

DIASONICS

NMR IMAGING

**QUESTIONS &
ANSWERS**

DIASONICS NMR

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INTRODUCTION

Within a short period of time, the performance capabilities of NMR imaging equipment have advanced dramatically. This progress has occurred primarily in the physics laboratory on prototype imagers. Clinical experience has been rather limited due to shortness of time and unavailability of equipment.

Because of the exciting clinical potentials of this new modality, many leading institutions are contemplating initiation of clinical research in NMR imaging. The question arises: what equipment capabilities are best suited to satisfy near term research objectives and at the same time allow the unit to meet future applications and function in a clinical diagnostic environment?

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1. Should an NMR system have a superconducting or resistive magnet?

2. Will NMR imagers undergo generations of development as did x-ray CT scanners?

Superconducting magnet systems produce higher quality images than do resistive magnet systems due to their higher field strengths and better stability. For clinical assessment of the capabilities of NMR imaging, only a high performance instrument will provide unequivocal results. It appears that resistive magnet units will prove to have limited diagnostic applicability compared to superconducting systems. However, there are areas of the world where, due to a lack of cryogenics, resistive units may be the only feasible way to operate an NMR imager.

While resistive magnets are less costly initially, they require high power and closely regulated power supplies, which likely will be prone to costly reliability problems. A superconducting magnet basically has no moving parts and no electronic components to fail. It is an intrinsically reliable device. Additionally, operating costs for electrical power needed for resistive units can be greater than cryogenic costs needed to maintain superconducting magnets.

By going directly to superconducting magnet technology, Dasonics has avoided the path taken by other development programs. Resistive magnet imagers represent first generation technology and superconductive magnet imagers are second generation technology. The knowledge gained from the Dasonics clinical prototype will be incorporated into all future units, which will represent third generation technology. In this manner, much of the risk of rapid technological obsolescence will be eliminated during the development stage rather than by having to replace installed clinical equipment.

3. What capabilities should an NMR imager's computer system have?

The data processing and display requirements of an NMR imager are already greater than those of x-ray CT, primarily for two reasons. First, NMR images depend upon four parameters (hydrogen density, T1, T2 and flow rate), so that multiple images and calculations may be required for each section. Second, efficient imaging requires that multiple sections or volumes be imaged simultaneously. The computer system must be capable of meeting these requirements.

Efficient utilization of the imager demands a powerful computer system, for both high speed image processing and independent display capabilities. Moreover, since the imager's performance is likely to continue to improve, the computer system should be flexible to accommodate change. Machine performance should not be limited by inadequate computer capabilities.

4. Why are NMR imaging times so long?

Unlike other imaging modalities, NMR involves molecular relaxation processes, which are inherently slow. Because of this, high quality NMR images require a few minutes to produce. To make NMR imaging clinically practical, multiple cross-sections must be imaged simultaneously. This is the fastest NMR imaging technique.

5. *Will NMR imaging times be reduced in the future?*

Significant improvements in imaging time — for fixed spatial and contrast resolution — are unlikely to occur. Basically, imaging time is limited by the physics of the imaging process. For example, it takes 64 seconds to accumulate enough data to make an image with 128 lines and a sequence interval of 0.5 sec (which is an interval time chosen for high contrast). To further improve signal-to-noise, this process is repeated four times in one of the standard operating modes of the Dasonics clinical prototype NMR Imaging System. Thus, the image time for this mode is 4.25 minutes, with five sections imaged simultaneously in this time. In its present fastest high resolution operating mode, the Dasonics NMR Imager can image 15 sections simultaneously in 6.5 minutes — an average time of 26 sec/section.

Reducing this imaging time without sacrifice in contrast or spatial resolution can be achieved only through improvement in the signal-to-noise ratio or by using a shorter sequence interval (T1 parameter of the imager). Since the human body is already the major noise source in the Dasonics NMR Imaging System — and obviously cannot be eliminated — significant improvement is not likely to occur. In addition, sequence intervals of 0.5 sec or longer have been empirically found to provide the contrast required for clinically diagnostic imaging.

6. What is NMR patient throughput time expected to be?

7. What are the spatial resolution limitations of an NMR imager?

*T*his question cannot be answered definitively until protocols are established. However, if the equipment cost of an NMR imager is comparable to — or somewhat greater than — an x-ray CT scanner, NMR patient processing times must be made comparable to or better than CT. Since high resolution NMR imaging is an inherently slower process than x-ray CT, a clinical NMR unit must be capable of imaging many sections simultaneously to achieve an image time per section that is comparable to or better than x-ray CT. For example, the Dasonics NMR Imaging System can image 15 sections simultaneously in a total image time of 6.5 minutes, which is faster than x-ray CT operation.

*T*here are direct relationships among spatial resolution, contrast resolution and image time, and tradeoffs may be made among these parameters by the user. Spatial resolutions of 1.7mm for the head, and (depending on body thickness) 1.7, 2.1 or 2.5mm for the whole body are obtained on the Dasonics NMR Imaging System with high soft tissue contrast and imaging times of four to 13 minutes for up to 15 slices imaged simultaneously. Area of interest imaging at submillimeter spatial resolution is achievable and meets high resolution imaging requirements for most pathologies.

8. How important is the imager's ability to provide T1 and T2 information?

9. How is T1 and T2 information obtained?

*E*xtensive animal studies have shown that both T1 and T2 contrast are required to maximize detection of pathology. A number of lesions have been identified: those which have high T1 and high T2 contrast; those which have high T1 and low T2 contrast; and those which have low T1 and high T2 contrast. Preliminary confirmation of this has been shown in human imaging as well. If tissue characterization is demonstrated, it will be on the basis of both T1 and T2 as independent variables. Therefore, an NMR imager should be capable of efficiently and effectively providing T1 and T2 values for each pixel. Moreover, T2 values should be obtainable without re-imaging of the same cross-section.

*T*he T1 and T2 information is obtainable in two ways: from "intensity images" and from "calculated images." Different imaging techniques performed on the same imager produce images which have different degrees of tissue contrast. These images are analog maps of the NMR signal received by the antenna and are called "intensity images." The inversion recovery technique produces images which have high T1 contrast, but virtually no T2 information. Spin echo techniques produce images with both T1 and T2 contrast. An NMR imager should be capable of producing images of comparable spatial resolution with either technique. However, for many pathologies, the Diasonics clinical researchers report that the contrast resolution is clearly better with the spin echo technique.

10. *Can NMR do more than imaging?*

In order to obtain explicit T1 and T2 values, a "calculated image" must be derived. This is done by the imager's computer system using the data contained in the "intensity images." On the Diasonics NMR Imaging System, for instance, explicit computation of T2 tissue characteristic values are obtainable from two simultaneously generated intensity images with no penalty in imaging time. Explicit computation of T1 values requires imaging a section twice. Estimated T1 images are calculable without reimaging.

The T1 and T2 relaxation times depend upon the local physical and chemical state of the tissue. Thus, the contrast in an NMR image represents more than just morphological information. However, not enough is known at present to make assessment of physiological information from an NMR image possible. Although the promise of achieving physiological information from NMR images is exciting, extensive research is required to determine this capability.

11. *Can a hydrogen NMR unit image other elements?*

The hydrogen NMR signal from the human body is greater by a factor of 10^3 or more than the NMR signal from any other element. Consequently, only hydrogen can be imaged at high spatial resolution in clinically reasonable image times. Thus, anatomic detail will be obtained from hydrogen NMR images.

Since it is impractical to change magnetic field strengths quickly, a clinical NMR imager should operate at a strength suitable for hydrogen. A 3.5kG superconducting magnet, such as the one used in the Diasonics clinical prototype, was developed to fulfill this requirement. If it is determined clinically that imaging of other elements — such as sodium or phosphorus — is useful, the field strength and stability of a 3.5kG superconducting magnet should be sufficient to allow “area of interest” imaging of these elements. This could be accomplished by reducing the NMR signal frequency of the Diasonics NMR Imaging System. The resulting images could be displayed as superimposed over the corresponding high resolution hydrogen images of the same sections to improve spatial visualization.

12. Can an NMR device function as both a hydrogen imager and spectroscopy unit?

13. Can images be obtained in sagittal and coronal planes?

The magnetic strength and uniformities required for hydrogen imaging and for spectroscopy are greatly different and clinically incompatible. NMR imaging of hydrogen requires a uniform background magnetic field (which extends over the volume to be imaged) plus superimposed, switched, linear gradient fields for spatial discrimination. Spectroscopy requires a much higher field strength with a very uniform magnetic field which extends only over the limited voxel to be analyzed. Attainment of both these conditions with the same magnet necessitates extensive adjustments to the magnet each time one switches modes of operation. This is a time consuming process not practical in a clinical environment. Moreover, a magnet capable of both imaging and spectroscopy is significantly more expensive than a hydrogen imaging magnet.

Direct imaging in sagittal and coronal planes without the necessity of reconstructing from multiplanar transverse images is routinely done in NMR imaging. Thus, NMR is able to display certain anatomical structures and relationships more clearly than previously possible. This should be especially well suited to imaging the brain, spine, pelvis, joints, and cardiovascular system.

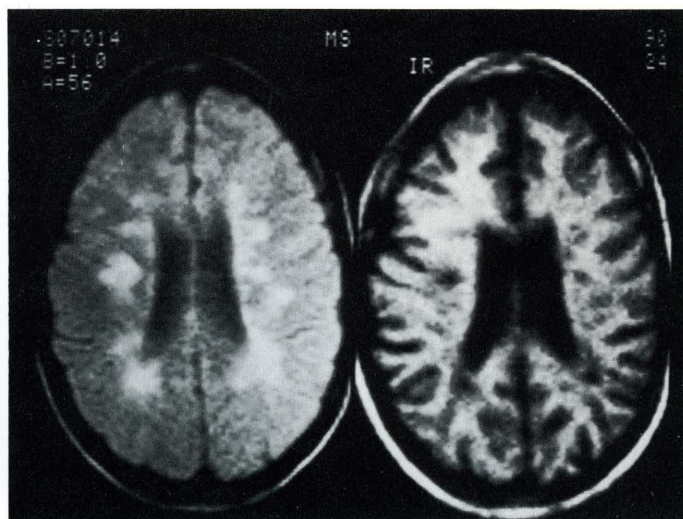
14. What special facility requirements does NMR impose?

*I*n many respects, facility requirements for a superconductive NMR imager are similar to those for an x-ray CT scanner. However, there are three significant differences due to the magnet, one associated with installation and two with the permanent placement. Installing a superconductive magnet requires large access — 8' wide by 9' high for a 3.5kG unit. When installed and operational, the magnet system, including bed and cryogenics, weighs 14,000 lbs., so floor loading must be considered. But by far the most severe restriction is imposed by the fringe field of the magnet. A 3.5kG magnet can interfere with electron devices (for example, a TV monitor) for distances of up to 35 feet. Although a complete NMR imager like the Dasonics NMR Imaging System can be installed in 1100 sq.ft., the area over which the magnetic field exceeds 1.5 Gauss is 3,000 sq.ft., and no large moving vehicles (cars, trucks or elevators) can be located within 35 feet of the magnet.

15. What will an NMR imaging system cost?

*T*he cost of an NMR imager is directly related to the magnet and computer system used. As discussed, both a superconducting magnet and powerful computer system are required. While it is premature to accurately predict production costs should NMR imagers be marketed, current price estimates for an imager are \$1,500,000 or more. Room preparation costs can vary depending upon the specific circumstances of the purchasing institution—estimates of \$150,000 to \$250,000 have been obtained for the Dasonics NMR Imaging System.

*Multiple sclerosis imaged
by spin echo and inversion
recovery techniques.*



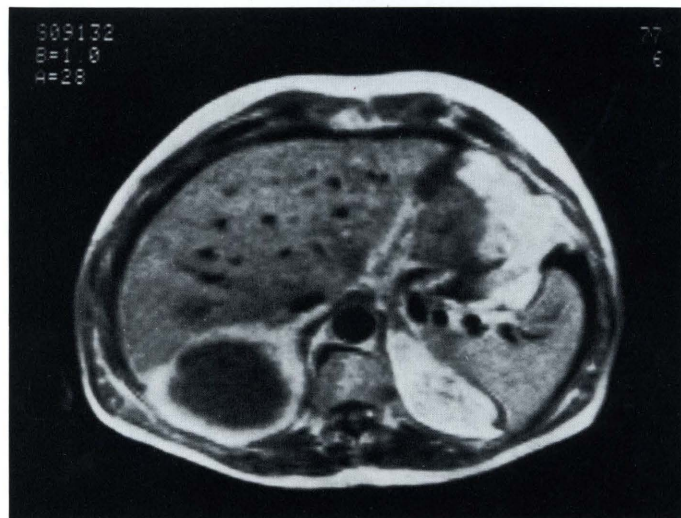
Sagittal image of head.



*Sagittal image
through neck showing
spinal cord tumor.*



*Body image showing
right renal cyst.*



Images obtained at the Radiologic Imaging
Laboratory, University of California —
San Francisco (UCSF)

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...IT'S WHERE IMAGING IS GOING

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