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Nuclear Magnetic Resonance Imaging of CT-Isodense Subdural Hematomas

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Although computed tomography (CT) is an accurate means of diagnosing subdural hematoma [1], 10%–25% of these lesions are isodense relative to underlying brain tissue, and accurate diagnosis in these cases is dependent on the detection of a number of indirect and sometimes subtle signs [1–4]. Nuclear magnetic resonance (NMR) imaging has shown great promise as a neuroradiologic tool by virtue of its excellent soft-tissue contrast resolution, its lack of bone artifact, and its direct multiplanar imaging capability [5]. We report a patient with a subdural hematoma that was isodense on CT examination but strikingly differentiated from underlying brain on NMR examination and discuss possible explanations for the NMR appearance of intracranial hematoma.

Case Report

A 77-year-old woman suffered blunt head trauma 8 weeks before admission. Ten days before admission she experienced the onset of right leg weakness followed shortly thereafter by right arm weakness. Neurologic examination revealed mild dementia and right hemiparesis (more pronounced in the legs), including a right central facial weakness. The patient was ambulatory, alert, and had no headache.

A non-contrast-enhanced CT scan on the day of admission (fig. 1) demonstrated minimal asymmetry of the lateral ventricles, poor visualization of sulci, and separation of the brain from the inner table of the skull over the left convexity by an isodense crescentic band. No midline shift was identified.

NMR was performed 16 hr after CT. (The characteristics of the imaging device and the imaging techniques used are summarized in table 1 and have been fully described previously [6].) Bilateral subdural hematomas were evident as crescentic high-intensity collections that were sharply demarcated from the underlying lower-intensity brain over both convexities (figs. 1 and 2). Examination of the T1 estimate [7] and T2 images showed the left hematoma to have shorter T1 and longer T2 values than underlying brain, while the right hematoma had equal T1 and longer T2 values than brain. The right hematoma had a somewhat longer T1 and an approximately equal T2 value compared with the left and was slightly less intense on all spin-echo (SE) images.

The patient underwent bilateral frontal and parietal burr-hole placement after the NMR examination, and bilateral chronic subdural hematomas were confirmed. Thin, dark red, homogeneous fluid was evacuated from both sides. The patient's hemiparesis resolved within 2 weeks and her dementia improved slightly.

Discussion

The CT diagnosis of isodense subdural hematoma depends on the recognition of one or more indirect signs: effacement of sulci on the involved side [2, 3]; presence of a midline shift without a visible mass [2]; distortion or effacement of the ventricles or the white matter [4]; and separation of sulci from the inner table of the skull [3, 8]. These findings are frequently subtle, and significant bilateral isodense hematomas can exist in patients with cortical atrophy without obvious CT signs indicating their presence [1, 3].

The sensitivity and specificity of NMR imaging in subdural hematoma and the spectrum of NMR appearances in this condition are not known at the present time. Early experience, however, suggests that a hematoma has a characteristically high-intensity appearance relative to underlying brain tissue on SE and inversion-recovery (IR) images [5–7, 9, 10]. The high signal intensity of hematomas relative to brain can be understood on the basis of their observed relaxation characteristics. On SE images, signal intensity is roughly proportional (in a nonlinear fashion) to hydrogen density $\times$ T2/T1 [11]. Reported clinical experience suggests that intracerebral hematomas typically have T1 values that are shorter and T2 values that are longer than normal brain tissue [5, 7, 9, 10]. Other things being equal, both of these characteristics will tend to enhance the signal intensity of hematoma relative to brain, especially on images obtained using short pulse sequence repetition intervals (i.e., TR less than or equal to 1.0 sec) and/or long echo delay times (i.e., TE greater than 30 msec).

The T1 and T2 relaxation rates of tissues and fluids, however, are known to be very sensitive to changes in water content [12], and it would not be surprising to find variations in the relaxation rates of hematomas associated with differences in their structure and composition. Indeed, one early report of an acute (24-hr-old) hematoma in a rodent model

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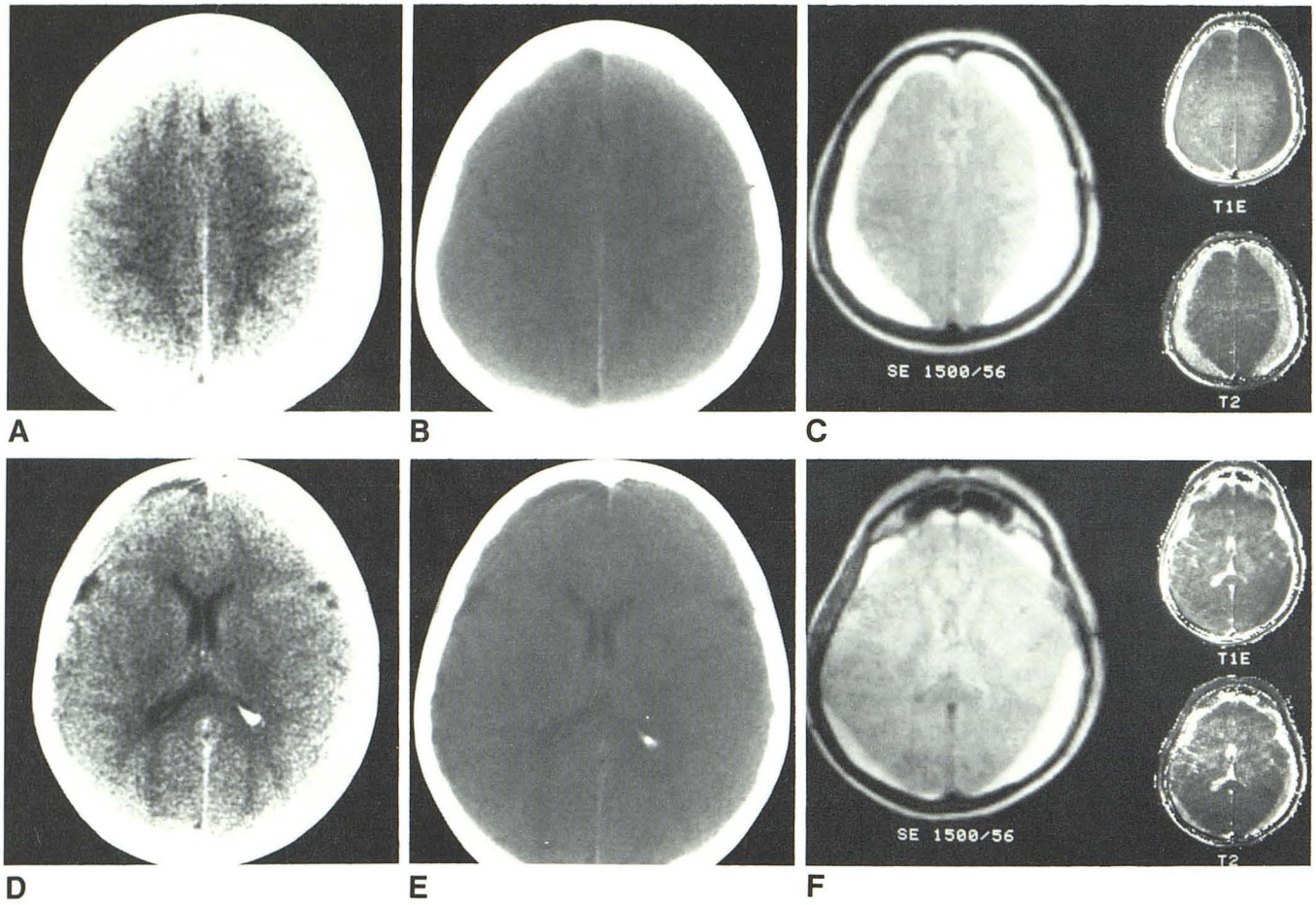

Fig. 1.—Transaxial sections above lateral ventricles (**A–C**) and through basal ganglia (**D–F**). **A** and **D**, CT scans with window levels of 40 H and widths of 80 H. **B** and **E**, CT scans with window levels of 80 H and widths of 300 H. **C** and **F**, NMR SE 1500/56, T1 estimate (T1E), and T2 images. On T1E and T2 images, high intensity corresponds to longer T1 and T2 values.

TABLE 1: **NMR Imaging Technique**

Imaging device:
Field strength: 0.35 T
Proton resonant frequency: 15 MHz
Plane selection: selective irradiation
Image construction: 2-D Fourier transform
Imaging technique:
Pulse sequence: SE (90°–tau–180°)
Number of echoes recorded: two
TE: 28 msec, 56 msec
TR: 1.5 sec
Imaging time: 13 min
Number of imaging planes: 15 simultaneously
Imaging plane orientation: transaxial
Section thickness: 7 mm
Resolution: 1.7 × 1.7 mm

Note.—SE = spin echo; TE = echo delay time; TR = pulse sequence interval.

[10] showed prolongation of T1 relaxation relative to brain. This seeming discrepancy from subsequent reports may relate to the different water and protein components in acute hemorrhage compared with subacute clots. In our case, the T1 value of the left subdural hematoma appeared to be shorter than the right (and its signal intensity enhanced as a result). It is tempting to speculate that this finding reflected differences in their molecular composition and structure despite their very similar appearances in the operating room. Unfortunately, detailed analysis of the specimens was not performed.

The mechanisms responsible for the relaxation characteristics of hematoma have not been completely defined, however, a number of investigators have studied the magnetic and NMR characteristics of blood and hemoglobin solutions in vitro [13–15], and some of their findings are of direct relevance to the NMR imaging situation. The ferrous ion (Fe^{2+}) is known to be strongly paramagnetic (i.e., it has a substantial intrinsic magnetic moment that tends to align with and add to the strength of any magnetic field), and paramagnetic species are known to enhance relaxation of nuclei in their vicinity. Initial expectations were that the hemoglobin molecule would also be paramagnetic, reflecting the presence of the ferrous ion in its core. Work by Pauling and Coryell [13], however, demonstrated that the magnetic behavior of hemoglobin depends on the configurational state of the molecule (which is

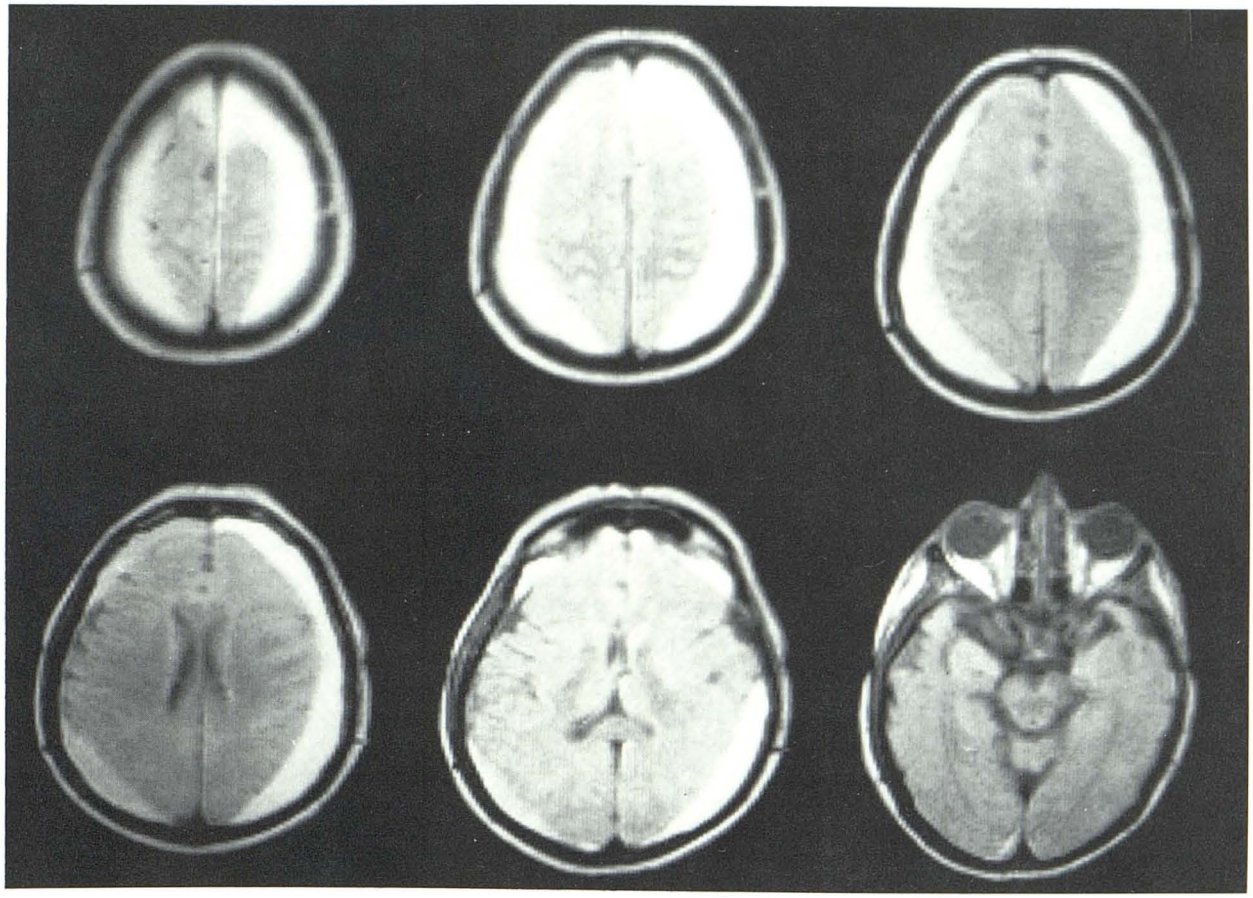

Fig. 2.—Series of sequential SE 1500/28 NMR images showing extent of bilateral subdural hematomas.

determined in large part by its oxygen content), with deoxyhemoglobin being paramagnetic and oxyhemoglobin being diamagnetic (i.e., the molecule has no intrinsic magnetic moment, but, in the presence of a strong extrinsic magnetic field, a weak magnetic moment is induced that tends to align opposite to and decrease the strength of the extrinsic magnetic field). Paramagnetic and diamagnetic species are known to have different effects on the relaxation of nuclei in their vicinity, with paramagnetic species enhancing relaxation and diamagnetic species having minimal effect on relaxation (primarily because the diamagnetic effect is of much smaller magnitude than the paramagnetic effect). Nonetheless, Fabry and Reich [14] and Singer and Crooks [15] found that deoxy- and oxyhemoglobin both enhanced in-vitro proton T1 relaxation equally, and in direct proportion to their molecular concentration, despite their very different magnetic characteristics. It is thus apparent that the magnetic properties of the hemoglobin molecule are not the dominant factor determining the relaxation characteristics of water protons in their vicinity.

A direct relation has been demonstrated, however, between the hemoglobin concentration of a blood sample and its measured T1 relaxation rate [14, 15], with higher hemoglobin concentrations being associated with more rapid T1 relaxation (i.e., shorter T1 values). This phenomenon has been noted in a wide variety of aqueous protein solutions and is believed to be due to the tendency of water molecules to adhere to the surfaces of macromolecules and form what are called "hydration shells" [12]. The motions of water molecules in these hydration shells are slowed and T1 relaxation of the protons in them is enhanced. An explanation of the mechanism of this relaxation enhancement is beyond the scope of this discussion but can be obtained in most standard NMR texts [16] and articles [12] dealing with this topic. The observed T1 and T2 values of blood are thus believed to represent a weighted mean average of the T1 and T2 values of the protons in "free" water molecules (which account for greater than 90% of the water molecules and have very long T1 and T2 values) and "bound" water molecules (which account for less than 10% of the water molecules and have very short T1 and T2 values). Since the concentration of hemoglobin in blood determines the relative proportions of "bound" and "free" water, this mechanism provides an explanation for the observed dependence of the relaxation rates on hemoglobin (or, inversely, on water) concentration.

On the basis of these considerations, it would be expected that the NMR imaging characteristics of hematomas should be dependent on their molecular composition and macroscopic structure, both of which are known to change over

time. Further experimental work and accumulation of more clinical experience is necessary to define the NMR characteristics of hematoma in all stages of its evolution. Nonetheless, the case presented in this report serves to emphasize the striking fashion in which intracerebral hematoma can be demonstrated on NMR SE images and raises the possibility that NMR imaging may be more sensitive than CT in diagnosing intracerebral bleeding, especially in the subacute period when the hematoma may well be CT isodense.

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