

Nuclear Magnetic Resonance (NMR): Background and Potential Impact on the Practice of Speech and Language Pathology

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When Tom Prescott asked me to speak about nuclear magnetic resonance (NMR), I thought he'd handed me a plum. After all, NMR has been described as "the most sophisticated probe of the human body developed to date" (Partain, James, Rollo, and Price, 1983). It has been called by some the most important diagnostic imaging development since the discovery of the x-ray. Some claim that it will replace computer assisted tomography (CT). Armed with such sweeping tributes, it seemed an easy job to summarize this diagnostic panacea that is going to tell us all we want to know about the relationship of speech and language neuropathologies to brain structure and function.

I realized that the task might be more formidable when, in a 1983 paper about the status of NMR imaging in Radiology, I read, "The idea of NMR imaging is exciting, but so was alchemy" (Kaufman, Tosteson, Crooks, Margulis, Herfkens, and Davis, 1983). Since that rude awakening, I've discovered that NMR is very complicated in principle and application, the precise meaning of much of the data it generates is not well understood, and its life as a diagnostic tool is so new that its specific implications for our understanding of speech and language pathologies are not yet clear. With those things in mind, I'd like to tell you a bit about what NMR is and review its uses, advantages, and disadvantages as a diagnostic and research method for imaging the brain. I'll also speculate a bit about how it is likely to contribute to our understanding and diagnosis of speech and language pathologies.

History

The concept of NMR isn't new. It was discovered in the 1940's, earned a Nobel Prize for Block and Purcell in 1952, and has become a standard tool for investigating matter in all forms in many chemistry and physics labs (Andrew, 1983). However, not until the early 1970's was it established that NMR scanning could be used to detect disease. Its development since then has been exponential.

Physical Basis and Principles of NMR

In NMR, the objects of study are the nuclei of atoms that have an odd number of protons. These are of interest because they have a property called "spin" (or magnetic moment) that makes them behave like small bar magnets spinning around their axes. The nucleus that has received the most attention in NMR is hydrogen, because it possesses this property of spin and is the most abundant atom in biological tissue. Consequently, hydrogen yields the strongest NMR signal.

If we think about the huge ensemble of hydrogen nuclei in the brain, we might imagine many of these tiny bar magnets rotating around their axes. Normally, their orientation at any point in time is randomly distributed and the net magnetization of the system is zero. If we then place the head in a strong static magnetic field like that induced by the superconducting magnets used in NMR, we can cause those spinning magnets to polarize or reorient

themselves with the external magnetic field. In a sense, this creates a state of equilibrium in which all the spins are oriented in similar fashion. This state of equilibrium can then be disturbed or "tipped" in a controlled way and in selected planes by applying a short burst or sequence of bursts of radio (RF) waves at a specific resonant frequency. Following the RF pulse(s), the disturbed nuclei will return, within a period of time, to their original equilibrium state. This return to equilibrium produces electromagnetic signals whose frequency and duration can be measured by a receiver and subsequently used to generate spatial coordinates and a visual image using methods similar to those employed for CT. The images generated by NMR depend on multiple influences, but they are primarily a function of hydrogen (or proton) density and the durations associated with the system's return to equilibrium following the RF pulses. These durations are usually referred to as T_1 and T_2 relaxation times. These relaxation times are the parameters which best distinguish among soft tissues because they are influenced by the presence of water content, lipids, protein and other tissue characteristics which influence the mobility of hydrogen nuclei. (For detailed explanations of the physical principles of NMR, see Partain *et al.*, 1983, and Kaufman, Crooks, and Margulis, 1981.)

NMR Images

What does an NMR image show us? In general, what we see is a reflection of the nuclear chemistry of the brain rather than its static tissue density, and for this reason the images are fundamentally different from those seen in CT. More specifically, NMR provides an image which correlates with anatomy and can (a) distinguish gray from white matter extremely well, (b) detect the presence of (e.g.) tumor, edema, atrophy, AV malformations, and hematoma, (c) identify the effects of demyelinating disease, and (d) potentially measure metabolism and blood vessel flow.

Figures 1-4 illustrate some NMR images obtained in a variety of planes. Figure 1 is a transverse slice through the temporal lobe. It demonstrates NMR's capacity to image the cerebral fissures and ventricles in detail, as well as capacity to distinguish cortical and subcortical gray matter from white matter.

Figure 2 is an NMR image in the sagittal plane, which is probably the most unique and anatomically impressive plane imaged in NMR. The posterior fossa is clearly imaged with good delineation of the cerebellum and its separation from the brain stem and occipital lobes. Among other areas clearly imaged are the pons, medulla, midbrain, corpus callosum, cingulate gyrus, subarachnoid space, and CSF cisterns.

Figure 3 is a high transverse slice in a patient with a negative CT scan during an acute exacerbation of multiple sclerosis (MS). The darkened area in the white matter region of the right hemisphere probably represents a huge MS plaque.

Figure 4 is a coronal slice in a patient with a negative CT scan, a mild aphasia, and a seizure disorder with a left temporal lobe focus. The whitened area near the tip of the left temporal lobe was felt to represent atrophy. This was confirmed during temporal lobectomy.

Advantages and Disadvantages of NMR

There are some disadvantages and a number of advantages associated with NMR. Some of these can be compared to CT, which seems to be the standard

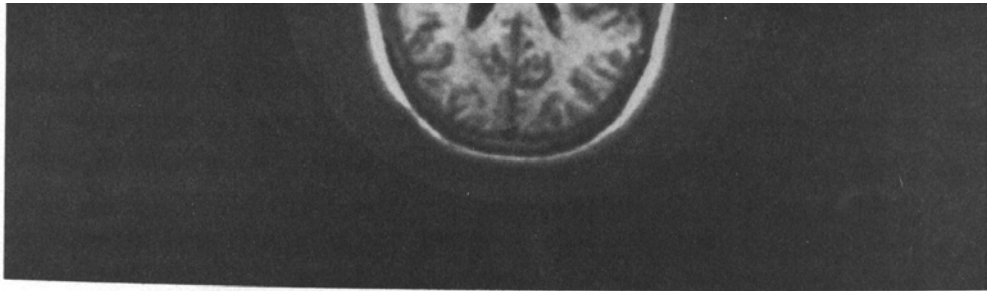


Figure 1. Transverse NMR slice through the temporal lobe.



Figure 2. NMR, sagittal plane.

against which NMR is being measured (James, Pickens, Rollo, Stephens, Erickson, Patton, Mitchell, Price, Partain, 1983). Very briefly, disadvantages include the following, many of which are likely to be overcome with further experience and research.

1. NMR is presently relatively unstandardized on parameters such as design, slice selection techniques, RF parameters, and imaging algorithms, making for difficulties in reliability and comparison from machine to machine and center to center (Saunders and Orr, 1983).

2. Because of its newness, interpretation is often difficult, and identifying the presence or absence of pathology and the nature of pathology is not always easy or possible.

3. The time necessary to acquire data is greater than that in CT.

4. NMR is not currently used under some conditions. For example, patients with pacemakers or metallic implants (Saunders and Orr, 1983) are not candidates for NMR.

5. Because of lengthy data acquisition time and a narrow gantry for the head some patients experience a feeling of claustrophobia.

6. NMR is expensive.

The advantages are several. They include:

1. NMR is noninvasive and does not employ ionizing radiation as CT does. Evidence thus far suggests no harmful effects of NMR exposure (Besson, Foreman, Eastwood, Smith, and Ashcroft, 1984; Saunders and Orr, 1983).

2. Unlike CT, it has very good resolution in transverse, coronal and sagittal planes.

3. Unlike CT, bone does not induce artifacts in the image. Because of this, the posterior fossa can be viewed in considerable detail.

4. Gray and white matter are distinguished quite well, better than in CT. This is because CT differentiation relies on a difference of only 0.2 percent between the specific gravity of gray and white matter. In contrast, NMR can make use of a difference of 15 percent in the amount of water in gray matter and white matter (Partain *et al.*, 1983). This difference in sensitivity also holds for other tissues, including the distinction between tumor and normal brain tissue.

5. NMR is sensitive to early changes associated with stroke. For example, there are data on primates showing that NMR detects changes secondary to edema and swelling as soon as 90 minutes after middle cerebral artery occlusion (Spetzler *et al.*, 1983). These and other data suggest that NMR will contribute to our understanding of the pathophysiology of CVA (Buonanno, Kistler, DeWitt, Pykett and Brady, 1983 a & b; Sipponen and Caste, 1983).

6. NMR is very sensitive to changes associated with demyelinating disease (e.g., Young, Hall, Pallis, Bydder, Legg, and Steiner, 1981).

7. NMR has potential for early detection of diseases in which chemical and physiologic alterations precede changes in anatomy (James *et al.*, 1983). This potentially makes NMR better than CT for this purpose.

8. NMR has great flexibility with regard to plane selection, RF frequency and pulse rate. This raises the possibility of disease/locus specific protocols.

9. In the future, NMR may be used to study metabolic processes and blood vessel flow. It is also possible that pathology-specific contrast agents will be developed and that these will greatly increase NMR's sensitivity to specific disease states (James *et al.*, 1983).

Implications

What are the implications of all of this? Because NMR as a clinical tool is so new, there is no literature to cite which demonstrates its specific application to our understanding of speech and language pathologies. I think, however, that we can anticipate that it will make certain important contributions.

1. NMR is likely to complement the contribution of CT to our understanding of the locus of lesions associated with aphasia. Its ability to distinguish cortical gyri and gray from white matter and deep subcortical structures, as well as locate infarcts and associated edema, may significantly increase and modify our current understanding of the anatomic correlates of aphasia, apraxia of speech, and other related disturbances.

2. The absence of radiation and knownside effects in NMR make it possible to monitor--at frequent intervals--changes in the brain which occur early post-CVA as well as through the course of recovery and treatment. Correlation of these data with changes in language behavior potentially will add to what we know about the time course and differential effects of factors like edema, mass effect, and neuronal death on recovery patterns in aphasia, apraxia, and dysarthria. NMR may help to define more precisely the boundaries of "spontaneous recovery" --a factor that has a profound influence on the conduct and interpretation of treatment efficacy studies.

3. NMR's sensitivity to changes associated with demyelinating disease is rapidly being established. From this standpoint, it will almost certainly add to what we know about the anatomic correlates of dysarthria in multiple sclerosis and the relationships among dysarthria type and severity, anatomy, and exacerbations and remissions of the disease.

4. It appears to me that NMR may make its most significant contribution to our understanding of the anatomic correlates of the central nervous system dysarthrias. Its capacity to image, without significant artifact, the posterior fossa opens the door to confirming what we have been assuming about the anatomic bases for many of the dysarthrias. It's important to recognize that the original dysarthria studies by Darley, Aronson, and Brown (1969) upon which so much of our clinical differential diagnosis of dysarthria is based, were conducted on patients grouped by well-documented clinical neurological symptoms but relatively limited anatomical verification. NMR would seem to provide an excellent opportunity for establishing where the lesions really are in patients diagnosed as having spastic, ataxic, or flaccid dysarthria of presumed cranial nerve nuclei origin, and mixed dysarthrias. NMR may help confirm, modify and establish boundaries for the localizing value of our differential diagnosis of the dysarthrias.

5. More speculatively, one suspects that NMR may enhance our understanding of the anatomic correlates of cognitive changes associated with dementing illness like Alzheimer's disease, particularly for those interesting patients beginning to show up in the literature and our offices with early and presumably focal language changes.

6. In the area of developmental problems, the noninvasive nature of NMR and its focus on biochemistry raises the possibility of its use in the never-ending search for neural correlates of childhood language and learning disabilities and so-called developmental apraxia of speech. One can also ask if NMR, because of its sensitivity to gray/white matter difference, might not serve as a useful measure of CNS maturity and a correlate of speech and language development (cf, Bydder, Steiner, Young, Hall, Thomas, Marshall, Pallis, and Legg, 1982).

Conclusion

As stated earlier, all of the above implications and applications are speculative. It's safe to assume, however, that NMR will be used as a tool in anatomic correlation studies of aphasia, apraxia, and dysarthria with the potential for significant increases in our knowledge about the anatomy and time course of those disorders. We need to recognize, though, that the significance and specific meaning of NMR is just beginning to be understood. It promises to become an imaging method with some special strengths and applications to speech and language pathology. It certainly isn't going to tell us all we want to know, but it's a long way from alchemy.

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