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Professor Herman Carr in Letters to the Editor *Physics Today* January 1993

Professor Carr, a distinguished early pioneer of NMR and a collaborator of Purcell's, is stating here that the use of the magnetic field gradient for spin mapping was not new but was known to many (e.g. Gabillard (22), Andrew (21), Hahn, Carr and Osheroff - references 1, 2, 3 in his letter) in the 1950's.

What Professor Carr has said was new was the vision that a "useful" spin map of an interior medical image was "obtainable". It is Dr. Damadian who supplied the vision for the "useful" map that was "obtainable". He showed its usefulness by uncovering the relaxation differences between tissues, cancer in particular, that made the spin map "useful." He showed it was obtainable by demonstrating the relaxation differences from one tissue to the next that would permit mapping and make the maps fruitful. It was Dr. Damadian who also demonstrated that it was a "goal worth pursuing" in Professor Carr's words, by showing that a disease as important as cancer could be distinguished from normal by its tissue relaxations. Indeed Lauterbur sets forth the "goal worth pursuing." As he wrote in his laboratory notebook at the time he first memorialized his own idea and had it witnessed, "The distribution of mobile protons in tissues, and the differences in relaxation times that appear to be characteristic of malignant tumors [R. Damadian, *Science*, 171, 1151 (1971)], should be measurable in an intact organism" (Mattson and Simon, <u>The Pioneers of NMR and Magnetic Resonance In Medicine: The Story of MRI</u>, 1996, Bar-Ilan University Press, Appendix, Chapter 9, pg. B3, Document 3.1a).

Felix W. Wehrli's article focuses on the development of clinical nmr imaging from the early 1970s on. One paragraph of the article might be interpreted as implying that a radically new component—the generation of spatial maps of spin distributions—was first added to nmr technology in 1973 with the superposition of "magnetic field gradients onto the main magnetic field to make the resonance frequency a function of the spatial origin of the signal." A radically new component *was* introduced in the 1970s, but it was [redacted] the basic concept of spatial locali[redacted] and spin maps, which had already been introduced for one (spatial) dimension in the early days of nmr.

The new component of the 1970[redacted] perhaps best described as the [redacted] that a [redacted] spin map as complicated as an [redacted] medical image was in principle [redacted] and was a [redacted] The remark[redacted] of excellent medical images in two and three spatial dimensions resulted from the foresight and determination of a small group of persons including Paul C. Lauterbur, Peter Mansfield, Raymond Damadian and others, who were soon helped by a rapidly increasing number of creative colleagues from a wide range of disciplines. This development was also grounded in the spectacular gains that had recently been achieved in signal sensitivity as well as in computer speed and memory.

To the best of my knowledge the idea for superimposing a magnetic field gradient onto the main homogeneous magnetic field had its origin in the self-diffusion effects Erwin L. Hahn observed on his spin-echo envelopes as nuclei diffused through the small residual inhomogeneity of his main magnetic field.[1] Based on this clue, Edward M. Purcell and I intentionally superimposed a strong magnetic field gradient onto the main field, giving a linear dependence of the resonant frequency on the spatial position of the diffusing nucleus.[2] The enhanced diffusion effect then enabled us to make accurate quantitative measurements of the self-diffusion coefficient for suitable fluids.

In my 1952 Harvard thesis I described a one-dimensional phantom. It was constructed to produce an nmr response similar to the newly discovered chemical shift in ethyl alcohol. I used the imaging concept, with its [redacted] gradient and [redacted] to relate [redacted] frequency-encoded spatial structure of the phantom to the nmr response in the time domain. Similar one-dimensional phantoms are currently used in mri textbooks to introduce the imaging concept. The most notable physics application of a simple one-dimensional spin map was in the discovery[3] at Cornell University of the superfluid states of helium-3. Today's two- and three-dimensional medical images, envisioned by the pioneer workers of the 1970s, involve complex pulse sequences and transformations now attainable with modern computers.

References

1. E. L. Hahn, Phys. Rev. 80, 580 (1950).
2. H. Y. Carr, E. M. Purcell, Phys. Rev. 94, 630 (1954).
3. D. D. Osheroff, W. J. Gully, R. C. Richardson, D. M. Lee, Phys. Rev. Lett. 29, 920 (1972).

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