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Magnetic Susceptibility Effects Secondary to Out-of-Plane Air in Fast MR Scanning

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Areas of signal loss in brain overlying air-containing structures at the skull base are commonly observed on axial fast MR images. The nature of this effect, which can mimic the appearance of cerebral hemorrhage, is investigated in a phantom study and in a normal volunteer. The magnitude of the signal loss is found to be inversely related to the distance of the scanning plane from the air-containing structure and directly related to the echo time.

We have used fast MR imaging to identify products of hemorrhage in focal brain lesions that are detected on inversion-recovery (IR) and spin-echo (SE) sequences [1]. Signal loss, similar to that seen with hemorrhage, has been observed during the evaluation of cerebral lesions near the skull base on these fast images (Figs. 1 and 2). The nature of these effects is investigated with a phantom and in vivo.

Materials and Methods

MR examinations of the brain are performed in our department with a 0.6-T Technicare superconducting imager as previously described [1]. Focal cerebral lesions are investigated with fast imaging: gradient reversal is used to generate a set of images of progressively lengthened TR/TE: 100/15, 100/30, 100/50, and 120/100. For the 100/15 sequence, a tip angle of 120° is used for enhanced T1-weighted contrast. A tip angle of 20° is used for the 100/30, 100/50, and 120/100 sequences. For each pulse sequence a single-slice axial acquisition is obtained with four excitations.

A phantom, consisting of air- and water-containing plastic test tubes immersed in a water bath, was imaged with a spin-echo pulse sequence to provide localizing guidance for fast imaging in the indicated plane (Fig. 3). A normal volunteer was also examined. Coronal images were obtained to provide a reference plane defined by the upper border of the sphenoid sinus and mastoid air cells. This reference plane indicates the air-brain interface. Axial gradient-echo imaging was performed at 1, 2, 4, and 6 cm above this reference plane. The magnitude of the signal loss in the images of the phantom and the volunteer was qualitatively assessed as a function both of TE and of the distance of the imaging plane from the air interface.

Results

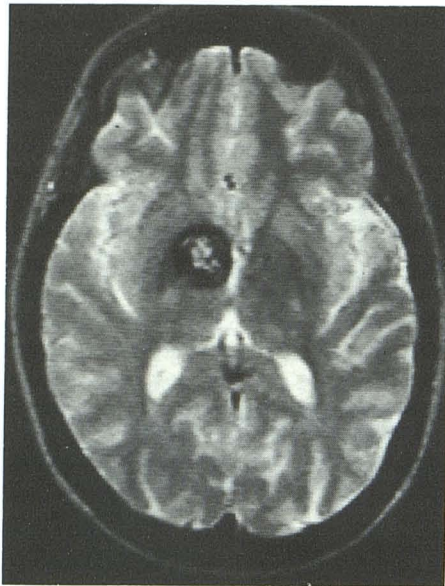
The fast MR images from the phantom study show signal loss in the imaged plane in relation to the air-containing tubes (Fig. 4). The magnitude and area of signal loss in the image decrease with increasing distance of the imaged slice from the air: compare tubes 1 and 2. The air in tubes 3 and 4 on either side of the imaged plane creates even more marked loss of signal. There is no signal loss seen in relation to an identical tube filled with water, tube 5. As the TE is increased, with distance from the air interface kept constant, the magnitude of the signal loss increases.

The fast images from the normal volunteer demonstrate signal loss in the brain tissue overlying the sphenothmoid sinuses and the mastoid air cells. The signal

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A

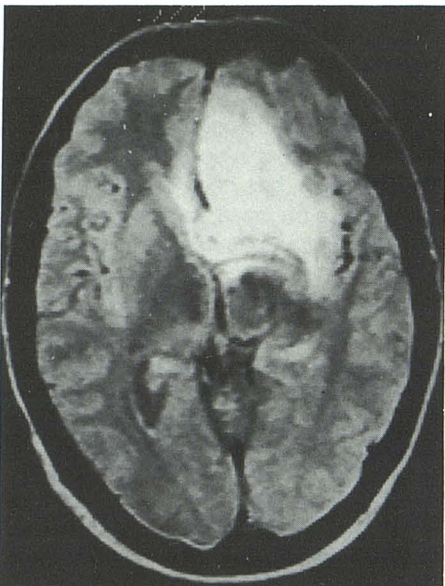


B

Fig. 1.—MR images of 34-year-old woman with right basal ganglionic arteriovenous malformation and previous hemorrhage.

A, Spin-echo MR image (2000/120/4) shows T2 shortening in lesion.

B, Fast imaging at same level (100/50/4, tip angle = 20°) shows marked loss of signal at site of previous hemorrhage. Similar signal loss is also seen in anterior interhemispheric region, directly overlying ethmoid air cells.



A



B

Fig. 2.—MR images of 26-year-old woman with a glioma.

A, Spin-echo MR image (2000/60/2) shows prolongation of T2 in lesion and surrounding edema.

B, Fast image at same level (100/50/4, tip angle = 20°) shows marked signal loss such as seen with hemorrhage, but that instead is related to subjacent ethmoid air cells.

loss is more marked as TE is increased (Fig. 5) The magnitude of the signal loss decreases as the imaged plane is further removed from these air cells (Fig. 6).

Discussion

Previous investigators have shown that geometric and intensity distortion can arise in spin-echo images of phantoms containing components of variable magnetic susceptibility [2]. Such effects can occur when a region of differing magnetic susceptibility is adjacent to but nonetheless out of the imaged plane. Ferromagnetic materials found in surgical clips or mascara are known clinical examples of such susceptibility artifacts seen on spin-echo images [3–5].

Variations in magnetic susceptibility in tissue causes local

variation in the applied magnetic field within voxels. This field variation causes dephasing of spins within the locally perturbed voxels and attenuation of signal from these voxels. As more time is allowed for such dephasing to occur, the attenuation of signal is more marked. Thus the observed effects on signal increase as TE is increased. The dephasing due to these local field inhomogeneities are largely refocused in spin-echo imaging by the 180° pulse. Since fast imaging employs gradient reversal to generate an echo, the dephasing of spins within a voxel due to local field inhomogeneity is not refocused. The fast sequence is therefore particularly sensitive to the T2* dephasing induced by variation in magnetic susceptibility and thus more readily depicts the local signal loss caused by such variation [6, 7].

The presence of local field inhomogeneities induced by

Fig. 3.—Phantom used to identify susceptibility effect caused by out-of-plane air. Phantom is viewed from above (left) and from side (right), with plane of imaging indicated by dotted line. Tubes 1–4 contain air, and tube 5 contains water; all are immersed in a water bath.

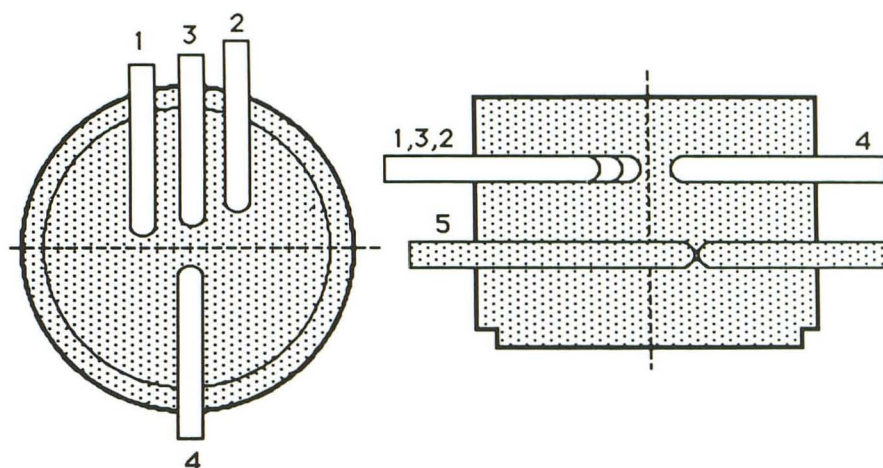
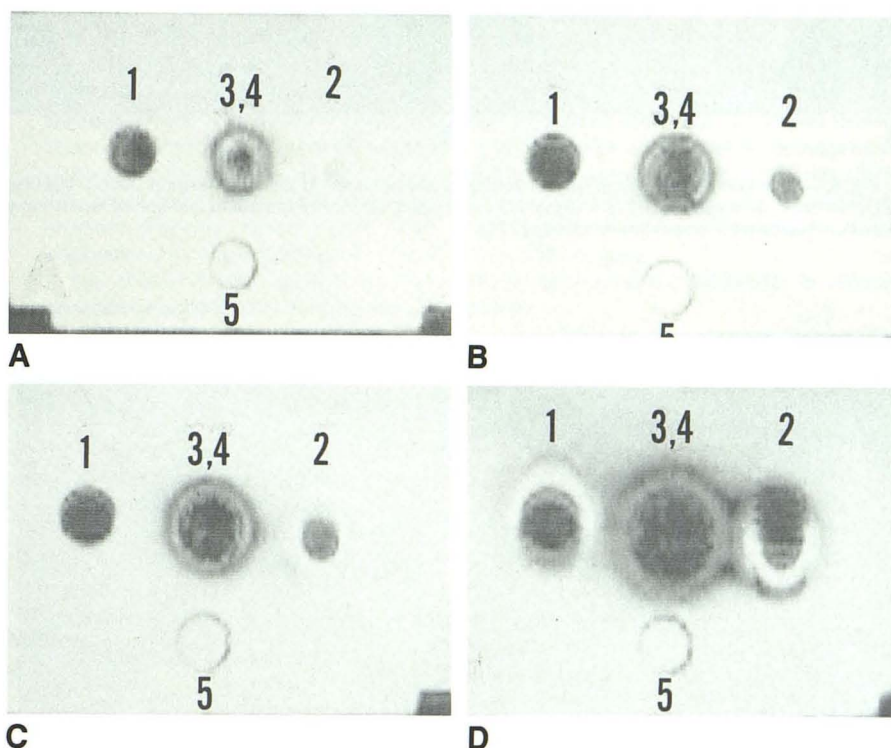


Fig. 4.—A–D, Axial fast images of phantom (100/15/4, tip angle = 120°) (A), (100/30/4, tip angle = 20°) (B), (100/50/4, tip angle = 20°) (C). There is loss of signal in image seen in relation to out-of-plane air in tubes 1, 2, 3, and 4. The effect in tube 2, which is farthest from imaged plane, is less than that seen with tube 1. Tubes 3 and 4 exert an additive effect on signal loss. No signal loss is seen in relation to water-containing tube 5. Magnitude of signal loss in image is increased as TE is increased.



deposition of products of hemorrhage can be detected with great sensitivity using gradient reversal [1]. Similarly, air-containing structures can cause similar signal loss near the skull base. The loss is attributable to the abrupt and large susceptibility difference between air and tissue. There is resultant distortion of the local magnetic field in the region of the interface. We have found that the magnitude of the signal loss resulting from the dephasing of spins within nearby voxels falls off with increasing distance from the interface with the air-containing structure. The signal loss is more prominent at larger values of TE, as greater time for local dephasing is provided. The magnitude of the effect we have described would be greater at higher field strength, although we have not been able to evaluate this variable.

We have used fast imaging as a supplement to spin-echo

imaging to identify products of hemorrhage in focal cerebral lesions. If fast imaging is to assume a primary role in cranial MR evaluation then approaches to minimizing signal loss due to out-of-plane air must be developed. Choice of small values of TE provides one approach to minimizing this signal loss. Another approach to minimizing this artifact would be to develop the means to permit application of refocusing 180° radiofrequency pulses during fast imaging, as has been suggested [7]. Perhaps development of other alternative pulse sequences for fast imaging will help overcome this problem.

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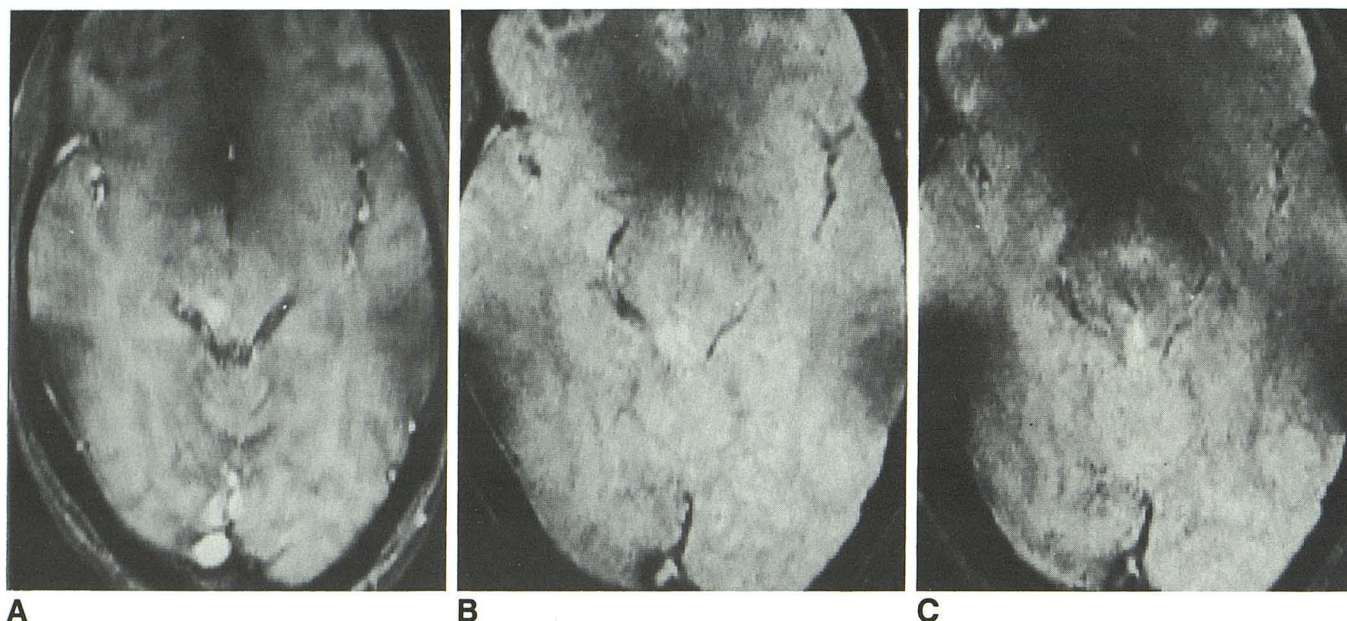


Fig. 5.—Axial fast MR images in normal volunteer are obtained at 2 cm above skull base (100/15/4, tip angle = 120°) (A), (100/30/4, tip angle = 20°) (B), (100/50/4, tip angle = 20°) (C). Signal loss in imaged slice corresponds to location of out-of-plane air in mastoids and sphenoid cells. Loss of signal increases with increasing echo delay (TE).

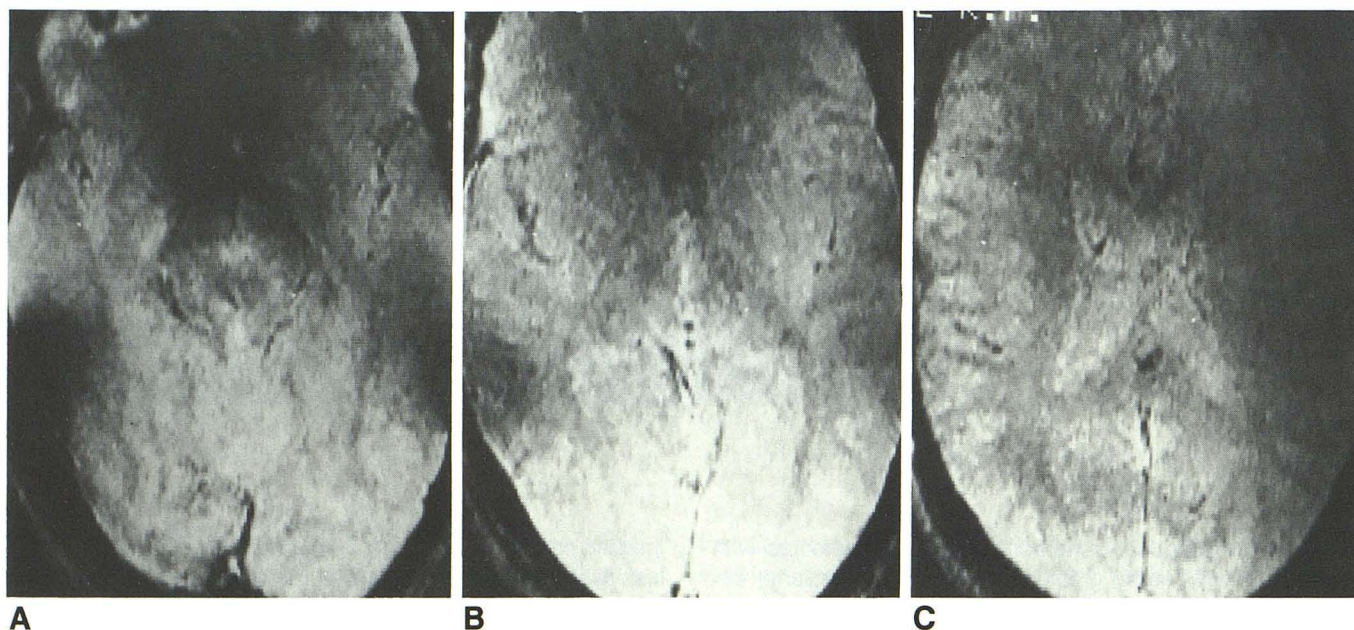


Fig. 6.—Axial fast images in normal volunteer (100/50/4, tip angle = 20°) are obtained at 2 cm (A), 4 cm (B), and 6 cm (C) above skull base. Signal loss is much less marked at 4 cm above plane of sinuses, and is not apparent at 6 cm above that plane.

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