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R C Hawkes, G N Holland, W S Moore, D M Kean and B S Worthington

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NMR Tissue Characterization in Intracranial Tumors: Preliminary Results

R. C. Hawkes,[1] G. N. Holland,[1, 2] W. S. Moore,[1] D. M. Kean,[3] and B. S. Worthington[3]

Nuclear magnetic resonance (NMR) has been shown to have high sensitivity for detecting intracranial pathology. A study was devised to determine what information about tissue characteristics can be derived from steady-state free-precession NMR images alone and when compared with computed tomographic (CT) scans. The flow-dependent sequences allow diagnosis of intrinsic vascular lesions. Whereas precise characterization of some pathologic groups such as fat-containing tumors is possible, other important groups cannot be clearly differentiated. Preliminary findings suggest that it may be possible to predict the texture of extrinsic tumors from their NMR signals.

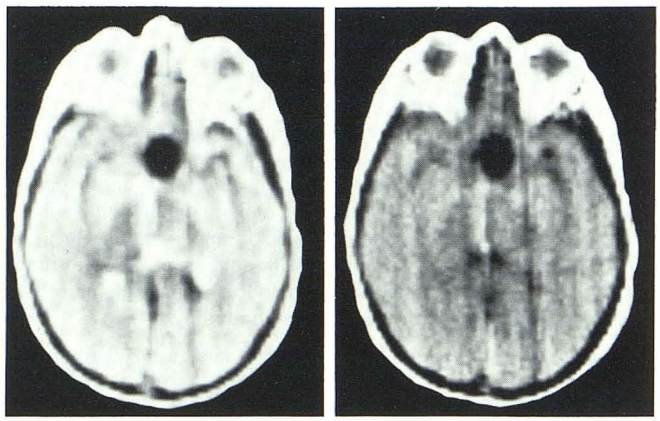
The high sensitivity of nuclear magnetic resonance (NMR) imaging for detecting intracranial pathology has been reported by several authors [1, 2]. On the basis of the 1971 observation of Damadian [3] that both the spin-lattice (T_1) and spin-spin (T_2) relaxation times of neoplastic tissue are prolonged, it was hoped that NMR would allow a more precise prediction of tissue characteristics than is possible with computed tomography (CT). The tissue relaxation times of excised tumors have been measured and in vivo measurements have made of tumors in experimental animals [4]. A clear overlapping of the values representing tissue relaxation times has been demonstrated between different types of neoplasm and between these and other pathologies.

Methods and Rationale

We recently began a study to determine: (1) what information about tumor characteristics can be derived from NMR images produced with different steady-state free precession (SSFP) sequences; and (2) whether more information about tissue characterization can be obtained from a joint consideration of NMR images and CT scans than from either alone. We used two SSFP sequences in which the overall tissue contrast is given by the formula ρ (T_2/T_1). With the modified SSFP (MSSFP) sequence, all structures whose T_1 is greater than 0.8 sec give a zero signal; this means that cerebrospinal fluid, which has a very long T_1, appears black despite its high proton density. With the unmodified SSFP (USSFP) sequence, which embraces all the T_1 values, cerebrospinal fluid appears white (figs. 1 and 2). In pure water, where there is free proton mobility, T_1 and T_2 are equal at several sec. In biologic tissues, water molecules have various degrees of association with macromolecules; free and bound phases have been distinguished [5]. Bound water has slower motional characteristics than pure water and thus has a shortened T_2 time, whereas T_1 is shortened to a lesser degree and becomes several times larger than T_2. Our images reflect complex averages over the cell types in the component tissue of the ratio (T_1/T_2), and we may suppose that this is related to the average organization of cellular water.

In extrinsic tumors of uniform tissue type such as pituitary adenoma and acoustic neuroma, we have observed a range of NMR signal intensities, probably reflecting their differing water content. In a study of experimental tumors in animals, Herfkens et al. [4] observed that the lengthening of T_1 values in neoplasms broadly correlated with their water content. In our limited experience we have observed that extrinsic tumors with a high density on NMR prove to be soft or semiliquid at operation, whereas tumors more isodense with brain are firmer. The consistency of such tumors is an important factor in treatment considerations, since it is easier to remove a tumor that can be aspirated than one requiring piecemeal dissection in a confined space.

Because multiple-pulse NMR techniques are sensitive to motion, there is selective removal to signal from areas of high blood flow. However, by employing the two imaging sequences in succession,



A B

Fig. 1.—Axial transverse NMR scans. Suprasellar aneurysm. Blood flow in aneurysm yields zero signal with both unmodified (**A**) and modified (**B**) SSFP sequences, while cerebrospinal fluid appears black in **B** and white in **A** because of its long T_1.

[1] Department of Physics, University of Nottingham, Nottingham NG7 2RD, England.
[2] Present address: Picker International, Inc., Highland Heights, OH 44143.
[3] Department of Academic Radiology, Queen's Medical Centre, University of Nottingham, Nottingham NG7 2UH, England. Address reprint requests to B. S. Worthington.

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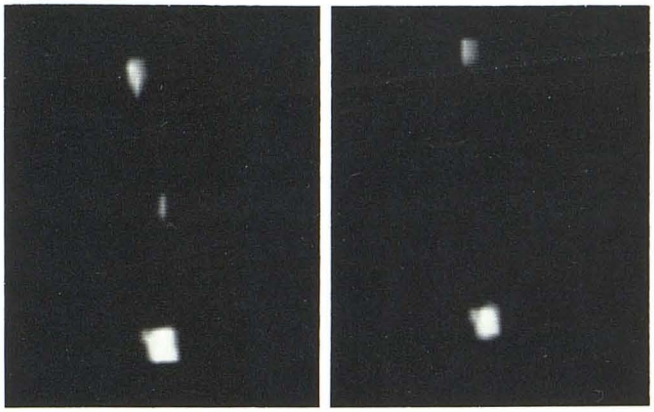
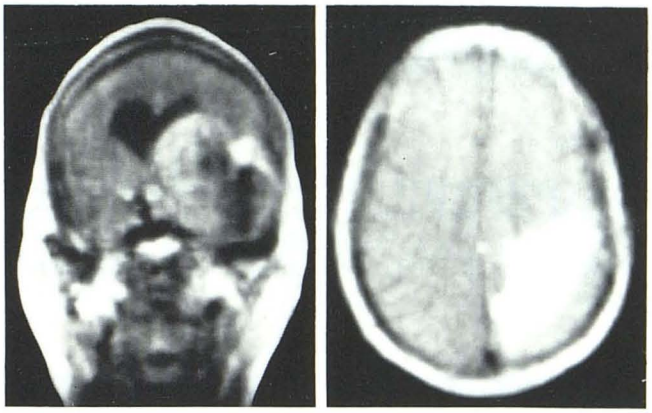


A B

Fig. 2.—Transverse NMR scans through three tubes containing (*top to bottom*) fresh blood, cerebrospinal fluid, and clotted blood, respectively. Cerebrospinal fluid is visualized with the unmodified SSFP sequence (**A**) but not with the modified sequence (**B**). The signal from clotted blood is higher in **A** than in **B.**



3 4

Fig. 3.—Coronal NMR scan. Epidermoid in middle cranial fossa. Areas of high signal in tumor corresponded to areas of negative CT attenuation.

Fig. 4.—Axial transverse NMR scan. Left-sided parietal hematoma.

TABLE 1: **NMR and CT Characterization of Intracranial Tumor Tissues and Other Components**

Tumor Component	NMR (Pixel Value)		CT (Attenuation Value)	
	USSFP	MSSFP	Without Contrast Medium	With Contrast Medium
Solid tumor (T_1 value >0.8 sec)	High	Low	Variable	Enhances (variable)
Tumor tissue with T_1 value <0.8 sec	High	High	Variable	Enhances (usually)
Blood:				
Static	Very high	Very High	High (proportional to age)	...
Moving	Low	Low	High	Enhances
Fat	High	High	Low	...
Cerebrospinal fluid	High	Low	Low	...

Note.—NMR = nuclear magnetic resonance; CT = computed tomography; (U)MSSFP = (un)modified steady-state free-precession sequence; T_1 = spin-lattice relaxation time.

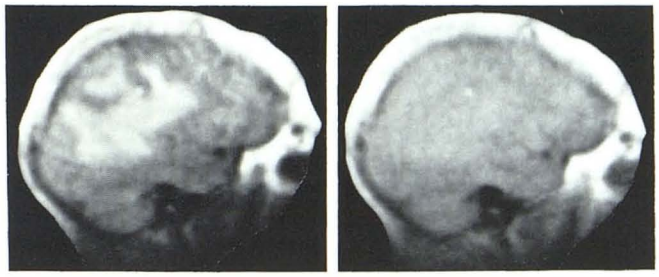
the presence of blood flow within a lesion can be established, since a zero signal is obtained with both sequences (fig. 1). When a zero signal is obtained on the MSSFP sequence and a high signal on the USSFP sequence, the tissue corresponds to pure water, its very long T_1 yielding the former signal and its high proton density yielding the latter (fig. 2).

Results and Discussion

It was first observed by Ambrose [6] that fat within a tumor has a very low CT attenuation value. This is frequently though not invariably associated with a high negative Hounsfield number. The presence of fat can be confirmed by observing a very high NMR signal with the same distribution as the low-attenuation area on CT; for example, in the epidermoid tumor shown in figure 3.

Occasionally the clinical context does not allow a precise distinction to be made on the basis of CT between an area of confluent calcification and hematoma when the CT attenuation value is compatible with either. On an NMR scan, however, the calcification will be invisible because of its low proton density, whereas the hematoma will yield a high signal (figs. 2 and 4). The inability to visualize calcification is a serious drawback since this is often a useful sign in discriminating between pathologic alternatives in intracranial mass lesions.

On the basis of studies in experimental animals, it appears that a prediction of the histologic tissue type in intrinsic tumors is not possible by NMR imaging. Nevertheless, some preliminary observations can be made about the information that can be obtained from both the NMR images and CT scans; these are listed in table 1. As with other spin sequences, more than one choice of parameter may be necessary to demonstrate the presence of a lesion. For example, an infiltrating glioma that was clearly demonstrated with the USSFP sequence was not visible when the MSSFP sequence was used (fig. 5). Some observers have noted that the differentiation of tumor margins from surrounding edema is not as clear-cut on



A B

Fig. 5.—Parasagittal NMR scans. Infiltrating glioma. Because T_1 value of this tumor is greater than 0.8 sec, it is clearly visualized with the unmodified SSFP sequence (**A**) but not visible with the modified sequence (**B**).

NMR as on contrast-enhanced CT scans. There may well be a place in NMR as in CT, for contrast media that delineate the damaged blood-brain barrier.

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