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Hyperintense Thrombus on GRASS MR Images: Potential Pitfall in Flow Evaluation

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Gradient-recalled acquisition in the steady state (GRASS) MR images, obtained in four patients with angiographic evidence of successful occlusion of cerebral arteriovenous malformations, demonstrated hyperintense signal intraluminally. Although this was initially mistaken as evidence of persistent blood flow in the arteriovenous malformation, the short TR/TE spin-echo images showed hyperintense signal rather than flow void, thereby indicating the presence of subacute thrombus.

GRASS images alone should not be used to determine the success of embolotherapy of cerebral arteriovenous malformations or to determine aneurysm patency, since the hyperintense signal is a potential pitfall that may mislead the radiologist in the absence of corroborative images, particularly the short TR/TE spin-echo sequences.

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Gradient-recalled acquisition in the steady state (GRASS) MR images are currently used to evaluate vascular lesions in the head and neck [1–3]. The high signal intensity associated with flowing blood has allowed noninvasive determination of patency of blood vessels. Such a determination can prove particularly useful in assessing the efficacy of embolotherapy in arteriovenous malformations (AVMs) of the brain [2, 3]. However, we recently encountered four cases of subacute thrombosis of feeding arteries and/or draining veins after embolization of AVMs that caused hyperintense signal on GRASS images, giving the false impression of patent vessels with flow.

Materials and Methods

As part of an ongoing study on the use of MR imaging in the evaluation of cerebral vascular malformations before and after embolotherapy, we acquired MR scans with T1-, T2-, and proton-density-weighted spin-echo (SE) and GRASS parameters one day prior to, one day after, and 3–6 weeks after embolization of feeding vessels to AVMs. T1-weighted images had a 500–600/20/4 (TR/TE/excitations) sequence, a 128–256 × 256 matrix, and a 24-cm field of view. Long TR sequences were ECG-gated, had a 2500–3500/30,80/1 sequence, a 128–256 × 256 matrix, and a 24-cm field of view. GRASS sequences had flip angles of 10° to 30°, a 30/17/6 sequence, and a 128 × 256 matrix.

Angiograms were obtained prior to and directly after the therapeutic embolization of the AVM by using bucrylate, dura mater, polyvinyl alcohol particles, Gelfoam, and/or balloons. Repeat angiograms were obtained at a 3–6 week follow-up examination. Films were reviewed by at least four neuroradiologists.

Results

In all four cases the angiograms obtained immediately after and 3–6 weeks after embolization of the nidus and/or feeding vessels of the AVM demonstrated successful occlusion of the AVM. All four cases had similar MR appearances (Figs.

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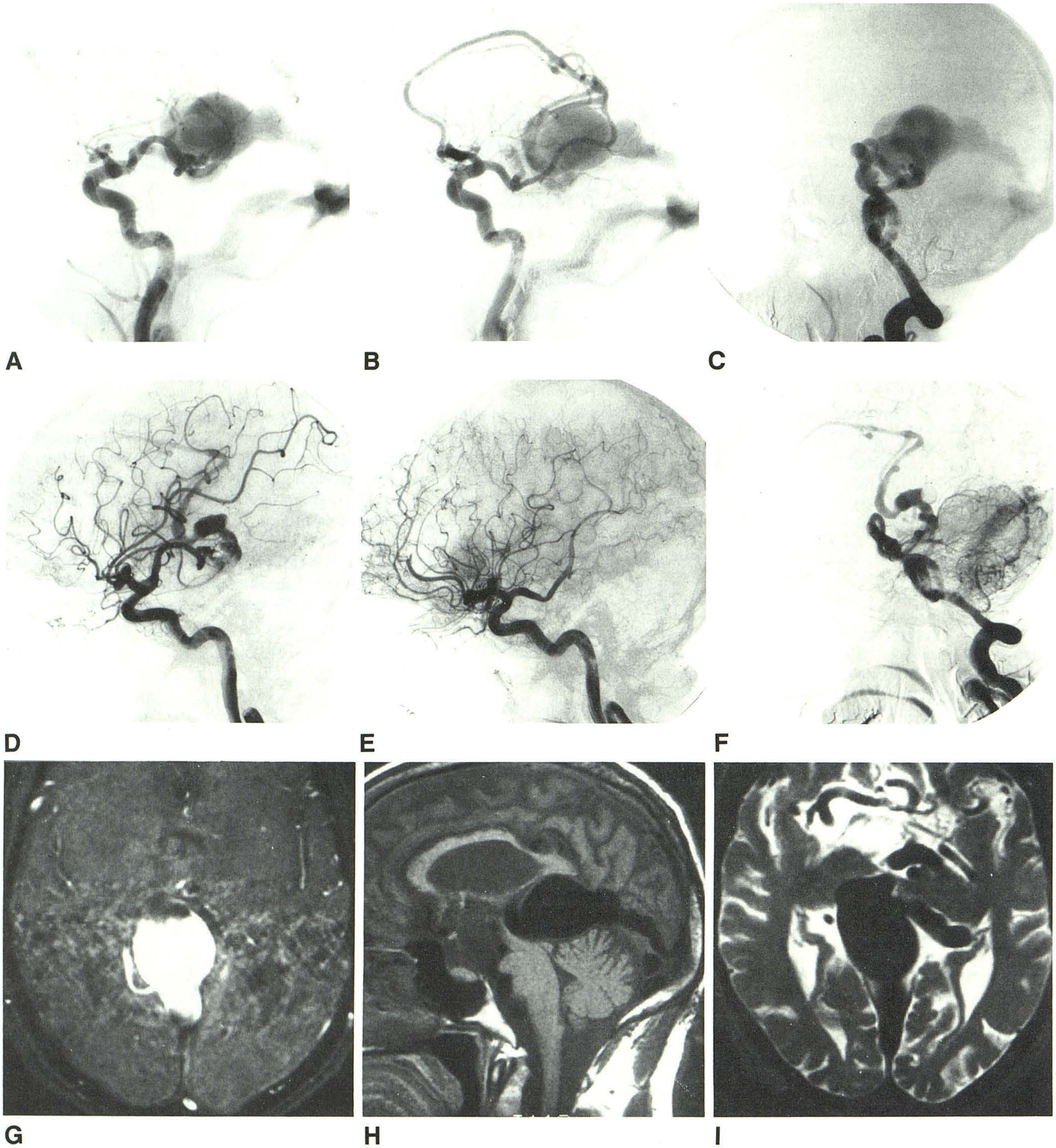

Fig. 1.—Vein of Galen aneurysm in 37-year-old man.

A–C, Left internal carotid angiogram (*A*), right internal carotid angiogram (*B*), and left vertebral angiogram (*C*) reveal large arterial feeders to a vein of Galen aneurysm and early filling of straight sinus.

D–F, Postembolization left internal carotid angiogram (*D*), right internal carotid angiogram (*E*), and left vertebral angiogram (*F*) show complete occlusion of vein of Galen aneurysm and no filling of straight sinus.

G–I, Preembolization GRASS image (*G*) shows hyperintense signal caused by flow within vein of Galen aneurysm while T1-weighted (*H*) and T2-weighted (*I*) images show signal void resulting from flow.

(Fig. 1 is continued on the opposite page.)

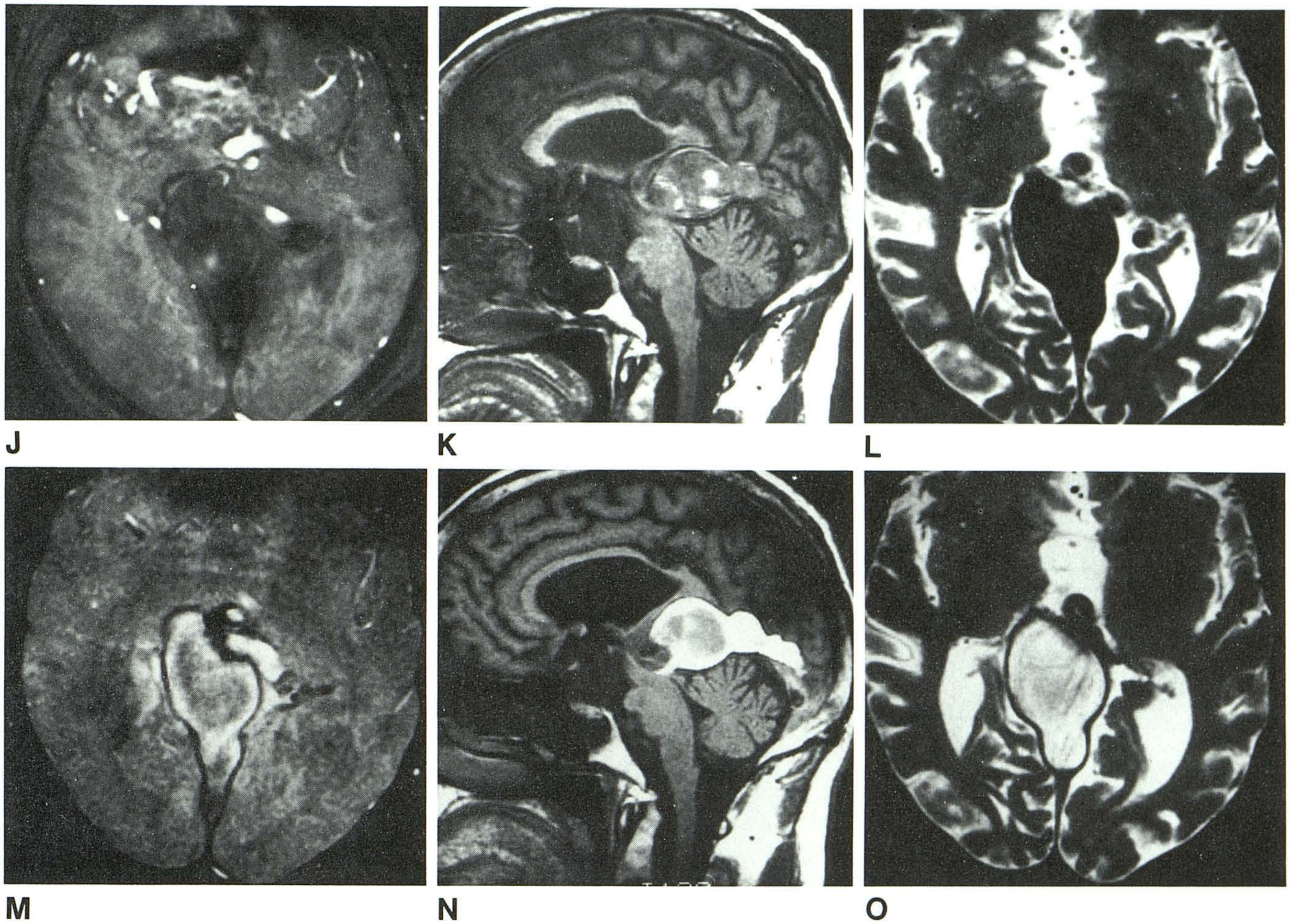

Fig. 1 (Continued).

J–L, **4 days after embolization, GRASS image (*J*) shows decreased signal. T1-weighted image (*K*) shows signal isointense with gray matter and few foci of bright signal caused by methemoglobin formation. T2-weighted image (*L*) shows decreased signal.**

M–O, **6 weeks after embolization, GRASS (*M*), T1-weighted (*N*), and T2-weighted (*O*) images show hyperintense signal within vein of Galen aneurysm and straight sinus consistent with thrombus formation.**

1–3). Preembolization scans showed signal void on short TR/TE and long TR/TE SE images, but increased signal intensity on GRASS scans with flow compensation. The immediate (1–4 days) postembolization scans showed variable signal intensity on short TR/TE SE images and decreased signal intensity on long TR/TE SE and GRASS scans. The 3–6-week posttreatment scans showed increased signal intensity on all pulse sequences. These findings are summarized in Table 1. While the impression from the postembolization GRASS sequences alone was that of patent vessels at the 3–6-week study, worrisome for recanalization or reopening of previously occluded channels, correlation with the short TR/TE SE images indicated the presence of subacute thrombus in successfully occluded vessels. This was confirmed by the late postembolization angiographic studies.

In two cases a hypointense peripheral ring outlined the bright intraluminal signal on the GRASS image of the subacute thrombus (Fig. 2J). The thickness of this circumferential area of signal loss was 2–3 mm and was not seen on the preembolization GRASS images.

Discussion

As techniques in MR advance and the use of MR-angiography becomes more widespread, the postoperative and postembolotherapy evaluation of AVMs and aneurysms may rely more heavily on MR imaging. Gradient-echo images, because of their ability to evaluate flow, will be employed more frequently in time-of-flight and phase-contrast protocols. Correct interpretation of MR vascular images must be based on an understanding of gradient-echo signal changes in flow and thrombi, as well as on the sequence's potential pitfalls.

As usually implemented, GRASS-technique images produce high signal in vessels at each scan level when flowing blood is present [4–6]. This bright signal is caused by three

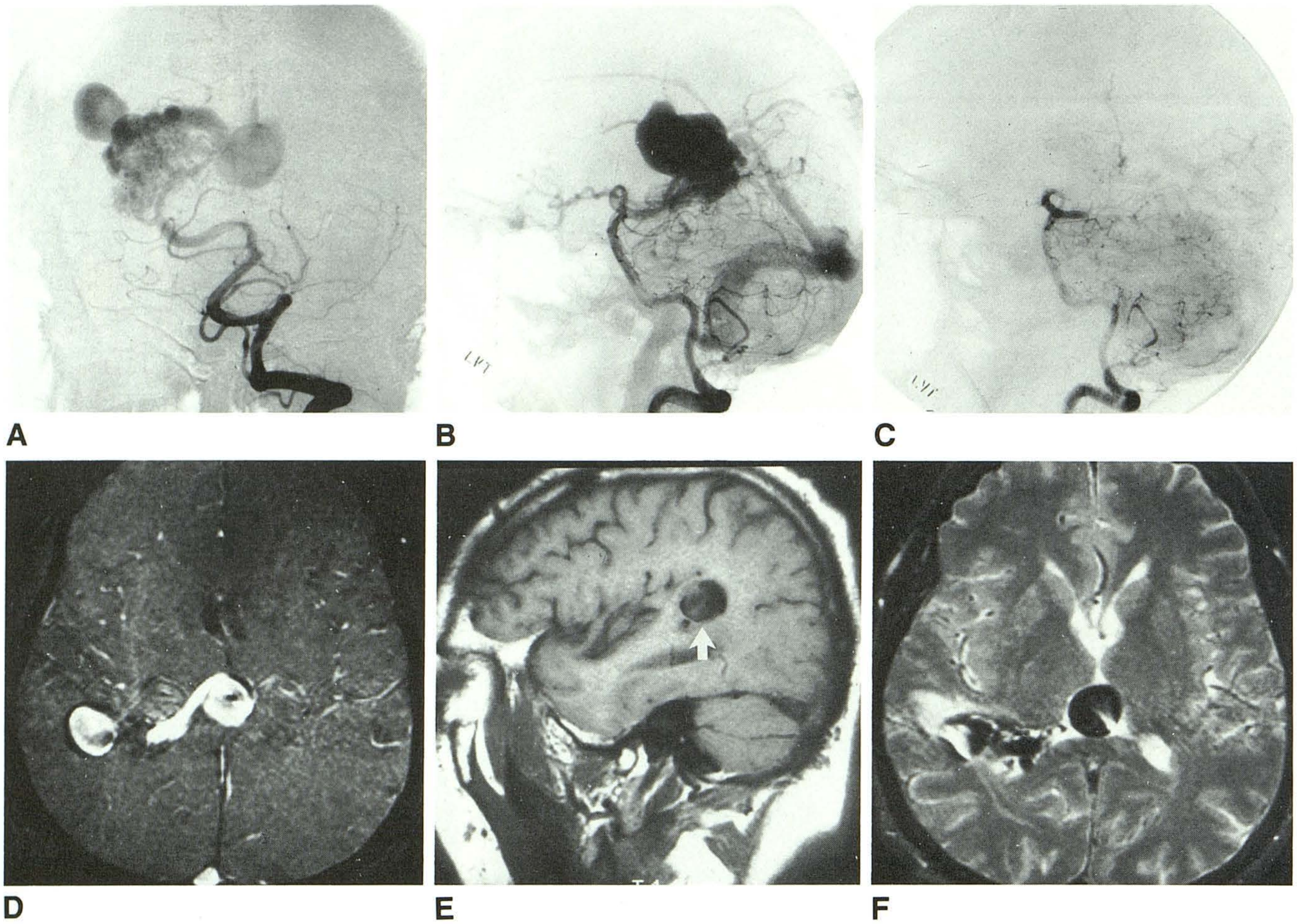

Fig. 2.—56-year-old man with recurrent subarachnoid hemorrhage.

A and *B*, Left vertebral angiograms, anteroposterior (*A*) and lateral (*B*) views demonstrate direct arteriovenous fistula from right posterior cerebral artery associated with varices draining into Galenic system.

C, 4 weeks after embolization, left vertebral angiogram shows almost complete occlusion of nidus and complete occlusion of varices.

D–F, Preembolization GRASS image (*D*) shows bright signal within malformation while T1-weighted (*E*) and T2-weighted (*F*) images show signal void, consistent with high flow within malformation. Isointense signal within anterior portion of varix (*arrow* in *E*) probably represents swirling slow flow.

(Fig. 2 is continued on the opposite page.)

factors: entry-slice phenomenon, non–slice-selective gradient echos, and gradient reversal flow compensation [1]. The entry-slice phenomenon (a type of flow-related enhancement) is due to the replacement of partially saturated protons by unsaturated protons entering the slice being studied. This flow-related enhancement is maximized with short TR/TE sequences, increasing velocity, and laminar flow patterns [4–5]. The non–slice-selective refocusing technique of GRASS images allows signal from spins moving out of as well as into the slice. In spin-echo imaging, flow perpendicular to the scanning plane demonstrates a signal void caused by time-of-flight effects occurring as a result of rapid flow of spins out of the readout section between slice-selective 90° and 180° pulses. The time-of-flight effect in GRASS images has less relevance, since the refocusing echo is a non–slice-selective reversal of the readout gradient [1]. This allows spins that have moved out of the plane of initial excitation, but that are still within the volume sampled by the readout gradient, to emit a signal rather than producing a flow void. Finally, the gradient-reversal flow compensation refocuses spins dephased by motion across gradients, allowing signal contribution from these dephased protons. Through these three mechanisms, bright signal emanates from flowing blood, contrasting with the lower signal of brain. For these reasons, MR pulse sequences employing gradient echos (GRASS, FLASH, FISP, LFA, gradient-echo acquisitions, flow imaging) offer great potential for determining the efficacy of therapy after embolization of cerebral AVMs.

GRASS sequences incorporate significant spin density, T2, T1, and flow information [5]. The weighting of these parameters in a gradient-echo image is determined by three major parameters; flip angle, TR, and TE. Image contrast, and particularly the T1 contribution to the image, is most sensitive to variations of the flip angle. As the flip angle is reduced, one obtains less contribution from longitudinal magnetization relaxation and therefore less T1 dependence. By decreasing

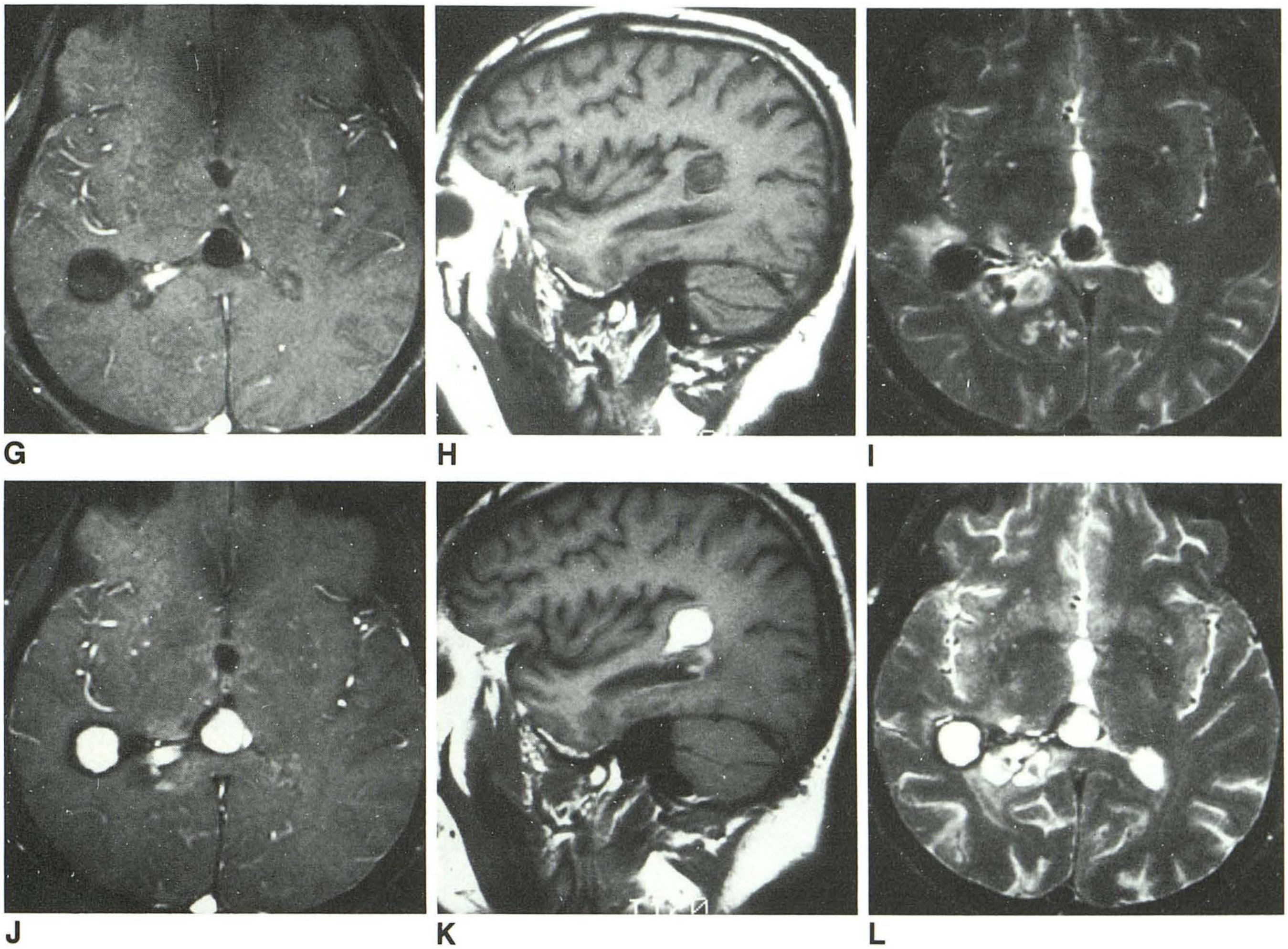

Fig. 2 (Continued).
G–I, 3 days after embolization, GRASS image (*G*) and T2-weighted image (*I*) show low signal while T1-weighted image (*H*) shows isointense to low signal, suggesting acute thrombosis of the varices.
J–L, 4 weeks after embolization, GRASS (*J*), T1-weighted (*K*), and T2-weighted (*L*) images show hyperintense signal within malformation, consistent with complete subacute thrombosis.

the flip angle below 45°, more T2* weighting occurs, and, coupled with a longer TR (200–400) and longer TE (30–60), maximum T2* contrast occurs. Proton-density information also occurs with small flip angles, but is maximized with smaller TEs (12–15). T1 weighting can be achieved with long TRs, short TEs, and most importantly, an increased flip angle to the 90° range. Maximum flow-related enhancement is achieved at intermediate flip angles and short TRs and TEs.

A thrombus will alter the proton density, T1, and T2 parameters of signal emanating from the vascular lumen. The oxidation state of hemoglobin and its by-products within the thrombus may mimic the flow signal on GRASS sequences. Gomori et al. [7] have thoroughly described the appearance of intracranial hematomas on spin-echo sequences at various field strengths. The T1 shortening effect and T2 lengthening effects of free extracellular methemoglobin in subacute clots cause hyperintense signal on both short TR and long TR/TE sequences. The high proton density of the clot, dilute-free methemoglobin, and the loss of proton-relaxation enhancement as red cells lyse contribute to the high intensity on long TR/long TE images of subacute hematomas. The appearance of intraluminal thrombus parallels that of intracranial hematomas with minor differences, such as the variable presence of hemosiderin within a thrombus. Therefore, the peripheral rim of hypointensity on long TR/TE images in the chronic stage of hematomas due to hemosiderin is usually not seen in vascular thrombi [2]. Atlas et al. [8] noted another difference between thrombi and hematomas. The T1 and T2 hyperintensity of extracellular methemoglobin in the subacute thrombus progresses from central to peripheral in partially thrombosed aneurysms rather than first appearing peripherally as in intracranial hematomas.

Since high-intensity signal is produced on proton-density-, T1-, and T2-weighted scans of subacute and chronic intraluminal thrombi, a thrombus demonstrates hyperintensity on GRASS images despite the mixed weighting of gradient-echo

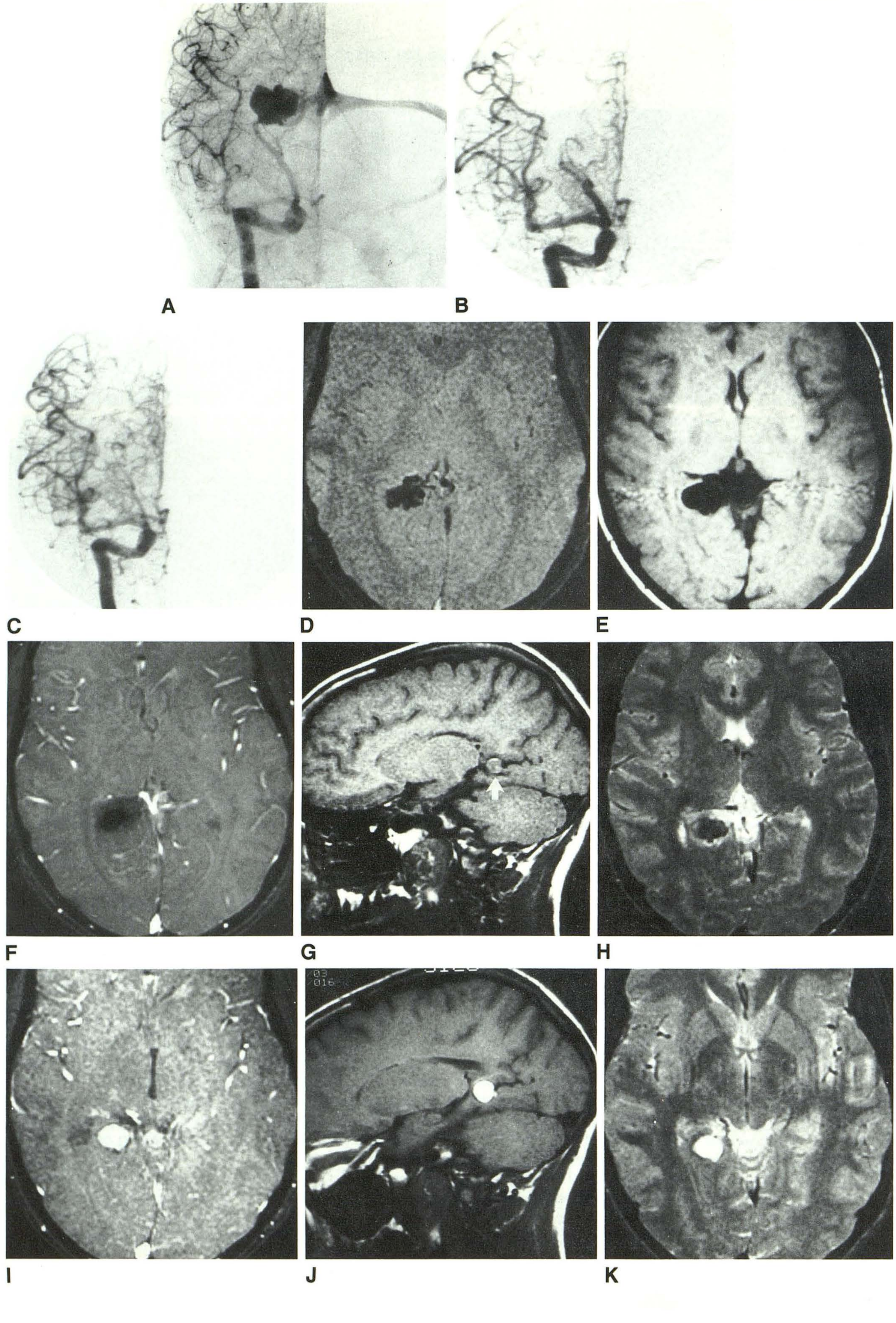
A
B
C
D
E
F
G
H
I
J
K

TABLE 1: Signal Intensity Relative to Brain

Imaging Sequence	Preembolization	Immediately After Embolization	Late Postembolization
GRASS	Increased	Decreased	Increased
T1-weighted	Decreased	Decreased, isointense, increased	Increased
T2-weighted	Decreased	Decreased	Increased

sequences. The sequence employed in the present study had a short TR/TE, a small flip angle, and incorporated considerable spin density as well as T2* information, accounting for the bright signal in subacute thrombi that mimicked the appearance of fast-flowing blood. Correlation of GRASS images with other pulse sequences, particularly the short TR/TE SE sequence, is critical in preventing misdiagnosis of failed embolotherapy. The T1-weighted SE image will show hyperintense intraluminal signal in the case of thrombus, but a signal void with fast flow. Long TR/TE SE images may also show a hyperintense signal in older hematomas and thrombi but this appearance generally lags behind the T1 shortening effects. Thus, the short TR/TE SE sequence is more helpful.

Recognition of these misleading GRASS appearances may be important in settings other than AVMs. Superior sagittal sinus and aneurysm thromboses may be falsely suggested, and feeders of meningiomas or glomus tumors could be erroneously interpreted to be patent in the presence of subacute thromboses on GRASS images. Therefore, GRASS sequences should always be accompanied by SE, particularly short TR/TE, images to verify that the high signal intensity within blood vessels on flow images is indeed due to flowing protons in patent lumina and not to thrombosis.

The peripheral hypointensity we saw on the GRASS sequences of two patients was thought to be due to a local magnetic susceptibility effect. However, this might have been caused by early hemosiderin deposition, fibrosis of the wall, or a boundary effect of intraluminal methemoglobin [9]. GRASS is more susceptible to local field inhomogeneities than T1 or T2 SE sequences and accentuates such signal loss. This boundary effect in gradient-echo imaging has prevented implementation of this technique in regions such as the sella and temporal bone, where susceptibility effects from the interfaces of bone, air, fat, CSF, and soft tissue cause artifactual signal loss. The artifact can be reduced with shorter TEs and higher flip angles [9].

Additional problems can arise from the high sensitivity of gradient-echo acquisitions to local magnetic field inhomogeneity. The acute and subacute blood breakdown products of intracellular deoxyhemoglobin and intracellular methemoglobin plus fibrin clot can cause signal loss on long TR/TE SE and T2-weighted GRASS sequences [10]. These compounds produce a magnetic field gradient across the cell membrane, thereby causing dephasing of protons leading to the hypointense signal on T2-weighted images. On short TR/TE images the signal of an acute hematoma is isointense with gray matter, while the subacute hematoma is hyperintense relative to gray matter. These same characteristics apply to intraluminal thrombi. The hypointense intraluminal signal on low flip angle, long TR/TE GRASS sequences will indicate no flow (Figs. 1J, 2G, 3F). However, there is the potential for mistaking acute thrombus, which may eventually lyse, for permanent occlusion or for the presence of the embolant (which may also be hypointense, especially glues). Follow-up studies are therefore necessary to document permanent occlusion. Also, a calcified thrombus or calcification in or around an AVM may mimic thrombosed vessels.

Finally, flow parallel to or within the imaging plane, turbulent flow, and nearby hemosiderin with partial volume effects can change the normally bright flow image on GRASS sequences to an intermediate intensity [3, 11]. This may simulate stages of thrombus formation, further confusing image analysis. Multiplanar views with correlation with short TR/TE SE sequences will assist in accurate image interpretation.

In summary, preliminary results from a small group of patients indicate that the combined use of GRASS and short TR/TE SE images in patients who have undergone embolotherapy for cerebral AVMs has the potential to eliminate the need for multiple follow-up angiographic studies. MR imaging is capable of satisfying many of the demands of the neurovascular surgeon and interventional neuroangiographer. Patency of major vessels, the presence or absence of thrombi, and associated hemorrhage or infarction can be determined without resorting to an invasive procedure through the knowledgeable interpretation of GRASS and SE MR sequences. However, the need for further research in evaluating the temporal sequence of intensity changes on various GRASS sequences after intravascular thrombosis and in developing alternative flow sequences is well recognized.

Fig. 3 (Facing page).—17-year-old girl with severe headaches of recent onset.

***A* and *B*, Right internal carotid angiogram (*A*) demonstrates arteriovenous fistula (AVF) associated with giant varix fed by posterior cerebral artery. Right internal carotid angiogram (*B*) immediately after embolization demonstrates complete occlusion of varix and no filling of AVF.**

***C*, 4 weeks after embolization, right internal carotid angiogram (*C*) shows persistent occlusion of AVF and varix.**

***D* and *E*, Preembolization GRASS image (*D*) shows low signal within varix because it was obtained without flow compensation. T1-weighted image (*E*) shows flow void as well as a horizontal band caused by phase-encoding artifact from pulsatile flow in AVF.**

***F–H*, 1 day after embolization, GRASS image with flow compensation (*F*) shows low signal, T1-weighted image (*G*) shows isointense signal (*arrow*), and T2-weighted image (*H*) shows low signal.**

***I–K*, 4 weeks after embolization, GRASS image with flow compensation (*I*), T1-weighted image (*J*), and T2-weighted image (*K*) show hyperintense signal within varix, consistent with subacute thrombosis.**

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