type of sequence, are presented in Table 1. Slight motion was present on a couple of the MRA studies but was never judged to result in a nondiagnostic study.

Overall, the 512 3-D TF had the greatest sensitivity at 55.6% (Table 2). For aneurysms equal to or greater than 5 mm in size, 3-D TF was the most sensitive technique and allowed detection of 87.5% of the 16 aneurysms. Five millimeters appeared to be a critical size with poor sensitivities for the 11 aneurysms less than 5 millimeters including 0% for 3-D PC and 9.1% for 3-D TF. The T2 sequence had the highest sensitivity for aneurysms less than 5 mm in size. Three 4-mm aneurysms including 2 middle cerebral artery trifurcation aneurysms and 1 anterior cerebral artery aneurysm were identified on T2 sequences but not on either PC or TF sequences. Two of these 3 aneurysms were conspicuous on standard MR imaging because of adjacent blood products (Fig 1). Aneurysms detected with TF but not PC included 2 middle cerebral artery trifurcation (4 and 6 mm), 1 posterior communicating (7 mm), and 1 proximal middle cerebral artery (5 mm) (Fig 2). The sensitivities for each sequence according to aneurysm size are provided in Table 3.

Because the control patients did not undergo conventional angiography to prove the absence of aneurysms, a true specificity could not be calculated. However, a pitfall for TF resulting in a false-positive diagnosis was subacute thrombus simulating an aneurysm (Fig 3). One of

TABLE 1: Size and number of readers identifying aneurysms

Patient	Aneurysm Location	Size, mm	T1	T2	PC	TF	Confirmed at Surgery?
1	R ACA	4	0	2	0	0	Yes
	R MCA trifurcation	4	0	0	0	0	
2	R MCA trifurcation	4	3	3	0	1	Yes
	R siphon	5	0	0	0	1	
3	R MCA trifurcation	5	0	3	3	1	Yes
4	R siphon	7	1	0	2	3	
5	L MCA	5	1	2	1	3	
6	L siphon	7	0	0	2	3	
	L ophthalmic	3	0	0	0	1	
	R MCA trifurcation	4	0	2	0	0	
	R supraclinoid	2	0	0	0	0	
7	L siphon	14	3	3	3	3	
	R MCA trifurcation	4	0	0	1	2	
8	L ophthalmic	6	0	0	3	2	Yes
9	R siphon	21	3	3	3	3	Yes*
10	Basilar tip	17	3	3	3	3	Yes
11	L supraclinoid	6	1	0	2	3	
	R superior cerebellar	4	0	0	0	0	
	R siphon	2	0	0	0	0	
12	L posterior communicating	7	0	1	0	2	Yes
	L supraclinoid	5	3	3	3	3	Yes
13	Basilar tip	8	3	3	3	3	
	L superior cerebellar	3	0	0	0	0	
14	R ophthalmic	8	3	3	3	3	
15	L MCA trifurcation	6	0	3	1	3	Yes
16	R siphon	3	0	0	0	0	
	R MCA trifurcation	7	0	2	2	3	Yes

Note.—ACA indicates anterior cerebral artery; MCA, middle cerebral artery; and *, found at autopsy.

TABLE 2: Sensitivities (95% confidence intervals) for detecting intracranial aneurysms, %

	Reader			Consensus*
	1	2	3	
T1	29.6 (13.8, 50.2)	29.6 (13.8, 50.2)	29.6 (13.8, 50.2)	25.9 (11.1, 46.3)
T2	44.4 (25.5, 64.7)	40.7 (22.4, 61.2)	48.1 (28.7, 68.1)	48.1 (28.7, 68.1)
PC	33.3 (16.5, 54.0)	48.1 (28.7, 68.1)	48.1 (28.7, 68.1)	44.4 (25.5, 64.7)
TF	59.3 (38.8, 77.6)	59.3 (38.8, 77.6)	51.9 (32.0, 71.3)	55.6 (35.3, 74.5)
T1 <5 mm	9.1 (0.2, 41.3)	9.1 (0.2, 41.3)	9.1 (0.2, 41.3)	9.1 (0.2, 41.3)
T2 <5 mm	18.2 (2.3, 51.8)	18.2 (2.3, 51.8)	27.3 (6.0, 61.0)	27.3 (6.0, 61.0)
PC <5 mm	0	0	9.1 (0.2, 41.3)	0
TF <5 mm	9.1 (0.2, 41.3)	9.1 (0.2, 41.3)	18.2 (2.3, 51.8)	9.1 (0.2, 41.3)
T1 ≥5 mm	43.8 (19.8, 70.1)	43.8 (19.8, 70.1)	43.8 (19.8, 70.1)	37.5 (15.2, 64.6)
T2 ≥5 mm	62.5 (35.4, 84.8)	56.3 (29.9, 80.3)	62.5 (35.4, 84.8)	62.5 (35.4, 84.8)
PC ≥5 mm	56.3 (29.9, 80.3)	81.3 (54.4, 96.0)	75.0 (47.6, 92.7)	75.0 (47.6, 92.7)
TF ≥5 mm	93.8 (69.8, 99.8)	93.8 (69.8, 99.8)	75.0 (47.6, 92.7)	87.5 (61.7, 98.5)

Note.—* indicates two or more readers detecting an aneurysm; PC, phase-contrast; and TF, time-of-flight.

the control patients had hemorrhage in the prepontine cistern identified on computed tomography and MR examinations. Conventional angiograms were performed immediately and 6 weeks after hospital discharge, neither of which demonstrated evidence of an aneurysm. All three readers identified the high signal from the thrombus as an aneurysm on the TF study, whereas none identified an aneurysm on the PC study.

Eight of the 16 patients underwent aneurysm clipping. Surgery confirmed the presence of an aneurysm in 7 patients and 2 aneurysms in 1 patient. One aneurysm was confirmed at autopsy following a fatal myocardial infarction (Table 1).

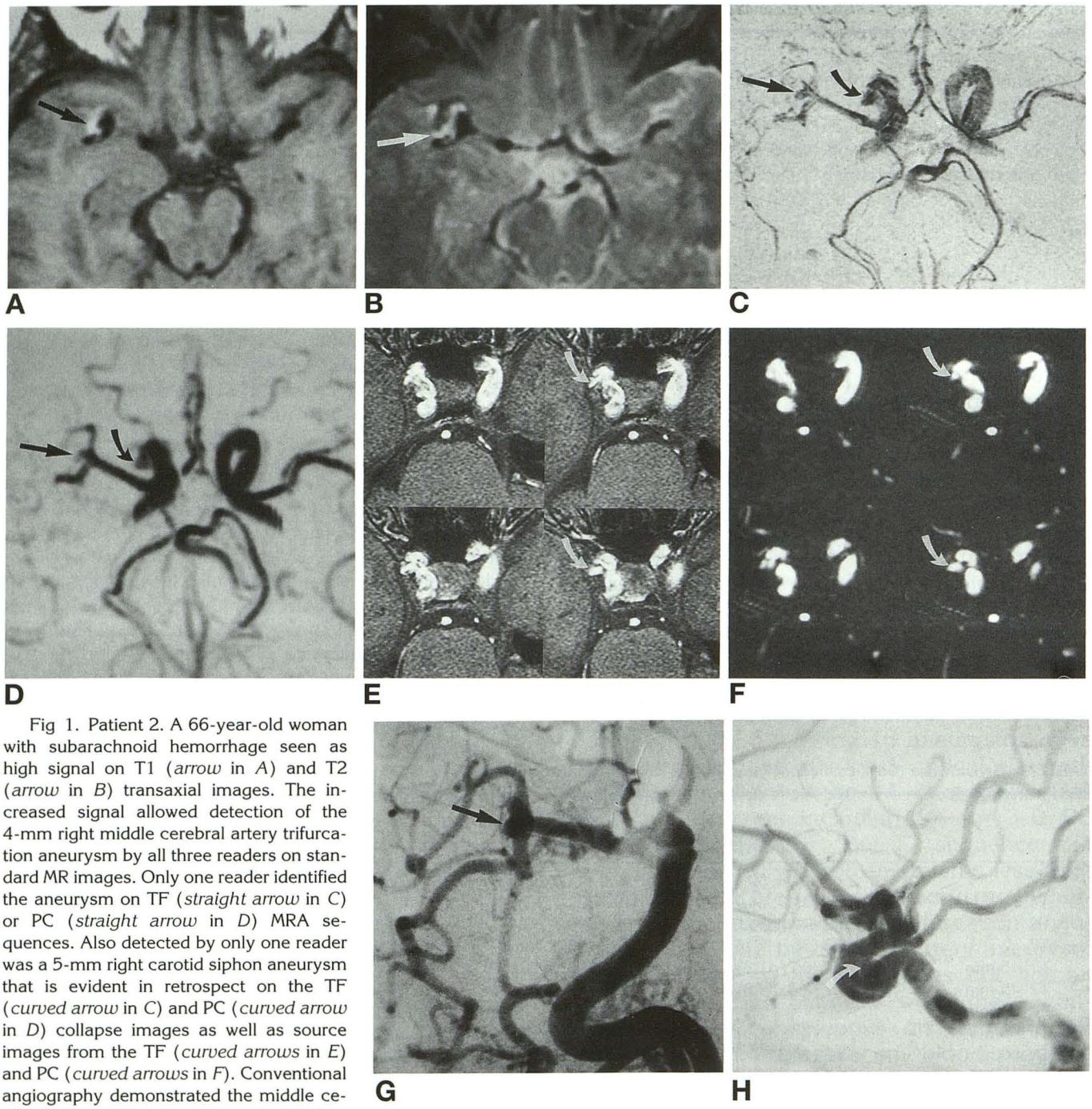

Fig 1. Patient 2. A 66-year-old woman with subarachnoid hemorrhage seen as high signal on T1 (*arrow* in *A*) and T2 (*arrow* in *B*) transaxial images. The increased signal allowed detection of the 4-mm right middle cerebral artery trifurcation aneurysm by all three readers on standard MR images. Only one reader identified the aneurysm on TF (*straight arrow* in *C*) or PC (*straight arrow* in *D*) MRA sequences. Also detected by only one reader was a 5-mm right carotid siphon aneurysm that is evident in retrospect on the TF (*curved arrow* in *C*) and PC (*curved arrow* in *D*) collapse images as well as source images from the TF (*curved arrows* in *E*) and PC (*curved arrows* in *F*). Conventional angiography demonstrated the middle cerebral artery trifurcation aneurysm with a submental vertex view (*arrow* in *G*) and the siphon aneurysm with a lateral view (*curved arrow* in *H*).

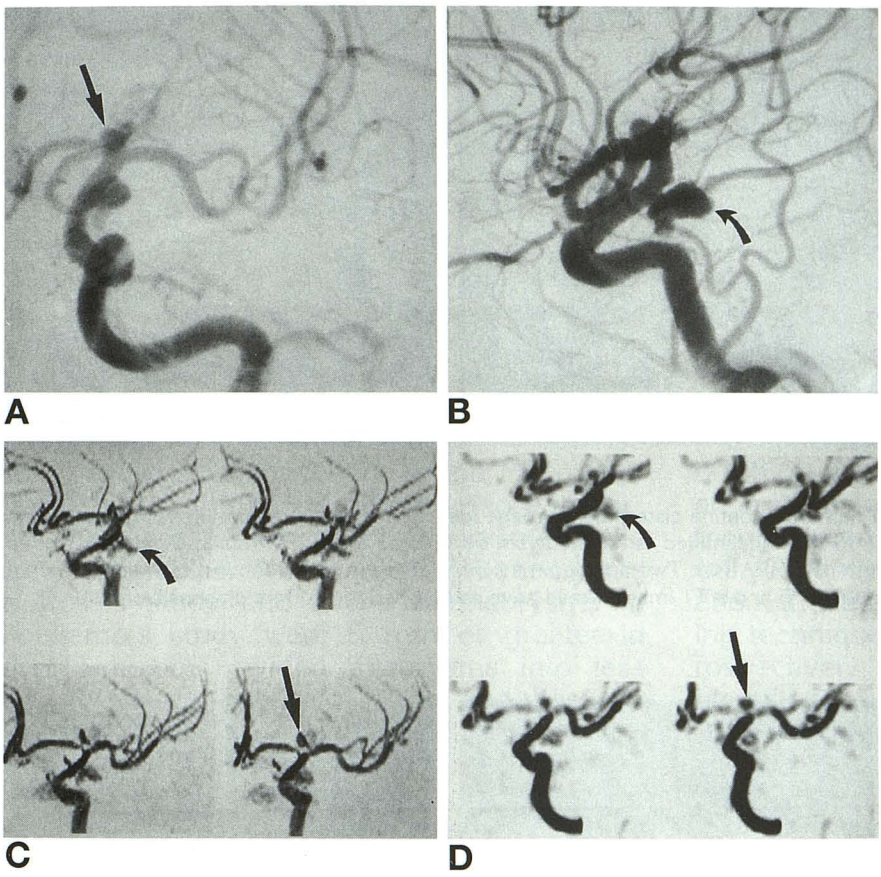

Fig 2. Patient 12. A 30-year-old woman with a 5-mm left supraclinoid aneurysm (*straight arrow* in *A*) and a 7-mm left posterior communicating artery aneurysm (*curved arrow* in *B*). All three readers detected the supraclinoid aneurysm with both TF (*straight arrow* in *C*) and PC (*straight arrow* in *D*). Two of the three readers detected the posterior communicating artery aneurysm with TF (*curved arrow* in *C*), but no reader identified the aneurysm with PC (*curved arrow* in *D*). In retrospect, both aneurysms are easily seen with both techniques.

Discussion

The technique of MRA is rapidly evolving, as is its role in evaluating intracranial aneurysms. Potential applications include general screening for aneurysms (10, 11), screening selective patients such as those with autosomal dominant polycystic kidney disease (9), evaluating aneurysm hemodynamics (12, 13), following aneurysms treated with endovascular techniques (14, 15), monitoring mycotic aneurysms during antibiotic therapy (16), and detecting aneurysms not seen on conventional angiograms in patients with subarachnoid hemorrhage (17). Previous retrospective work suggested MRA could show aneurysms greater than or equal to 3 mm in size (6–8). Published studies have reported sensitivities between 86% and 92% (6, 11, 18). The poor sensitivity of MRA for aneurysms in this study was disappointing and unexpected. If the detection criteria for each sequence were made more stringent and defined as all three readers detecting an aneurysm rather than two readers, the overall sensitivities for MRA fall to 29.6% for PC and 44.4% for TF.

TABLE 3: Sensitivity according to aneurysm size

Size, mm	No. of aneurysms	Sensitivity, %*			
		T1	T2	PC	TF
≥2	27	25.9	48.2	44.4	55.6
≥3	25	28.0	52.0	48.0	60.0
≥4	22	31.8	59.1	54.6	68.2
≥5	16	37.5	62.5	75.0	87.5
≥6	12	41.7	58.3	83.3	100.0
≥7	9	55.6	66.7	88.9	100.0
≥8	5	100.0	100.0	100.0	100.0

Note.—* indicates two or more readers detecting an aneurysm.

The 25 known aneurysms from conventional angiography 3 mm or greater in size were identified retrospectively on MRA (Fig 4). That several of these aneurysms were not detected prospectively suggests an underlying deficiency in the MRA technique. Perhaps one factor contributing to the low sensitivity for aneurysms in this study could be the learning curve associated with viewing MRA studies. However, all three blinded readers routinely use MRA in their daily MR practice. The two

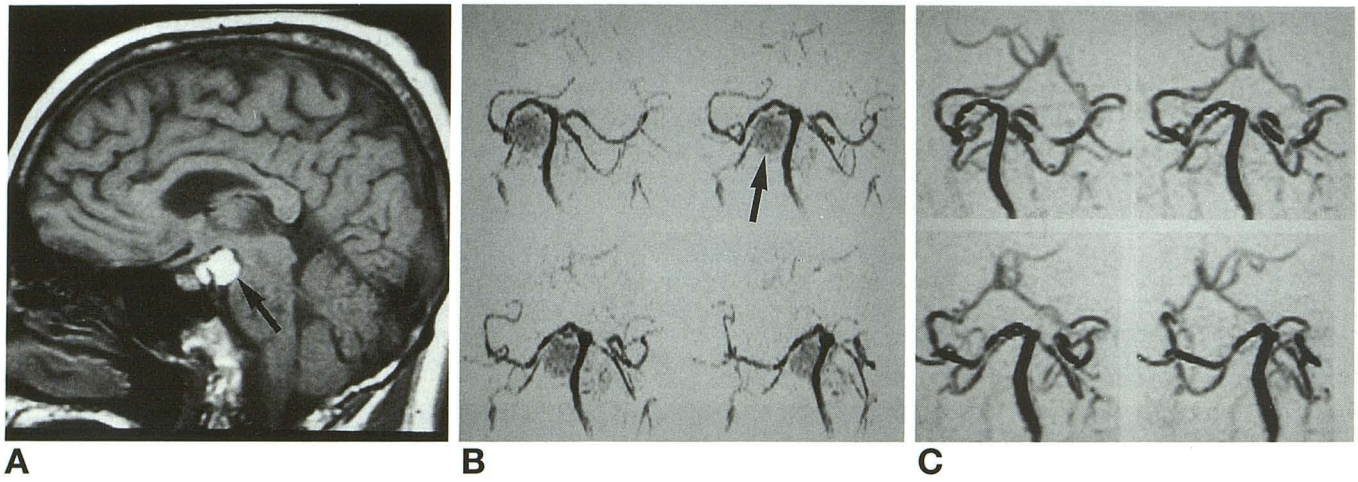

Fig 3. This 51-year-old male control patient had a prepontine cistern hemorrhage identified with MR (*arrow* in *A*). The subacute thrombus with high T1 signal was seen on the TF MRA and identified as an aneurysm by all three readers (*arrow* in *B*). Because of its subtraction technique, no signal was present on the PC MRA (*C*). Two angiograms separated by 6 weeks showed no evidence of an aneurysm. In a clinical situation, comparison between TF and a T1 image would have established the correct diagnosis of clot.

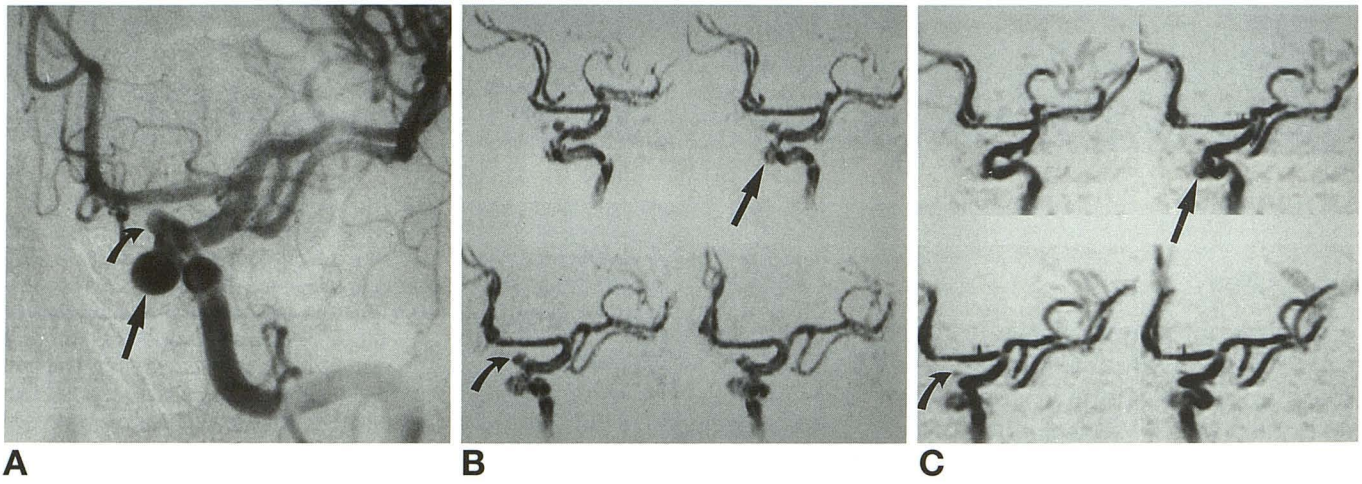

Fig 4. Patient 6. A 43-year-old woman with a 7-mm left carotid siphon aneurysm (*straight arrow* in *A*) and a 3-mm ophthalmic aneurysm (*curved arrow* in *A*). The 7-mm carotid siphon aneurysm was detected with both TF (*straight arrow* in *B*) and PC (*straight arrow* in *C*). The 3-mm ophthalmic aneurysm was not detected by either TF (*curved arrow* in *B*) or PC (*curved arrow* in *C*) but was seen in retrospect on both sequences. The small ophthalmic aneurysm was displayed better with the 512 TF than with the PC technique.

2-mm aneurysms could not be identified retrospectively on MRA.

More significant are image display considerations. Even motionless PC and TF exams with a 512 matrix had a "venetian blind"-like appearance. This inherent unsharpness masks vascular lesions and may simulate vascular irregularities such as aneurysms. Additional shortcomings are found with the maximum intensity projection technique. Because the projection identifies the most intense voxel, aneurysms with internal lower signal may not be as fully seen as on the source images (19).

Another factor may be "image overload." When performing a conventional angiogram, the best arterial images from the angiographic series are scrutinized. Typically, three or four oblique views are obtained for each vascular distribution. In contrast, the readers in this study reviewed 19 maximum intensity projection images on a viewer-controlled cine loop and 60 source images for each vascular distri-

bution. During the study the readers described being overwhelmed by the amount of data contained in the MRA sequences. Perhaps during the review of these large image sets, subtle vascular abnormalities were overlooked that can be appreciated when viewed retrospectively.

The overall sensitivities found in this study for detecting intracranial aneurysms were significantly below those of previous reports. Gouliamos, using both TF and PC, reported an overall sensitivity of 92%; Ross and Schuierer, using TF only, reported sensitivities of 86.0% and 86.4%, respectively. In our prospective study, care was taken to shield the readers from viewing the conventional and MR angiograms before the blinded review. More important, however, is the size of aneurysms in the previous studies. Nineteen of 21 aneurysms in Ross's study and 9 of 11 aneurysms in Gouliamo's study were 5 mm or greater in size. Schuierer divided aneurysms into less than or greater than 1 cm in size and therefore it is unclear how many were equal to or greater than 5 mm; however, 11 of the 18 aneurysms were equal to or greater than 1 cm. When the bias for including aneurysms equal to or greater than 5 mm is considered, our finding that TF was 87.5% sensitive for aneurysms equal to or greater than 5 mm is comparable to the previous studies. Thus our results and those of previous studies support 5 mm as a critical size for MRA detection of aneurysms.

In our study, the field of view in a superior-to-inferior direction was limited to the circle of Willis, distal basilar artery, and middle cerebral artery trifurcation. Thus, this study did not address the sensitivity for diagnosis of aneurysms deep in the posterior fossa such as posterior inferior cerebellar artery aneurysms. The patient with a prepontine hemorrhage with a false-positive diagnosis of an aneurysm on the TF sequence is an artifact of the study design. This patient was included as a control in an effort to dilute the known aneurysms among exams without aneurysms. In actual clinical practice, comparison between the standard T1-weighted images and the TF MRA would have indicated that the abnormality was clot.

The MRA techniques continue to progress rapidly and likely will improve the sensitivity for detecting aneurysms in the future. Already, magnetization transfer has improved image quality. Higher spatial resolution parameters including 1024 × 1024 matrix will certainly reduce the vessel irregularity and decrease the venetian-blind effect. Clearly, one of the reasons TF was more sensitive than PC was the superior spatial resolution offered by the 512 matrix. Blood-pool contrast agents would improve the signal and potentially increase conspicuity of aneurysms, especially if higher spatial resolution techniques, which result in lower signal, are used. Finally, improved image-processing techniques that more fully incorporate the data from source images will improve visibility of aneurysms.

In conclusion, 512 TF MRA allowed detection of 55.6% and PC 44.4% of known intracranial aneurysms in a blinded prospective study. Although improvements in the MRA techniques will continue, these results raise questions about the reliability of MRA as a routine screening technique for intracranial aneurysms. Retrospectively, aneurysms 3 mm or larger can be identified; however, for prospective detection, 5 mm is the critical size. The 512 TF MRA prospectively showed 87.5% of aneurysms equal to or greater than 5 mm in size and was more sensitive than PC, which showed 75% of aneurysms equal to or greater than 5 mm.

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