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From Numbers to Pictures: The Development of Magnetic Resonance Imaging and the Visual Turn in Medicine

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Magnetic Resonance Imaging (MRI) occupies an important symbolic space in contemporary science and popular culture. MRI—used to create anatomical images of the body—is considered the gold standard in imaging diagnostics by policy makers and medical practitioners (see Figure 1). In 2003, Drs Paul Lauterbur and Sir Peter Mansfield—two developers of MRI technology—were awarded the Nobel Prize in Physiology and Medicine, signalling the importance of the technique to the broader scientific community. MRI is also featured in mass media and is included in newspaper and magazine articles, films, and television dramas and detective shows such as *Law and Order* and *ER*. Today, MRI images and technology are central to medical practice, identities of health and illness, and social life more generally. Yet there is nothing natural or inevitable about how MRI is presently designed or interpreted.

In this article, I discuss how the name of the technology, the design of the machine, and the representation of MRI data were debated and transformed during its initial development in the 1970s and after its introduction to clinical medical practice in the 1980s. During these periods, research scientists, in response to culturally embedded interactions with other scientists, radiologists, and prospective patients, creatively appropriated and adapted machine design, the appearance of data output, and terminology to collectively produce what is now known as MRI. MRI technology transforms the inner body into a picture. Its creation occurred in relation to the socio-technical turn towards visualization via the development and expansion of television, film, video, computers, and other imaging techniques.

This article explores how choices that led to the development of MRI technology relate to two broader cultural contexts: the socio-technical turn towards visuality and a new emphasis on nuclear technologies and knowledge that occurred in the twentieth century.

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Drawing on the technology innovation literature, I address the following questions: how did research scientists choose to represent MRI data in changing ways—from numbers to pictures of specific kinds? How did these decisions, as well as issues of professional control, relate to the broader cultural context of visualization? And, finally, how did the development of MRI relate to both scientific work in and shifting public perceptions of atomic research? In answering these questions, I show that scientists select from a range of possibilities to create a new technology and that these choices can only be understood through sustained discussion of larger cultural priorities and conventions.

Theorizing Technological Innovation

The research presented here engages and contributes to the literature on the development and stabilization of medical imaging technologies (see, for example, Blume, 1992; Kevles, 1997; Pasveer, 1989; Yoxen, 1987). While each author focuses on different components of imaging innovation, the imaging technology literature taken as a whole shows how the development and stabilization of particular imaging technologies emerged from interactions among relevant social groups, interpretations of data, and organizational practices and structures. Stuart Blume concentrates, for example, on the structure of the relations between radiologists and imaging machine manufacturers, and shows how the strength of this relationship influenced the development and diffusion of diagnostic imaging technologies such as MRI and computerized axial tomography (CT) (Blume, 1992, p. 54). Edward Yoxen, in contrast, focuses solely on the early years of ultrasound research and explores how the appearance of the ultrasound image and machine design were stabilized.

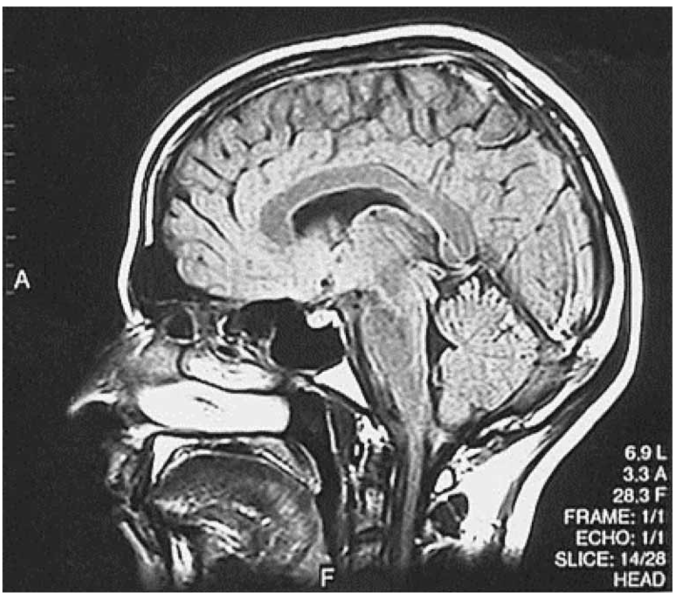

Figure 1. MRI scan of a normal brain. *Credit*: Spencer S. Eccles Health Sciences Library, University of Utah Health Sciences Center, Salt Lake City, Utah; www-medlib.med.utah.edu/WebPath/histhtml/neuranat/mrifs06.html

He contends that stabilization was a multilinear, overlapping process—'one in which different strategies were pursued with mixed results . . . and the decisions to continue as before, to diversify, or to abandon the work were made by reference to a whole set of factors' (Yoxen, 1987, p. 300). Such factors included perceptions of technical constraints and possible clinical applications; the results of experimental evidence alone were not enough to cause researchers to radically change their agenda (Yoxen, 1987, p. 302).

The medical imaging innovation literature taken as a whole shows how successful representational strategies and techniques emerge from multiple possibilities and social interactions. Access to resources, professional authority, and institutional relations all influence innovation outcomes, co-constituting the artefact developed. Yet, while earlier work illuminates how innovation is a social (and not a predetermined or inevitable) process, it does not delve into the relationship between the development of a particular technology and the contemporary emphasis on images and visuality. The literature also does not fully explore how scientific interest in and public discussions about nuclear technologies shaped imaging technology research and development.

The lack of attention to particular forms of culture is also found in broader theories of technological innovation. General social scientific theories of technological change, like the more specific imaging technology literature, typically trace networks between interest groups, laboratories, industries, and institutions (Latour, 1987; Bijker, 1995; MacKenzie and Wajcman, 1999). In doing so, this work also shows that innovation is not the linear or predetermined process that popular historical accounts usually construct, and is instead the result of alliances, contingencies, and one's location within social, economic, and political hierarchies. However, as Nelly Oudshoorn (2003, p. 11) points out, these theories 'conceptualize scientific and technological change as a social process and not as a cultural process'. In *The Male Pill: A Biography of a Technology in the Making*, Oudshoorn insists that the 'cultural' construction of technology be taken into account. By this, Oudshoorn means that cultural belief systems, conventions, and identities are part of technological change. Her recent research investigates how a particular aspect of culture—gender identities—influenced the creation of networks and the development (or lack of development) of the male birth control pill. Therefore, cultural contexts of science differ from social networks, and should be carefully interrogated.

This article demonstrates how the twentieth century emphasis on technologically-produced images influences innovation processes. Throughout the 1900s, the use of pictorial images proliferated in private and public spaces in the United States and Europe (Clarke, 2004; Mirzoeff, 1998; Sturken and Cartwright, 2001). The transformation of daily life into visual form, while gaining momentum throughout the last century, intensified in the 1980s and 1990s as video cameras and recorders, Xerox machines, and computer visualization technologies became more available. Now referred to as 'visual culture' or 'scopic regimes', the production and incorporation of the visual into all aspects of life is well-recognized by theorists and cultural critics.[1] In this article, I explore how the turn toward visualization provided ideological and technological support for the decision to turn the numerical data obtained from MRI machines into an image; the transformation of the name of the technology from Nuclear Magnetic Resonance (NMR) to Magnetic Resonance Imaging (MRI); and the growing authority of radiologists.

The twentieth century fascination with the atom also provided an important context for the development of MRI technology. Physicists' research into the spin and movement of nuclei in the first half of the 1900s produced the basic scientific knowledge used in contemporary MRI machines. Backlash against nuclear power and weapons in the 1960s and 1970s shaped interpretations of the emergent technology and supported name changes and machine design that hid its nuclear roots. Finally, the profound cultural turn toward visualization cemented the shift from numerical measurements and nuclear terminology to a visual form with new language that highlighted 'the image' component. As Haraway (1997) and others have shown, the influence and prestige of physics and nuclear research waned in the 1980s as biology, genetics, and imaging techniques gained prominence in both scientific and popular cultures.[2] Two crucial components of culture—a growing public concern about the safety of nuclear power and weapons and the transition away from nuclear knowledge and physics to visualization technologies and biology—therefore helped co-produce the final form of MRI.

Materials and Methodology

My analysis is based on in-depth interviews and archival research. First, I conducted in-depth interviews with key scientists involved with the development of MRI technology. In fall, 2000 I interviewed Paul Lauterbur, Raymond Damadian, Larry Crooks, and John Mallard, four scientists involved in the creation of MRI technology, about design and data decisions made in the 1970s and 1980s. Each researcher was trained in a different scientific profession and was part of a different research site. Chemist Paul Lauterbur headed a laboratory at the State University of New York in Stony Brook, New York; physician Raymond Damadian directed the research laboratory at Downstate Medical Center in New York; engineer Larry Crooks worked with the University of California at San Francisco research team; and physicist John Mallard led a laboratory at the University of Aberdeen in Scotland. While other scientists also contributed to the development of MRI technology, these four diverse researchers provide insight into the context and decisions that shaped early MRI research. I used open-ended questions to interview each scientist, and all interviews were tape-recorded and transcribed.

Second, I critically analyzed scientific papers and patents related to MRI, newspaper articles published during the 1970s and 1980s, and secondary historical accounts. These materials were used to understand the scientific innovations, political pressures, and social actors and networks involved in the development of MRI technology. I also coded historical accounts for reoccurring themes and omissions. Examining how its creation is typically framed, I found that a sustained discussion of cultural contexts was often missing from standard histories. Analysis of both the archival materials and the in-depth interviews provide the data for this particular re-writing of the development of MRI technology.

An 'Imaging' Machine?: Nuclear Physics and the Development of MRI

Now associated with biology, medicine, and imaging, the ideas that provide the foundation for MRI technology are rooted in early 1900s investigations of the internal structure of the atom and the rise of physics in twentieth century scientific practice (Kevles, 1987). An understanding of the centrality of nuclear physics to MRI development provides insight into how this technology produces anatomical images, and, in doing so, complicates common perceptions of it as an *imaging* apparatus. MRI, despite its current construction as a visualizing technique, does not produce anatomical images in a straightforward fashion, nor does it use X-ray techniques to create pictures of the internal body. Instead, it is used to numerically measure how hydrogen nuclei absorb and release energy in response to particular frequencies. Each numerical value is then coded and transformed via computer software into a component of an image. These reconfigured numerical measurements are compiled to create an anatomical picture of the inner body. MRI thus initially produces numerical values that refer to the energy absorption and emission of hydrogen nuclei; anatomical pictures are not produced at the outset, but are instead created through the translation and compilation of numerical values via computer software.

Nuclear Magnetic Resonance

The understanding of nuclei as a site of energy absorption and emission builds on nuclear magnetic resonance (NMR) research, a scientific area of inquiry developed in the first half of the twentieth century. The term 'nuclear magnetic resonance', coined by physicist Isidor Rabi in the 1930s, describes how nuclei of atoms absorb and release energy in response to specific frequencies when placed in a magnetic field (Wehrli, 1992, p. 34). This process is similar to that of a tuning fork. If a person strikes a tuning fork tuned to a particular frequency, other tuning forks in the vicinity tuned to the same frequency will pick up the energy from the humming tuning fork, start to vibrate, and emit a sound. The nucleus of an atom does the same. In response to a particular frequency, the nucleus of an atom will absorb energy and then relax by emitting energy. Since different atoms (or the same atom in different environments) have different relaxation rates, this information can be used to identify the composition of a molecule; in the case of MRI, the machine measures how hydrogen nuclei absorb and release energy, which in turn provides knowledge about anatomy in the body.

The theoretical ideas that gave rise to nuclear magnetic resonance (NMR) research are often traced to Austrian physicist Wolfgang Pauli's predictions about motion and magnetic fields. In 1924 Pauli theorized that the nucleus of an atom spins around on its axis. Drawing from previous research on energy, Pauli speculated that the movement of this spin must create a magnetic force around the nuclei. The portion of space around the nuclei created by this force is called a magnetic field or a magnetic moment (Grant and Harris, 1996, p. 3).

Pauli's theoretical work sparked empirical research that documented and measured the spin of nuclei. Physicist Isidor Rabi transformed Pauli's theories into technique. In the early 1930s, Rabi designed an apparatus that used magnets and atomic beams to show that the nuclear spin did actually exist (Mattson and Simon, 1996, p. 60). After this success, Rabi continued to try and develop a way of directly measuring the magnetic moment of a nuclei. Rabi's breakthrough came after Cornelius Gorter visited his lab at Columbia University in 1937. Gorter suggested that Rabi shift the design of his machine to include an oscillator, which would create a much smaller magnetic field through the use of radio frequency waves (Mattson and Simon, 1996, p. 66). Rabi and his team then used radio frequency waves and a changing electromagnetic field and learned that the nucleus of an atom will resonate in response to a specific frequency.[3]

Rabi's ideas and methods were crucial to the development of knowledge about nuclear magnetic resonance and still inform the construction of contemporary MRI machines. His experiments, however, focused on the detection of NMR in isolated molecules. The next two decades of research would develop the theories and tools necessary to measure nuclear magnetic resonance in bulk materials.

In the 1940s and early 1950s physicists continued to develop their understanding of NMR, laying the foundation for later applications of NMR techniques in health care. During this time, two physicists, Edward Purcell at MIT and Felix Bloch at Stanford University, independently developed techniques that allowed for more precise measurements of nuclear magnetic resonance in bulk materials. Their work, for which they were jointly awarded the Nobel Prize in Physics in 1952, provided a more in-depth understanding of the way the spin of nuclei absorbed and released energy (OTA, 1984, p. 4). Bloch, in addition to this work, also developed a series of equations that produced two different measurements, T1 and T2 relaxation times; these relaxation times provided nuanced information about the absorption and emission of energy by protons (Mattson and Simon, 1996, p. 353). Other physicists, such as Nicolaas Bloembergen and Erwin Hahn, further created techniques and theories that helped turn this relatively theoretical knowledge into practical knowledge; this knowledge was applied toward the production of tools useful beyond the physics laboratory.

While efforts to use this technology for medical diagnosis did not occur until the early 1970s, several shifts are important to the move from research science to clinical practice (Kevles, 1997, p. 177; Lauterbur, 1996, p. 447). NMR, now a commercially available technology, expanded into the realm of chemistry in the late 1950s (Blume, 1992, p. 191). This move marked the slow transformation of NMR into a visualizing technology—one that produced pictorial representations as well as numerical values. Chemists primarily used NMR to identify the structure of molecules. Research showed that each type of molecule had its own unique frequency at which resonance occurs. The property of resonance at a particular frequency allowed chemists to use NMR as a way to identify the types of molecules present in a particular substance thereby analyzing the exact makeup of complex substances. Chemists represented the information produced by NMR as lines with peaks on a graph. This form of representation was used to represent different frequencies, and became the standard way of portraying the information within chemistry.

Beyond chemistry, some researchers began using NMR techniques to measure blood flow and muscle movement in live animals. This work, however, remained marginal. It was in the 1970s that NMR research firmly shifted to the realm of medical applications.

Constructing a Medical Technology

During the early 1970s, two Americans, physician Raymond Damadian and chemist Paul Lauterbur, and British physicist Peter Mansfield each independently tinkered with existing NMR techniques, looking for ways to extend its applications. Demonstrating how science is culture, each man's research was shaped by his professional training and his location within broader cultural contexts.

One of the first to explore how to use NMR techniques in medical practice, Raymond Damadian, a physician at the Downstate Medical Center in New York, experimented with using NMR techniques to diagnose cancer; he hoped that this new procedure could replace surgery and biopsies in cancer care. Damadian's choice of cancer was not arbitrary, but was shaped by the culture of the early 1970s in the United States where cancer was constructed as a central social problem. In 1970, the US Senate evaluated the state of cancer research, and, after doing so, recommended that the diagnosis and treatment of cancer should become a national priority. Continuing to emphasize cancer, in his State of the Union message on 22 January 1971, then president, Richard Nixon, proclaimed that 'The time has come in America when the same kind of concentrated effort that split the atom and took man to the moon should be turned toward curing this dread disease. Let us make a total national commitment to achieve this goal'. At the end of that same year, Nixon signed the National Cancer Act, and encouraged researchers to come up with a cure for cancer in five years. The visibility of this legislative act was high; the popular press featured articles on what became known as Nixon's 'War on Cancer'. Research money became available and scientists were enrolled to find ways to detect and understand cancer.

As an American physician, Damadian's clinical attention, like many American scientists and physicians at this time, was focused primarily on cancer. In an effort to develop a diagnostic procedure for cancer that did not require surgery, Damadian decided to use NMR to analyze the differences between cancerous and normal tissue. Building on previous research that showed cancer cells filled with water, Damadian hypothesized that 'it would be possible to detect the difference between a cancerous cell and a normal cell purely from its chemistry' and decided to use NMR techniques to do so (Kleinfield, 1985, p. 18). In his research, Damadian placed normal and cancerous tissue from rats in a NMR apparatus. The technology measured the time it took for the hydrogen nuclei in the tissue to absorb and release the energy from the radio waves. Damadian found that 'cancerous' and 'normal' tissues had different measurements, i.e. T1 and T2 relaxation times. Hopeful that he had discovered an important diagnostic technique, Damadian published this research in the 19 March 1971 issue of *Science* under the title 'Tumor Detection by Nuclear Magnetic Resonance' (Damadian, 1971).

Damadian also filed a patent that described a full body NMR scanner (see Figure 2). The patent application 'Apparatus and Method for Detecting Cancer in Tissue' was filed on 17 March 1972 and eventually issued in 1974 (Mattson and Simon, 1996, p. 668). The patent covered the use of NMR on both excised tissue samples and living human bodies (Mattson and Simon, 1996, p. A15). In both the article and the patent Damadian makes no mention of turning the NMR data into an anatomical picture; the information obtained about the body through NMR technology was portrayed as numbers.

Damadian's article in *Science* sparked interest. Concern about cancer was prevalent among the public, government officials, and in scientific communities. Researchers, like Leon Saryan, grabbed hold of Damadian's work and tried to replicate his results. In early September 1971, Saryan worked on this project at NMR Specialties in New Kensington, Pennsylvania (Hollis, 1987, p. 138). While at this laboratory, chemist Paul Lauterbur watched Saryan's research and imagined different uses for the information produced by NMR (Lauterbur, 1996, p. 447). Describing his impression of Saryan's work, Lauterbur explained:

> Although there were clear differences between samples taken from rat hepatomas and those removed from other tissues of the animal, there seemed to be no plausible explanation for the differences, nor did it seem likely to me that one more method of characterizing biopsy specimens would have much medical impact. However, even normal tissues differed markedly among themselves in NMR relaxation times, and I wondered whether there might be some way to noninvasively map out such quantities within the body (Lauterbur, 1986, p. 1899).

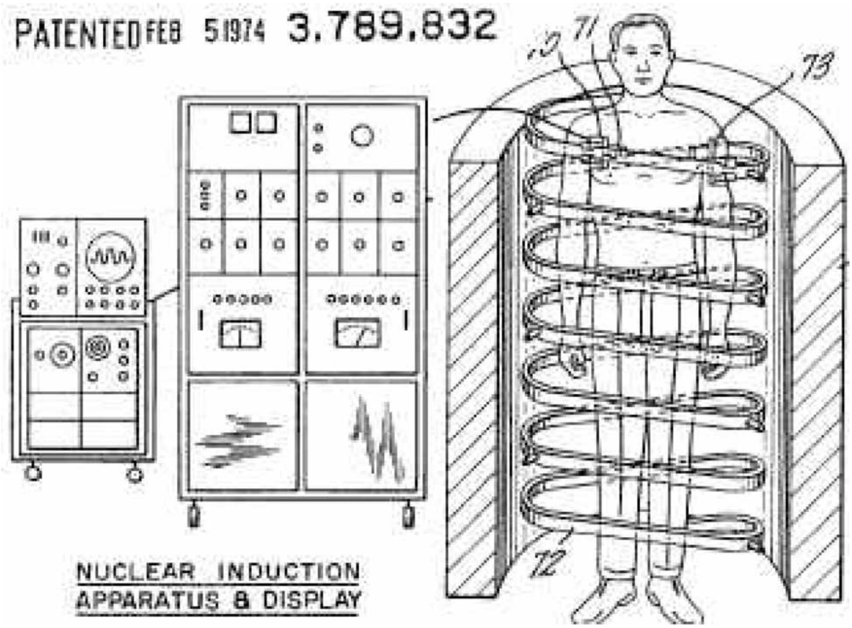

Figure 2. Damadian's patent filed on 17 March 1972. *Credit*: http://www.fonar.com/pdf/doc_7.pdf

Intrigued, Lauterbur continued to think about how normal tissue relaxation times differed. He decided this information could be used to make a new technology—one that would create anatomical pictures, or what Lauterbur referred to as 'maps' of the inner body. In what is now recognized as an important innovation, Lauterbur decided to use a gradient, which is a coil that creates a second magnetic field, in addition to a large magnet, to produce this type of information. This technique initially created numerical data that demonstrated the location of the signal emitted by nuclei. This data, Lauterbur suggested, could then be coded and transformed into an anatomical picture of the internal body.

The decision to produce anatomical images shifted NMR use in an important, new direction even as it simultaneously drew upon what Charles Goodwin (1994) calls Lauterbur's professional vision. In his analysis of archaeologists and expert witnesses, Goodwin shows how professionals learn, through a process of interaction with colleagues, the material world, and events, to order and represent the world in a occupationally specific manner. This 'professional vision' shapes how one highlights, ignores, and thus portrays aspects of objects and relations. Lauterbur, as a chemist, learned through interactions with colleagues to organize and produce the physical world using a particular set of methods and representational strategies. Although chemists produce and interpret other modes of representation, visual displays, such as three-dimensional models and graphs, are embedded in their discipline and are commonly used. Chemists, for example, portrayed the information produced through NMR techniques in visual form, representing NMR frequencies as lines on a graph. They did not primarily work with NMR data as numbers. Lauterbur's professional vision thus emphasized the use of visual depictions, and, in doing so, facilitated his ability to translate this data into graphic form.

Lauterbur discussed the proposed visual output through the use of cartographical metaphors. Trained as a chemist, Lauterbur described the image as a mathematical representation of spatial information. As noted earlier, Lauterbur used words like 'map' to describe the output, and when he used terms like picture and image, he defined them in mathematical terms (Lauterbur, 1973; Lauterbur *et al.*, 1975). For example, Lauterbur writes, 'an image of an object may be defined as a graphical representation of the spatial distribution of one or more of its properties' (Lauterbur, 1973, p. 190). Here the image is primarily described as a 'graphical representation' that visually shows the spatial distribution of hydrogen nuclei, and its meaning is not assumed to be evident.

Lauterbur's choice of cartographical metaphors stands in sharp contrast to the way physicians and patients now describe the image. Today, language that highlights the relation of the image to pictures of the anatomical body are often used in clinical practice while language that calls attention to maps and spatiality is less common (see, for example, Beaulieu, 2002; Dumit, 2004; Joyce, 2005). This linguistic difference occurs in part because of the broader recognition of the centrality of images to contemporary life as visualizing technologies such as cameras, computers, video games, and picture-producing cell phones, become more common. Medical imaging technologies like ultrasound and computerized axial tomography (CT) technology—which were in initial stages of diffusion in the early 1970s—are routinely used in clinical practice and are a crucial part of this trend.

However, the linguistic difference between Lauterbur and practising physicians is not simply a matter of time, i.e. then versus now. Rather, it shows how professional contexts shape which metaphors are used to describe representations of the body. Anne Beaulieu (2002) demonstrates this point in her work on brain scans. Beaulieu's research shows that neuroscientists in research laboratories use narratives that emphasize the mathematical components of brain images. In contrast, pictorial metaphors are typically used in clinical practice to describe the same sort of scan (Beaulieu, 2002, p. 63). Thus, there are multiple ways to discuss anatomical images and professional and cultural contexts support the choice of particular rhetorical practices over others.

Lauterbur wrote his ideas about NMR and gradients in his notebook on 2 September 1971, and had this entry witnessed (Mattson and Simon, 1996, p. 714). Securing additional recognition of his contribution, Lauterbur then published a paper in the 16 March 1973 issue of *Nature*. In this piece, Lauterbur argued for the use of anatomical representations as the form of display for the information obtained by the technology. He also proposed the name 'zeugmatography' for his invention and called the images produced 'zeugmatograms'. Zeugmatography, derived from the Greek word zeugma, means 'that which is used for joining'. Emphasizing the technique itself, the term symbolizes how the magnet and the gradients 'join together' to create information about the inner body (Lauterbur, 1973, p. 190).

With this publication, Lauterbur entered the public scientific dialogue about possible new uses for NMR techniques. Lauterbur was not the only scientist, however, to imagine extending NMR techniques to create spatial information. In the United Kingdom, physicist Peter Mansfield also envisioned using NMR technology in this manner, but with a different target. In contrast to Lauterbur, Mansfield wanted to use NMR to map inert matter, not human anatomy. As a trained physicist, Mansfield studied rigid matter such as crystals. Mansfield hoped that NMR techniques could be extended to produce spatial information about this type of substance. Using NMR to produce information about human anatomy is not a central focus for physics, and, not surprisingly, was not part of Mansfield's original proposal.

Mansfield and his colleague Peter Grannell published their ideas about using NMR techniques to produce spatial data in a letter called 'NMR Diffraction in Solids?' in *The Journal of Physics C*, an academic journal dedicated to reporting new solid state physics theory and research, in 1973. In this letter Mansfield and Grannell explained how gradients could be used to obtain spatial information about solids like crystals. They made no mention of using this technique on human or animal tissue, nor did they discuss turning the information into a picture.

Mansfield did speculate about using visual representations, however, when he presented his ideas in September 1973 at the 1st Specialized Colloque AMPERE in Poland. Ulrich Haeberlen, a participant at the conference, remembers, 'And Peter Mansfield, what did he talk about? He began with reflection symmetry in sequences but soon turned to NMR diffractometry. In retrospect, he talked and speculated about spin imaging and actually showed pictures of phantoms!' (Grant and Harris, 1996, p. 118). Haeberlen's excitement here refers to Mansfield's reflection about the potential use of images to represent NMR data. Although unknown at this time, the turn toward the visual would prove to be a key component of the medical device eventually developed for use in clinical practice and embraced by popular culture.

Mansfield's presentation made him aware of Lauterbur's research. After Mansfield delivered his lecture, a member in the audience, 'stood up during the question period and asked Mansfield if he knew of Paul Lauterbur's recent paper which presented the idea of using NMR to form images' (Grant and Harris, 1996, p. 387). Mansfield hadn't heard of Lauterbur at the conference and when he returned home he looked up his work. Mansfield quickly noted the similarities between their ideas and experimented with transforming Lauterbur's idea of using NMR to visualize anatomy into a viable technology.

In this early stage of research and development, Damadian, Lauterbur, and Mansfield all worked on extending NMR technology use. While each man's professional location shaped his initial work with NMR—Damadian, an American doctor, focused on cancer, Mansfield, a physicist, concentrated on crystals, and Lauterbur, a chemist, imagined using NMR techniques to produce pictorial representations—their research agendas expanded and changed in response to exchanges with each other. All three scientists incorporated Lauterbur and Damadian's insistence on using NMR technology to produce knowledge about the human body and Lauterbur and Mansfield's desire to create spatial information into their research. Each changed their investigations to focus on these issues.

Standardizing Terminology, Representational Practices, and Machine Design

Throughout the mid- to late-1970s, the desire to create a medical technology out of existing NMR techniques gained momentum, and the circle of researchers involved expanded. Research teams in Japan, the United Kingdom, and the United States worked on transforming Damadian, Lauterbur, and Mansfield's insights into a viable medical technology. As research moved into more laboratories and sites, scientists negotiated the name, design, and mode of representation of the technique. In this early stage of innovation, decisions about data output and machine design were primarily shaped by competing professional visions of the research scientists intimately involved in MRI development. While access to funding and institutional structures clearly enabled their work, the research scientists' expectations and training significantly impacted this period of development.[4]

During this round of innovation and development, the new, extended community of researchers quietly rejected Lauterbur's proposed name for the emergent technology. While some scientists did initially adopt zeugmatography to talk about the new technology, most continued to use NMR—an already familiar term that highlighted connections to its scientific roots in nuclear physics and chemistry (Hoult, 1979; Lauterbur *et al.*, 1975; Kumar *et al.*, 1975).

Scientists also rejected the idea that the numerical data was not of interest in itself. In his early work, Lauterbur argued that the picture was *the* component of NMR data to be produced and used. Despite his insistence, scientists continued to publish NMR data as both an array of numbers and an anatomical image (Lauterbur, 1986; Mallard *et al.*, 1979; Mansfield and Maudsley, 1977). Some researchers thought that the number values provided a degree of specificity that was lost when these values were turned into parts of an image. Damadian, explaining this belief to me in an interview, noted, 'We thought that an actual knowledge of the T1 and T2 [measurements], rather than translating it into a pixel brightness, would give an additional quantitative handle on how big the differences were' (Damadian, 2000). The numerical measurements might provide additional knowledge about a person's health that would be unavailable once these values were translated into components of an image.

In addition to deciding to *produce* images, researchers also had to figure out the *appearance* of image content. NMR research scientists typically had little experience working with anatomical images in medicine. Still operating in the laboratory, they did not have to answer to the needs and expectations of professions that routinely worked with images or patients. These men, free to tinker with the representational form, chose vibrant, rainbow colours, such as green, yellow, and red, to represent the inner body (Damadian *et al.*, 1978; Mallard *et al.*, 1979; Edelstein *et al.*, 1981). Resembling Andy Warhol or Roy Lichtenstein's bright colour prints, the scientists' choices mirrored the aesthetics of popular art and television in the 1970s, a decade known for psychedelic colours and artefacts like mood rings and Pop Rocks candy (Panati, 1991).

These decisions about data portrayal subsequently shaped decisions about machine design. Representational practices were built into the design of the machine, and early scanners were made so that both forms of representation—numerical and visual—could be easily accessed. Engineer Larry Crooks notes that the UCSF scanner 'had a track ball (a belly up mouse) that let one position a cursor on the image and read the intensity number from any location. There were also functions that would calculate the average and standard deviation of the numbers from any closed region one could draw on the image' (Crooks, 2000). Additionally, the scanners developed by other research teams were designed to allow users to move easily between the numerical and anatomical forms of representation.

By the end of the 1970s, the research teams had arrived at a working consensus about the name of the technology, the representation of the data, and the machine design. The common name for the technology was *nuclear magnetic resonance imaging*, or *NMR*. The display of the data included print outs of multi-colour images and arrays of numbers, and machines were designed to produce this output. Emerging from discussions between the chemists, physicists, and research physicians who worked on the technique, these researchers drew on professional knowledge and exchanges with each other to stabilize the features of NMR imaging. In doing so, the scientists created a new cultural product—a medical technology called *NMR* and an understanding of the inner body as T1 and T2 relaxation times, represented in both numerical and multi-coloured, visual form. The name NMR imaging highlighted the connections between the new technology and its scientific roots in nuclear physics and chemistry while the production of both visual and numerical data created a new way of ‘knowing’ the internal body. As potential users expanded to include practising physicians and potential patients, these choices would be actively challenged.

MRI Machines in Clinical Practice

NMR imaging technology entered the clinical realm in the 1980s. When first introduced to medical practice, it was unclear which medical specialty should control NMR imaging technology. It could, for example, be placed in nuclear medicine or pathology departments. Nuclear medicine physicians or pathologists are trained to understand the body through a detailed knowledge of chemistry and nuclear physics and are able to interpret the biochemical, numerical information produced by NMR techniques. NMR, however, also produces anatomical pictures. As such, a link to radiology could be argued. Radiologists order and produce the body through anatomical pictures and are today considered experts in image interpretation. The diverse features of NMR technology—it produced both visual and numerical information—meant that the machine could potentially be placed in different departments.

During the early 1980s research scientists and nuclear medicine physicians publicly discussed machine placement and some expressed concern about radiologists’ bias toward images. John Mallard, for example, questioned radiologists’ ability to interpret numerical information, noting that:

> The human body is extremely complex. When, in addition, we first attempt to image a new property such as proton magnetic resonance, there is bound to be difficulty in interpreting the results . . . With this in mind, we have carried out a biological back-up program of T1 measurement on normal and pathological tissues to ease the problem of image interpretation and to find pointers toward the most fruitful fields for the application of NMR imaging (Mallard quoted in Blume, 1992, p. 218).

Nuclear medicine physicians also challenged radiologists’ emphasis on images. Paul Lauterbur (2000) recalls:

> People in nuclear medicine, I had heard say about that time, said that radiologists could not be trusted with nuclear magnetic resonance imaging. It was too complicated for them. People in nuclear medicine were used to thinking about chemistry and complex physics while radiologists just looked at fuzzy pictures.

Thus, there was concern that radiologists would ignore ‘the most fruitful fields’ of NMR, the biochemical information, and only focus on the visual component of NMR imaging.

These expressions of unease remained minor though. NMR imaging, despite the potential connections to nuclear medicine and pathology and the misgivings of some scientists, eventually became part of radiology units in many countries.

Changes within radiology and medicine provided institutional support for this decision. Professional radiology organizations, such as the Radiological Society of North America (RSNA) and the American College of Radiology (ACR), reached peak membership numbers in the 1970s (Linton, 1997; RSNA, 2005). Drawing on their expanding membership base, these organizations actively lobbied to gain control over imaging interpretation. As the ACR Board Chairman Robert Wise noted, 'It has taken us a decade to build our specialty up to the point where we can contemplate providing the radiologic services needed by the American people. This puts us in a position to assert that radiology should be done by radiologists where we are available to do it' (Wise quoted in Linton, 1997, p. 86). Legally any licensed medical doctor has the right to interpret medical images, and radiologists lost revenue and status when other physicians did visual interpretation work. Instead of directly challenging laws that allowed any licensed medical doctor to interpret medical images, radiology organizations questioned the ability of other physicians to 'read' images correctly. This move was successful in many countries and helped produce the idea that radiologists are *the* professional authorities over image interpretation.

In the United States, radiologists gained even more independence and control. In the early 1970s the ACR encouraged radiologists to 'gain independent practice status in their hospitals' (Linton, 1997, p. 80). This move allowed radiologists to operate in hospitals but maintain control over their fees and income. Initially resisting, the American Hospital Association acquiesced to this demand and, due in part to lobbying efforts by the ACR, stopped pursuing legislature to 'recapture' radiology.

The 1970s, a key decade in the rise of radiology, also witnessed an increase in the range and number of imaging technologies available. In this decade, new imaging machines, such as computerized axial tomography (CT) technology and ultrasound, became part of clinical practice and increased physicians' choice of imaging techniques. X-ray had previously been the only imaging apparatus commonly used. The increased range and presence of anatomical pictures in medicine, coupled with the expansion of radiologists' authority and prestige, supported the plausibility of placing NMR imaging technology in radiology units. The high cost and large size of NMR machines further ensured that private physicians would not purchase their own machines, and cemented its initial placement in hospital-based radiology departments.

Radiologists Shape Machine Output and Design

The placement of NMR imaging into radiology departments was a crucial decision that opened up dialogue between the existing technique and radiologists' professional vision. As noted earlier, professional vision refers to the way individuals are trained through interaction processes to code and highlight the world in an occupationally specific manner (Goodwin, 1994). Radiologists are disciplined, through interaction with other physicians, medical textbooks, and imaging machines, to represent and interpret their area of focus—the body, health, and illness—as black and white images. They do not work with the body in numerical form.

The dialogue between radiologists' professional vision and NMR technology consequently resulted in two major changes in the appearance of the data. First, the practice of printing out both the array of numbers and anatomical pictures ceased soon after NMR technology was placed in radiology units. Instead of representing NMR data as both numbers and images, the data was now solely presented in image form.

Developers of MRI recall how radiologists' emphasis on pictures shaped decisions about representation practices. John Mallard remembers, 'Our very first mouse image, we did actually publish it with all of the numbers and then we showed a colour version of it, converting those numbers into the different bands of colour that we decided to use. You could see an abnormality in the mouse from the colour change. You could see it in the numbers as well, but radiologists don't think that way ... Radiologists just weren't interested in the numbers. They never have been' (Mallard, 2000). For Mallard, both forms of display, i.e. the array of numbers and the anatomical picture of the body, reveal the location of abnormalities, and it was radiologists' preferences that shaped the turn toward the image.

Larry Crooks, a member of the University of California at San Francisco NMR imaging research laboratory, also discussed the importance of radiologists' professional vision in decisions about data appearance. Crooks explained that the image came to dominate because, 'We were in the radiology department. The docs make their living looking at images' (Crooks, 2000).

The same pattern occurred when CT imaging was introduced to radiology units in the early 1970s. Similar to NMR technology, CT scanners do not take a 'picture' of the internal body; instead, they numerically measure the amount of X-ray absorbed by tissues. Mathematical formulas then transform numbers into visual representations of the internal body. Early scanners printed out both the array of numbers and the anatomical picture for each exam (Kevles, 1997, p. 161), and initial articles that reported CT scans included both the numerical and pictorial representations of the information (Ambrose, 1973).

As with NMR technology, the practice of printing both numerical and visual forms of representations ended shortly after CT technology was placed under the jurisdiction of radiologists and radiology units. Calling attention to the 'radiology' effect, historian Bettyann Kevles (1997, p. 161) writes, 'Few, if any, radiologists ever looked at the numbers' and the practice of printing out numerical data ceased after the incorporation of CT scanners into radiology units.

In the case of NMR technology, the professional vision of radiologists further altered data appearance by transforming the content of the image from multi-colour into a grey scale.[5] The machine design was altered so that the final product was not a multi-colour picture. Numerical values were coded into shades of grey and the resulting images were printed on black and white film. NMR machines now produced the body as a black and white image and representations of the body as arrays of reds, yellows, and blues disappeared from clinical practice.

John Mallard recalls, 'Our first images were in colour. The interesting thing is that all the radiologists couldn't abide by colours. They were used to grey scale on their X-rays and they wanted grey scale. So we put grey scale. Everybody else went to grey scale and colour was dropped' (Mallard, 2000). Paul Lauterbur also commented on the importance of the professional expectations of radiologists in the process of standardizing the colour of the image. He explained, 'The general practice of using grey scale came about because radiologists were used to such images from X-rays and CAT scanning' (Lauterbur, 2000).

Radiologists prefer grey scale images in part because they are trained to interpret this type of picture. To switch to a new mode of image appearance, such as multi-colour or an image printed in a different tint, would require a significant retraining of the eye and the mind. This time investment is impractical in the busy world of everyday medical practice and physicians resist such changes. In addition, since radiologists already worked with CT and X-ray images, supporting technologies such as printers and film accommodated the use of grey scale. As Lauterbur (2000) points out, 'their systems for recording and reproducing images used black and white film' and to change to other colours would be costly.

Radiologists also prefer images in hues of one colour because this form of representational practice allows them to identify subtle anatomical changes. As physician Raymond Damadian explains, 'When you start using [different] colours, you can go from one region of pixel brightness to another region where the difference between the two regions numerically is small, but you code one a yellow and the other a blue. There's this huge discontinuity on the picture, which on the grey scale would be a negligible transition' (Damadian, 2000). This abrupt change in colour can suggest that the difference between the two areas is very large, when in fact it is small. It can, as engineer Larry Crooks suggests, 'trick the eye into believing two close numbers are very different, because they are different colours in the image' (Crooks, 2000). This 'tricking' of an eye may cause physicians to misinterpret the exam as subtle transitions between parts of the body are not highlighted. The colour chosen, of course, could be any shade; it does not have to be shades of grey. The use of printers and film to produce black and white CT and X-ray images, coupled with radiologists' already disciplined vision, reinforced the decision to choose this particular colour over other possibilities.

Finally, as expectations of users are 'built-in' to technologies, the radiologists' interpretative practices also shaped subsequent changes in machine design (Bijker, 1995). New machines were crafted in ways that made it more difficult for physicians to move between the numerical values and the image. Now machines immediately produced and displayed anatomical pictures on the computer screen. While the quantitative information was often still available, it was no longer visible on the screen or printed as part of the exam process and required a series of software commands to become apparent.

Anti-nuclear Movements and Changes in Terminology

If the expectations of radiologists significantly altered both data representation and the machine itself, American perceptions of 'nuclear' also presented a crucial transformative force. The very name of the new technology—NMR imaging—was challenged once introduced into clinical medical practice in the early 1980s. A heightened consciousness about the problems associated with both nuclear power plants and nuclear weapons marked this time period. The anti-nuclear power plant movement in the United States had been building momentum since the 1970s. On 28 March 1979, the Three Mile Island Nuclear Plant released radioactive material into the air. Although not the first such release, it was the first to receive significant attention, and it mobilized the 'No Nukes' campaign. Many proposals for new plants were strongly contested. Between 1977 and 1989, for example, over 3,500 people were arrested in protests against the nuclear power plant in Seabrook, New Hampshire alone (Zinn, 1995, pp. 600–601).

In addition to the anti-nuclear power plant movement, other groups, such as the Nuclear Weapons Freeze Campaign, actively challenged the proliferation of nuclear arms in the US and the USSR. The actions of groups like the Nuclear Weapons Freeze Campaign, the Committee for a Sane Nuclear Policy (SANE), and others successfully challenged the legitimacy of nuclear weapons in the United States. In 1982, nuclear freeze resolutions were on many city and state ballots and there was a wide spread awareness of the 'dangerousness' of the nuclear arms race (Gusterson, 1996, p. 169).

It is exactly during the height of this national consciousness that NMR imaging made its way into American hospitals. The symbolic connection between the name of the new technology and nuclear weapons and power plants reverberated throughout clinical practice. What emerged was a cultural impossibility of separating the word 'nuclear' in 'nuclear magnetic resonance imaging' from the danger associated with the global nuclear social context. As John Mallard recalls, 'Nuclear was associated with bombs and wars and God knows what' (Mallard, 2000). Not surprisingly, people in neighbourhoods next to hospitals and prospective patients were wary of NMR imaging. They did not trust claims that it was safe or unrelated to nuclear power or weapons, and resisted the integration of these machines into their neighbourhoods and health care. Concerned about this negative association, American physicians and hospital administrators promoted a new name, *magnetic resonance imaging* or *MRI* (Kevles, 1997, p. 184; Mallard, 1993). It was quickly adopted world-wide.[6]

Emerging from local political contexts within the United States, the transformation in terminology also signals shifts in the larger cultural milieu. The linguistic change from NMR to MRI technology, while a direct response to negative public perceptions of nuclear technologies, occurred as physics lost cultural and institutional prestige.[7] Moreover, the removal of the word 'nuclear' not only distanced the technology from its roots in physics, but it also made it more difficult to imagine MRI as a producer of information about one's nuclei. In contrast, the new name—Magnetic Resonance Imaging—through its emphasis on images, discursively transformed the machine into an *imaging* technique. In doing so, it aligned the new technology with the visual and signalled the increasing importance of visualization and biomedicine in the late twentieth century.

From Nuclear to Visual: Shifting Cultural Contexts

The development of MRI technology illustrates the importance of culture to scientific innovation. The decisions about machine design, output, and name were profoundly shaped both by changes in public understandings of nuclear technologies and knowledge and by what I call the visual turn.

Throughout the twentieth century, the ability to technologically transform daily life into visual form significantly expanded (Clarke, 2004; Mirzoeff, 1998; Sturken and Cartwright, 2001). Older technologies such as film, photography, and television were joined by new technologies such as video cassette recorders (VCRs), cable television, computers, and video games in the 1970s and 1980s. In addition, a 'visual arms race' occurred as older, public space visual technologies like film tried to regain declining audiences through publicity about and use of new techniques such as Panavision and Dolby Sound. The expansion in the range of and accessibility to visual technologies as home cameras and computers became more affordable helped render the translation of life into image form common practice.

Technological innovation in science and medicine was part of this broader tendency to translate the world into techno-visual terms. Throughout the 1950s, 1960s, and 1970s, many researchers independently worked to create new technologies that would produce the body as anatomical pictures. This labour resulted in the now familiar imaging techniques such as ultrasound, computerized axial tomography (CT), single photon emission computed tomography (SPECT), and MRI (Blume, 1992; Kevles, 1997; Wobarst, 1999). The United States government recently recognized the importance of images to contemporary medicine. On 29 December 2000, the National Institutes of Health (NIH) created the National Institute of Biomedical Imaging and Bioengineering Establishment—the only institute of health dedicated solely to technology. The majority of institutes are organized around a particular disease or area in the body.

MRI and other medical imaging researchers' work thus tapped into and helped produce the centrality of images in modern life. The tendency towards visualization provided the technological support and cultural recognition needed to produce medical imaging as a desirable practice. The invention of new medical imaging technologies, in turn, aided visualization by producing more visual artefacts for consumption in scientific practice and popular culture.

The content of visual displays, of course, varies. Medical practice and popular culture have their own representational practices that at times overlap and at other times diverge. In the 1970s, MRI images, for example, converged with popular culture aesthetics. Television shows like *The Partridge Family*, the continued presence of Pop Art, and fashions associated with musical genres such as Glam Rock and Disco transformed the world into vibrant and at times psychedelic hues. The research scientists working on MRI development also chose bright, flashy colours to represent the inner body—a decision that resonated with the aesthetics of popular culture.

In the early 1980s, radiologists' professional vision significantly influenced the appearance of MRI output and machine design. Transforming the output into grey scale images, radiologists' preferences took precedence over other potential visual practices. As the 1970s waned, popular culture changed to accommodate new stylistic forms. In the 1980s, colours became more muted, denim made a comeback, and shows such as *Geraldo*, *Oprah*, *Cheers*, and *Miami Vice* took over the television screen. While the final choice of grey scale images shared some of the over-simplified realism that infused much of the decade's popular culture, the final decisions about MRI output diverged from other common stylistic practices like the use of colour and a tendency towards excess. Instead, the final form of MRI images emerged from radiologists' professional training and existing medical representational practices. X-ray, CT, and ultrasound images produce the body in shades of grey, and radiologists are trained to interpret the body in this form.

As grey scale images, MRI examinations were made to fit this already established medical visual culture, thus demonstrating how the visual turn takes local and specific aesthetic forms. The trend toward visualization, while shared across many milieus, produces multiple visual cultures—each of which has its own normative practices.

Conclusion

MRI technology now produces grey scale images of the inner body. The representation of the data solely as an anatomical picture resulted from culturally embedded exchanges initially between research scientists and then later between research scientists and radiologists. Encountering an open terrain of possibilities, Raymond Damadian, Paul Lauterbur, and Peter Mansfield all worked on extending existing NMR techniques to new applications. Damadian, a physician, imagined using NMR to produce numerical information about the human body, and Lauterbur, a chemist, catapulted the development of MRI forward when he suggested a technology could be designed to produce anatomical images.

In the next round of research and development, researchers in Japan, the United Kingdom, and the United States crafted machines to produce both numerical data and multi-colour images. These men, trained in a range of scientific disciplines such as physics, chemistry, and engineering, explored the potential of both numerical and visual information. Unhampered by ties to clinical medicine, researchers chose colours like red, yellow, and blue to depict image content. The multi-colour image aligned with the aesthetic practices of popular culture, mirroring the tendency to represent the world in bright, psychedelic colours.

Radiologists challenged the decision to represent data output as both multi-colour images and numbers immediately after the machine was introduced to clinical practice in the 1980s. Radiologists do not work with the body in numerical form nor do they interpret multi-colour images. Instead, they translate and understand the body as grey scale pictures. Responding to radiologists' professional expectations and the appearance of images produced by established technologies such as X-ray, CT, and ultrasound, MRI machines were designed to manufacture the body exclusively in shades of grey. While this choice shared the tendency of 1980s popular culture to produce the world through the lens of simplistic realism, it diverged from other popular culture practices that emphasized colour and excess. The divergence between popular culture and MRI examinations shows that there are multiple visual aesthetic practices and the final form of MRI output primarily met radiologists' professional requirements.

Professional training and vision significantly shaped choices about the appearance of MRI data. However, the decision to represent data output solely as an anatomical picture is also related to the broader context of visualization. The trend towards visualization provided the techno-scientific support via computer hardware and software innovations required to produce anatomical images. Without these supporting technologies, the use of images as the representational form would be next to impossible. The proliferation of images in all areas of daily life further supplied the cultural familiarity needed to position MRI examinations as recognizable and desirable.

Paying attention to visualization also shows the cultural role of images in professional development and power. Radiologists gained authority and wealth throughout the 1970s and 1980s as imaging technologies were developed and perceived as needed. In the United States, radiologists now earn as much, if not more, than other lucrative medical specialties like cardiac surgeons (RSNA, 2003). While factors such as lobbying efforts by professional organizations like the Radiological Society of North America (RSNA) and insurance reimbursement policies contribute to the prestige of radiologists, the cultural emphasis on images helped legitimize radiologists' work and secure this profession's status.

The development of MRI concurrently occurred in relation to the twentieth century emphasis on atomic research and technologies. The focus on nuclear research in the early 1900s provided the basic scientific knowledge used in contemporary MRI machines. Negative public perceptions of nuclear power and weapons post World War II influenced popular views of the technology and resulted in the transformation of the name from Nuclear Magnetic Resonance Imaging (NMR) to Magnetic Resonance Imaging (MRI). The removal of the word 'nuclear' helped distance the technique from its nuclear roots and aligned it more firmly with images and visuality.

This case study builds on earlier scholarship that shows how the invention of new medical imaging technologies results from multiple possibilities and social interactions (Blume, 1992; Kevles, 1997; Pasveer, 1989; Yoxen, 1987). Edward Yoxen, for example, conceptualized the stabilization of early ultrasound images and machine design as a social process—one that requires explanation and is not self-evident. His research shows that decisions related to innovation 'are rarely, if ever, dictated by experimental evidence alone' (Yoxen, 1987, p. 302). Instead, scientists' interpretations of technological constraints and possible applications are more important than a crucial experiment in design decisions. As Yoxen suggests, it is 'perverse to see this technology as emerging through a unilinear process of development from some initial breakthrough' (Yoxen, 1987, p. 300).

Yoxen's work, in conjunction with other scholarship in this area, stimulates discussion about the relations between social institutions, groups, and imaging technology innovation. However, this literature does not analyze the cultural role of images in linking information with aesthetics and metaphors, nor does it investigate how the contemporary emphasis on images might shape professional development and status. Science and Technology Studies scholar Nelly Oudshoorn (2003, p. 12) suggests more analysis of 'the broader cultural dimensions of human agency' is needed in studies of technological change. Such dimensions include representational conventions, belief systems, and the formation of identities. Following Oudshoorn's lead, this study demonstrates how the development of MRI is related to contemporary visual aesthetic practices and how radiologists, a newly formed professional identity, benefit from and contribute to the visual turn. Scientists creatively select, adapt, and appropriate from a range of possibilities to produce new technologies; these decisions, especially in the case of the medical imaging technologies, are intimately connected to the larger cultural context of visualization.

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Notes

[1]For a thorough introduction to critical studies of visualization, see 'Chapter Six: Mapping Visual Discourses' in Clarke (2004). Mirzoeff (1998), Mitchell (1994), and Sturken and Cartwright (2001) also provide excellent discussions of the visual turn in culture.

[2]See, for example, Doing's analysis (2003) of labour practices in a synchrotron laboratory. Doing shows how biologists slowly replaced physicists in scheduling and priority hierarchies, and, in doing so, radically restructured knowledge production in the laboratory.

[3]There are two ways to measure nuclear magnetic resonance. The first is to vary the external magnetic field while holding the frequency of the oscillator constant. The second is to hold the external magnetic field constant while varying the frequency of the oscillator. In Rabi's first resonance experiment he used the first method. After this, however, he switched to the second method (Mattson and Simon, 1996, pp. 66 and 117).

[4]For further discussion of the financial relations that structured MRI development, see Blume (1992, pp. 192–217).

[5]The early use of colour images continues to 'haunt' some contemporary MRI images. Occasionally, a very low signal is produced during an MRI exam. Some scanners, using a coding practice left over from earlier machine designs, still translate this signal into the colour red. The low signal thus appears as red dribbles above and below the anatomy in the image. Scientists jokingly call these distortions 'bleeding artefacts', using humour to trouble cultural boundaries that distinguish between the image as inanimate and the body as life (Crooks, 2000).

[6]Scientists and physicians outside of the US still resist this change. In my research, European physicians and scientists spontaneously discussed how the name of NMR imaging became MRI imaging, using terms such as 'self indulgence' and 'American silliness' to describe the change. These scientists expressed impatience with the way the rest of the world is expected to adjust to what is happening in the United States. Their critique calls attention to the techno-scientific forms of imperialism that structure the production of new technologies.

[7]Donna Haraway (1997) examines the move from a Cold War, physics-centred scientific practice to what she calls a New World Order, biology-based practice. Haraway shows how funding for biotechnology and genetic research increased in the 1980s and 1990s as interest in genetics and medical images replaced the mid-twentieth century fascination with the atom.

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