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Cerebral NMR Imaging: Early Results with a 0.12 T Resistive System

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Over a 6-month period, 157 patients, 89 of whom had central nervous system tumors, were examined on a prototype 0.12 T resistive nuclear magnetic resonance (NMR) imaging unit. All of the patients had computed tomography (CT), which was used as a standard to which the NMR findings were compared. Studies were done primarily by saturation-recovery technique with short repetition times. The signal intensity with saturation-recovery technique did not allow differentiation among most tumor types. Location, extent, and morphology helped to some extent in attempts at differentiation. In the multiplanar mode, NMR compared favorably to CT with regard to lesion detection. Limited early experience suggests that NMR also may detect some lesions when the CT is negative and may detect additional lesions when one or more are present. The NMR examination was well tolerated by selected patients.

In November 1982, a General Electric (GE) 0.12 T (5.1 MHz), developmental, resistive nuclear magnetic resonance (NMR) proton imaging system was installed at the Hospital of the University of Pennsylvania. This allowed the study of 157 patients for disease processes involving the brain, face, or upper cervical region over the next 6 months. During that time, software improvements were made, resulting in ability to obtain more sections in less time and simultaneous sectioning of a given volume of interest in coronal and sagittal planes, in addition to the transverse plane. We present the initial experience with this unit.

Subjects and Methods

Between November 1982 and May 1983, 11 volunteers and 157 selected patients were examined by NMR in order to evaluate the brain in most cases and in several instances the face, neck, and upper cervical spinal cord. Thirty-one patients were age 20 or younger. The youngest patient was 1 month old; the oldest was 82 years. Ninety-three patients were male and 64 were female.

The GE prototype resistive NMR system used is housed in a 90 decibel (dB) radiofrequency (RF) shielded room. The bore is 20 inches (50.8 cm) at aperture and 18 inches (45.7 cm) centrally. The head cone contains the RF coils and is 10 inches (25.4 cm) in diameter.

The spin-warp method (spatial encoding on X and Y axes) is used for NMR imaging [1]. Both planar two-dimensional (2D) and multiplanar three-dimensional (3D) data collection are available. Data are acquired on a 128×128 matrix and then interpolated to 256×256 for display. Slices are 10–13 mm thick. Time per slice is a function of the technique used, the repetition time (TR), the matrix size, and the number of data averages per pixel value.

All patients examined with NMR had complete neurologic evaluations and computed tomographic (CT) scans, and all had given informed consent before undergoing the NMR study. The NMR and CT findings were compared in each case, and attempts have been made to correlate the results to the clinical findings and subsequent patient course. The neuroradiologist interpreting the NMR scans was familiar with the CT findings in each case. In fact, the CT localization of lesions influenced the centering and choice of plane of sectioning for NMR.

During the first 2 months of operation, single-slice two-dimensional NMR sections were

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TABLE 1: **Central Nervous System Tumors Examined by NMR**

Histology	No. of Patients
Glioma-astrocytoma	52
Meningioma	10
Metastasis	8
Pituitary adenoma	7
Embryonal carcinoma	2
Chordoma	3
Other*	3
Not biopsied	4
Total	89

* One primitive neuroectodermal tumor, one lipoma, one pineocytoma.

TABLE 2: **Indications for NMR Excluding Intracranial Tumors**

Indication	No. of Patients
Infarct	15
Multiple sclerosis	9
Chiari malformation	7
Posterior fossa symptoms	5
Dementia	4
Psychiatric illness	3
Epilepsy	2
Congenital abnormality	2
Aneurysm	2
Miscellaneous CNS	11
Head and neck tumors	6
Cervical spine abnormalities	2
Total	68

TABLE 3: **CT and NMR Results from 157 Cases Evaluated from November 1982 to May 1983**

Period (dates): CT Diagnosis	NMR Findings	
	Positive	Negative
1 (11/18/82 to 1/17/83):		
CNS tumor:		
Positive	16	2
Infarct:		
Positive	1	3
Negative	1	2
Other*:		
Positive	5	1
Negative	0	4
2 (1/20/83 to 2/21/83):		
CNS tumor:		
Positive	26	0
CNS tumor postoperatively:		
Negative	0	1
Infarct:		
Positive	3	0
Negative	1	1
Other*:		
Positive	6	2†
Negative	0	2
3 (2/24/83 to 5/12/83):		
CNS tumor:		
Positive	42	0
CNS tumor postoperatively:		
Negative	0	2
Infarct:		
Positive	3	1
Negative	1	0
Other*:		
Positive	20	3
Negative	0	8

* Listed in Table 2.
† These patients could not be imaged on NMR.

obtained in the transverse plane using either saturation-recovery (SR) or inversion-recovery (IR) techniques. Our initial experience confirmed the conclusion of Edelstein et al. [2] that SR is superior to IR in differentiating tissues of similar proton density but different T1 values when equivalent examination times are considered. The repetition time (TR) for the SR technique was 150 msec with four to eight averages. A period of 5–10 min usually was required for data collection. Other TRs also were used in order to determine their effect on signal intensity and image quality. SR images with short TR gave T1 weighting to the images, shortened the scan time, and therefore resulted in better patient tolerance of the study.

During the next month, the multiplanar transverse mode became available and thus, it became possible to collect data for up to 16 transverse sections in 10 min. Reconstruction time for the 16 sections was around 20 min. For the last 3 months of our series, coronal and sagittal multiplanar modes, in addition to transverse, have been available and have been performed as clinically indicated. While IR and spin-echo (SE) techniques have been available, SR technique has been favored because of the better image quality achieved with the low field strength and low signal-to-noise ratio of the system used.

Results

Of the 11 volunteers studied, 10 had normal examinations, and one had atrophy. Of the 157 patients examined, 134 (85%) had CT-demonstrated lesions. An additional 23 patients who were examined (15%) had negative CT examinations but positive clinical findings. The vast majority of clinical material in this series consists of patients with central nervous system (CNS) tumors (89/157, 57%, table 1). Sixty-eight other patients were examined for a variety of symptoms, signs, and known or suspected disease states (table 2).

Thirty-five patients were studied during the first 2 months (period 1, table 3). The NMR examinations performed during this time were limited, consisting of only several slices, because of the long time required to obtain data for each slice. During the next month (period 2), 42 patients were examined using transverse multiplanar mode. During the last 3 months (period 3), all 80 patients were studied using multiplanar modes in transverse, coronal, and sagittal planes. Results of comparing the CT and NMR studies in the identification of lesion morphology during the three periods are given in table 3.

Of the first 50 patients selected for study, three patients could not be examined, one because of involuntary neck spasms (antedating the examination) and two because their shoulders were so large that their heads could not be satisfactorily placed in the magnetic field. Three patients during the course of the studies developed problems that led to early termination of the examination: Two patients had difficulty breathing. In one case it seemed to be a manifestation of

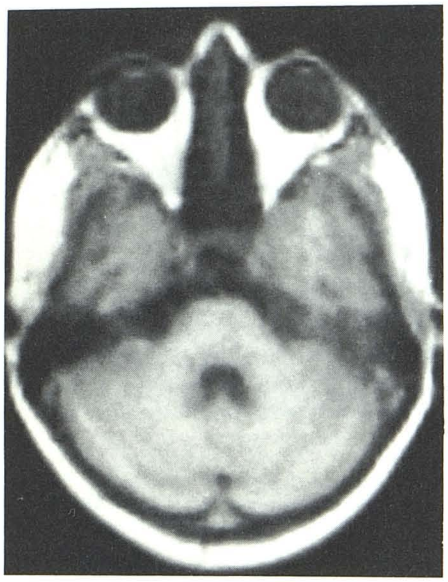
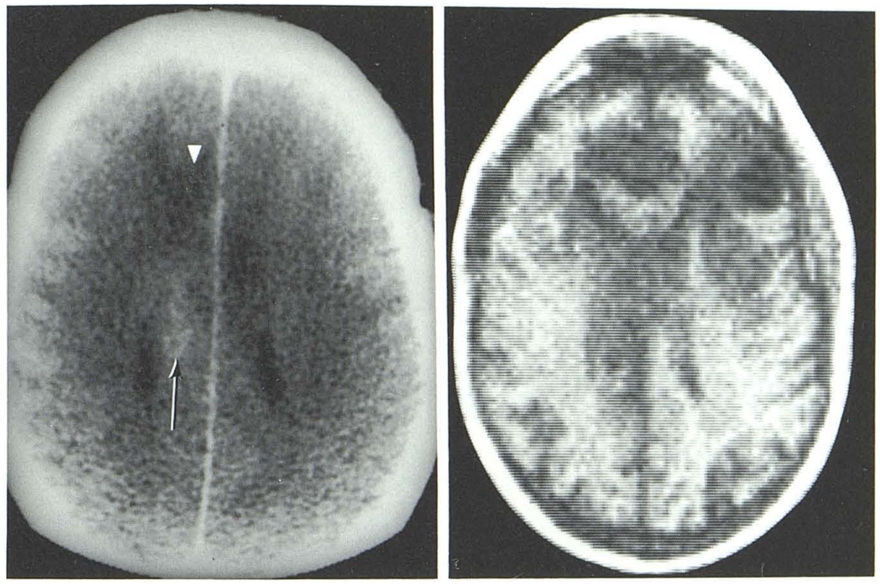


Fig. 1.—Normal posterior fossa; 24-year-old woman with seizures. Transverse NMR scan. Good anatomic detail of fourth ventricle, brainstem, and cerebellar hemispheres. Lack of signal from petrous bone and cerebrospinal fluid in cerebellopontine angle does not permit their differentiation.



A B

Fig. 2.—Low-grade astrocytoma, 54-year-old man with dementia. **A**, CT scan. Minimal contrast enhancement in corpus callosum (*arrow*) of right hemisphere. Possible small area of decreased density in right frontal lobe (*arrowhead*). **B**, Inversion-recovery NMR scan. Extensive areas of low signal intensity in right and left corpora callosa, in white matter of both frontal lobes, and in right basal ganglionic region.

anxiety and in the other, an accentuation of prior breathing difficulties in the horizontal position. One patient became claustrophobic.

The NMR studies display a satisfactory morphologic detail of normal brain anatomy (fig. 1). A limitation of the SR technique with short TR is its inability to differentiate such substances as bone, air, cerebrospinal fluid, and flowing blood. All show low intensity (fig. 1) and cannot be distinguished from each other when they abut (e.g., petrous bone, cerebellopontine angle cistern).

Of 86 CNS tumors positive on CT, 84 were positive on NMR. In two cases, the CT findings were subtle: one brainstem tumor with absent perimesencephalic cisterns and one infiltrating low-grade glioma with equivocal hypodensity in the white matter and slight contrast enhancement in the corpus callosum (fig. 2A). On the other hand, the NMR findings were unequivocal: an enlarged distorted brainstem (sagittal) and an extensive low-signal bihemispheric mass (fig. 2B). However, with the SR technique and short TR, it was not possible to distinguish clearly peritumoral edema from tumor mass in most of the cases. Also, the information on the NMR images did not serve to differentiate one tumor type from another (figs. 3–5). The only tumor characterization that was achieved was based on location, morphology, and extent. With the exception of a lipoma of the tectum of the mesencephalon (high signal intensity, fig. 6), the signal intensity as displayed on the images did not aid in the differential diagnosis. Future use of other techniques such as spin-echo with various TR rates may give additional signal-intensity information. It is also possible that when accurate measurement of T1 and T2 becomes available, greater specificity may be achieved. It is clear that, at present, multiplanar transverse, sagittal, and coronal NMR images offer valuable information relative to tumor location and extent and, therefore, provide helpful pretherapy information (fig. 3).

Of the 23 patients with clinical signs and symptoms of neurologic disease with negative CT examinations, three were examined after tumor resection and had no evidence of tumor. Of the other 20, three had NMR abnormalities, areas of low signal consistent with the diagnosis of infarction. One patient had a brainstem infarction, another an internal capsular infarct (fig. 7), and the third patient, who had dementia, showed bilateral white-matter infarctions on coronal NMR sections that were clinically unsuspected. Two patients with clinical evidence of multiple sclerosis and CT evidence of one plaque showed multiple areas of low signal intensity in the white matter consistent with plaques (fig. 8).

The identification of three positive NMR studies in 23 patients with negative CT examinations is a yield of 13%. Seven of the 23 studies (one positive NMR) occurred during period 1. The yield of the positive NMR examinations might have been even higher had all examinations been done in a multiplanar mode, but it must be noted that all of the patients with negative CT had definite abnormal clinical findings.

Discussion

Cerebral NMR studies, done in planes similar to those of CT, are already acknowledged to be of great clinical promise [3–8]. The current clinical in vivo standard for morphologic depiction of cerebral gross pathology is high-resolution CT. Thus, in our initial clinical evaluation of the GE prototype NMR

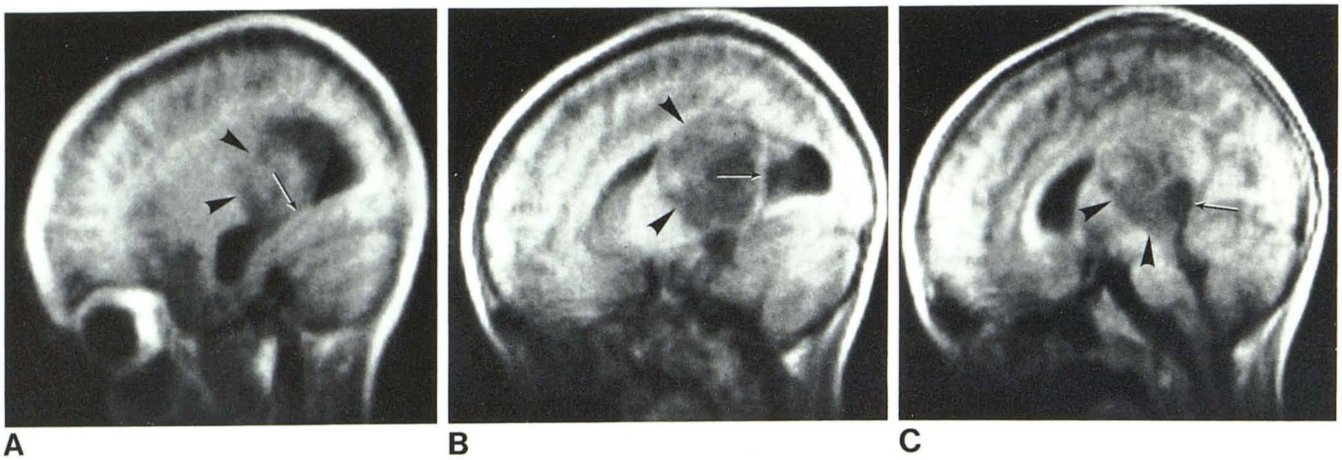


Fig. 3.—Malignant glioma of thalamus, 9-year-old boy with left sixth nerve palsy and headaches. **A**, Sagittal NMR scan. Mass of low signal intensity (*arrowheads*) compresses temporal horn (*arrow*) of lateral ventricle. **B**, More medial sagittal section. Mass (*arrowheads*) involves thalamus and cuts off occipital horn (*arrow*) of lateral ventricle. **C**, Still more medial section. Extent of mass is shown. Mass (*arrowheads*) of low signal intensity involves thalamus, hypothalamus, and tectum of mesencephalon. Quadrigeminal plate cistern (*arrow*) is displaced posteriorly.

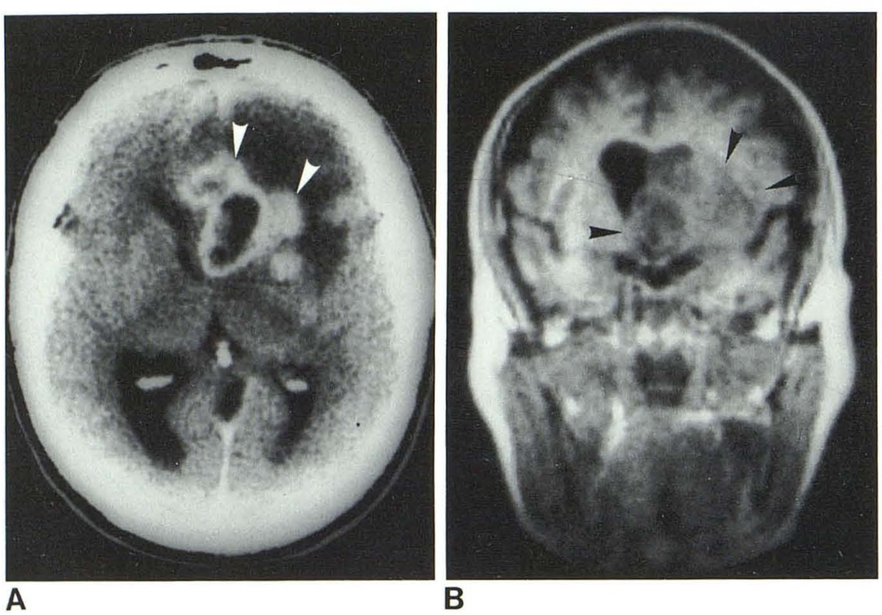


Fig. 4.—Malignant glioma, 55-year-old man. **A**, CT scan. Contrast-enhanced frontal ganglionic mass (*arrowheads*). **B**, Coronal NMR scan. Mass (*arrowheads*) of decreased signal intensity involves deep frontal white matter and basal ganglionic structures.

unit, we have used CT as a standard for evaluation of the NMR images. However, it is premature to critically compare NMR, which is rapidly evolving, to the well established technique of CT.

In evaluating the NMR images here, it is important to realize the studies were carried out on a prototype NMR unit during a period of time that saw implementation of significant software steps in order to improve the unit's performance. Thus, during the first 2 months (period 1, table 3), eight lesions in six patients seen on CT were not demonstrated on NMR examination. In one patient, two calcified parenchymal masses were not seen. This is not unexpected because calcifications do not produce a signal. In five other cases with six lesions, the problem was that of not having the correct level of sections. This is due to two problems: (1) Only a limited number of slices could be obtained, because they were done individually and each required significant time for data collection, and (2) the angle of the plane of section differs between CT and NMR in the two units used (fig. 9).

CT sections are performed at an angle varying between 0 to +20° relative to the orbitomeatal line, while the plane of the NMR section is −5° to −15° relative to the orbitomeatal

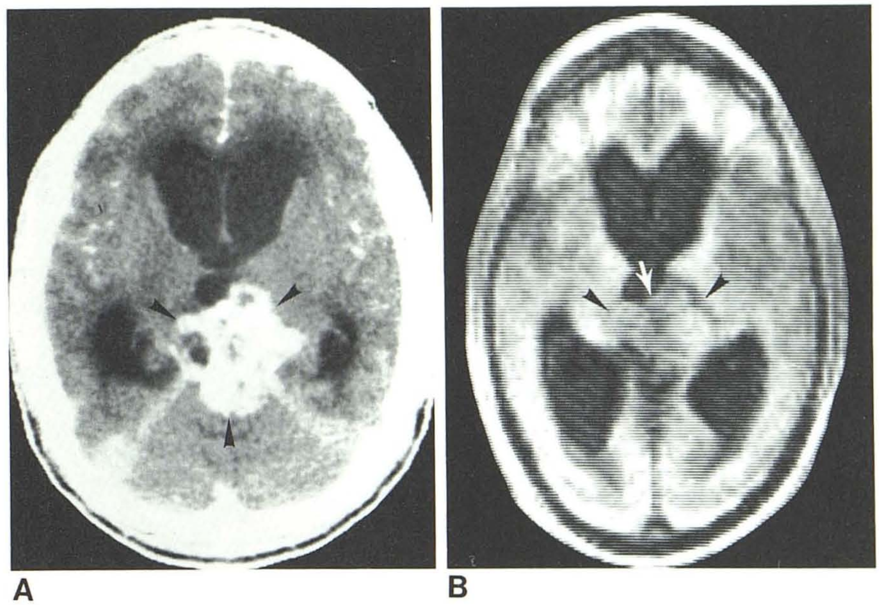


Fig. 5.—Embryonal cell carcinoma of pineal, 10-year-old boy with paralysis of upper gaze, blurring of vision, and headaches. **A**, Transverse CT scan. Contrast-enhanced mass of pineal region (*arrowheads*). Anterior third ventricle and lateral ventricles are dilated. **B**, Transverse NMR scan. Mass (*arrowheads*) in vicinity of pineal gland. Obstructed third ventricle is cut off in irregular fashion (*arrow*).

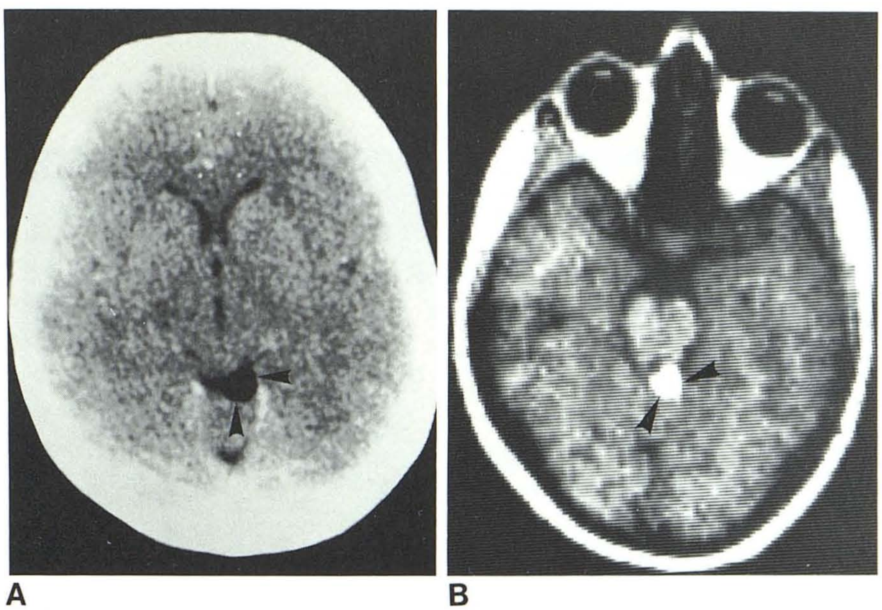
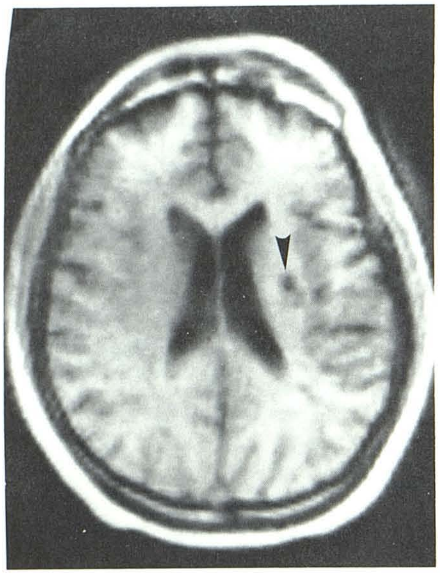


Fig. 6.—Lipoma of tectum of mesencephalon, 20-year-old woman with headaches. **A**, Contrast-enhanced transverse CT scan. Low-density region (*arrowheads*) in tectum of mesencephalon. **B**, Transverse NMR scan. Area of high signal intensity (*arrowheads*) in tectum of mesencephalon. Signal intensity is similar to that found in orbital and facial fat.

line. The plane of NMR sectioning is not easily controllable because of hyperextension of the neck induced by the close fitting of RF head coil. Thus, CT and NMR sections that appeared similar on casual inspection varied anatomically on closer inspection.

When multiplanar transverse sectioning became available during period 2, the time of data collection and reconstruction became shorter. During this time, all intracranial lesions shown on CT were identified on NMR. However, there were difficulties in evaluating extracranial lesions. Examination of two patients with head and neck tumors, a mandibular lesion and a carcinoma of the larynx, were attempted, but in each instance the lesion was at or beyond the lowermost edge of the imaged field.

During the third period, when multiplanar sectioning became available in three planes (transverse, coronal, and sagittal), again two head and neck tumor cases were unsuccessfully examined, one for reasons similar to that of period 2, and one because of poor signal. Poor signal also deteriorated the image quality in a patient with Chiari malformation, probably because of postoperative metallic hardware. In one case, thus far unexplainable, an infarct clearly defined on CT was



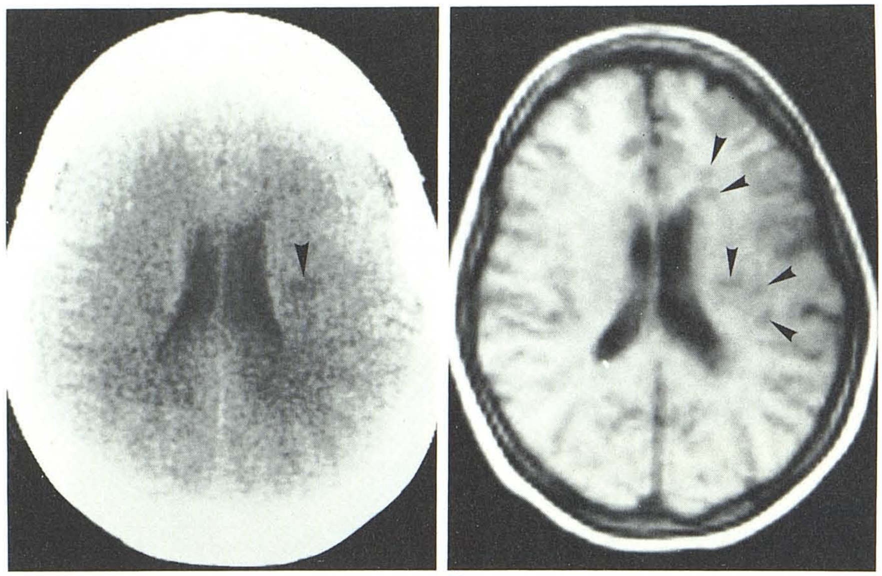


Fig. 7.—Infarction, 25-year-old man with abrupt onset of right-sided weakness. CT examination was normal. Transverse NMR scan. Small white-matter infarct (*arrowhead*).

Fig. 8.—Multiple sclerosis, 25-year-old woman with episode of right hemiparesis 3 months earlier, which resolved spontaneously. **A**, CT scan without contrast enhancement. Focal area of decreased density (*arrowhead*) in white matter of left hemisphere. **B**, Transverse NMR scan. Multiple areas of low signal intensity (*arrowheads*) in white matter of left hemisphere.

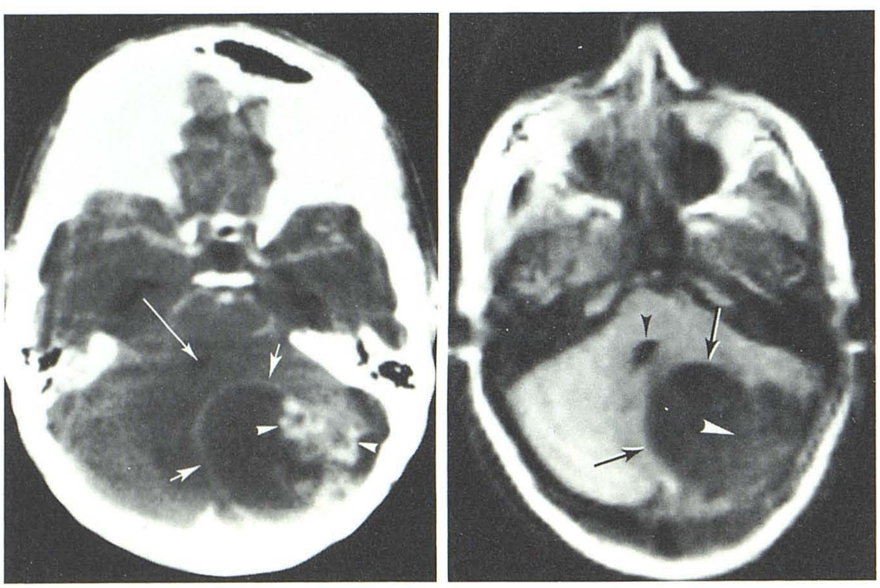


Fig. 9.—Cystic cerebellar astrocytoma, 16-year-old girl with ataxia and headaches. **A**, Contrast-enhanced transverse CT scan. Left cerebellar mass with contrast-enhanced mural nodule (*arrowheads*) and more medial cystic structure of low density with surrounding contrast-enhanced rim (*short arrows*). Fourth ventricle is displaced anteriorly and contralaterally (*long arrow*). **B**, Transverse NMR scan. Left cerebellar mass with area of greater signal intensity laterally (*white arrowhead*) and lesser signal intensity (*arrows*). Fourth ventricle (*black arrowhead*), clearly identified, is displaced and compressed.

not demonstrated on NMR despite comparable level of sectioning. CT and NMR were done only 4 days apart and were more than 1 week after the onset of the infarction.

It is clear from our initial experience that accurate morphologic comparison between CT and NMR requires complete NMR study of the region of interest. Multiplanar studies that encompass the entire brain or head and neck region are necessary.

A surprising finding in this series was the patients' acceptance of the procedure, their motivation, and their cooperation during the examination despite their often serious disease. This can be attributed to a combination of reasons: The study was explained, NMR represents a new test and one that does not involve radiation, and the design of the RF-shielded room permits the technician, physician, or family to be present in the scanner room during the patient's examination.

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