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Issue Stories

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Making Waves With MRI

by Dan Harvey

Market drivers push the envelope of this versatile modality.

Magnetic resonance imaging (MRI) has provided a solid foundation on which researchers and manufacturers have developed remarkable innovations. Interest in the technology has soared since it first emerged almost 20 years ago. And those first systems seem almost primitive when compared to the increasingly complex and effective systems available today.

Demand is a key word when looking at today's MRI market. Accelerating complexity has brought increased patient demand. At the same time, users demand even more sophisticated capabilities from manufacturers, who enthusiastically embrace the challenge. Drawing from the work of researchers developing new techniques and technology, the industry's leaders have helped make MRI one of the most versatile imaging modalities.

"I don't think any other modality has a larger base of students and other smart people just imagining new things every day," remarks David Weber, manager of the global high-field MR business for GE Healthcare (Waukesha, Wis). "We draw from that pool to solve a lot of technical problems, and it drives the technology forward."

As a result, MRI equipment sales represent one of the strongest markets in the medical imaging industry in the United States.

Market and Drivers

In 2002, the US MRI market had its best year ever, garnering $1.46 million in sales of 1,055 scanners, reports Monali Patel, research manager of medical imaging and patient monitoring for Frost & Sullivan (Palo Alto, Calif), a global growth consulting company.

In 2003, an estimated 21 million procedures were performed, according to Patel. That's a jump of 22% from the 18 million procedures performed in 2001, according to estimates from the IMV Ltd's Medical Information Division (Des Plaines, Ill), an international organization that analyzes science-based instrument industries. Looking ahead, Patel says that the installed base is predicted to grow about 35%–40% over the next 5 years. "Approximately 9,500 units are expected to be installed by 2008–2009," she adds.

Weber indicates that two major factors have driven the MR market: the focus on increased productivity and new applications that increase business for MRI buyers. "It revolves

around the customer's bottom line," he says. "Things that produce business are what drive the market."

Weber says that any new enhancements or products that improve the productivity of an existing scanner generate strong market response. "Data shows that [the current] market is behaving as if it is at capacity—meaning, if we see an upturn in procedures, we're also seeing an upturn in the number of MR scanners sold. So, it is acting as if the productivity, or capacity, of the installed base is at a point where incremental patients need incremental scanners," he explains.

New applications, Weber says, generate more business for MRI users because they open up access to new patient populations not previously serviced. Weber cites such applications as breast MR, body imaging, and vascular imaging.

On to Higher Fields

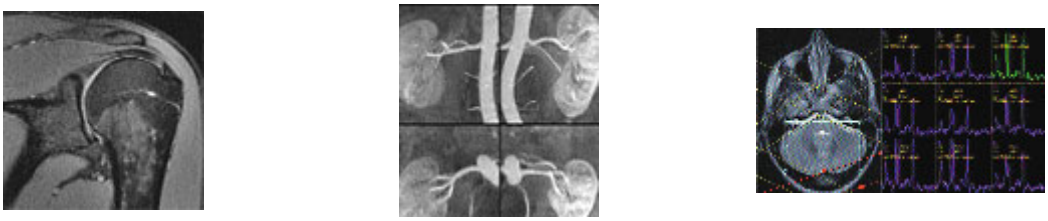
Bottom-line considerations, Weber explains, have steered the general marketplace trend toward higher fields, from 1.5 Tesla (T) to 3T. A customer who buys 3T will most likely have the only such unit in its local environment, he says. "Basically, 3T is a way of providing higher quality, faster results, and a way of garnering a bigger share of their local market."

Patel cites the main reason for the increase in recent sales as the replacement of older scanners with newer high-field (1.5T) and very high-field (3T) systems. Further, Patel expects the growth rate in revenues and unit sales to remain strong throughout 2004 as hospitals and imaging clinics continue to adopt to high-field MRI systems. The mid- and high-field scanners can provide advantages, such as additional applications, faster scan times, and increased image quality; therefore, they've become much more appealing. "The desire to have higher strength MRIs that offer increased application abilities is one of the primary market drivers," she says.

Indeed, the move to higher fields is the biggest trend in the MRI market, says Michael Brandt, field marketing manager of MR for Philips Medical Systems (Bothell, Wash). "The two significant market segments are the open market segment and the cylindrical market segment," he says. "The move in the open market is from low-field to mid-field. In the cylindrical segment, the bottom has dropped out of the 1 Tesla. The 1.5T has become the mainstay, but there is huge growth in the 3T market."

Both hospitals and imaging clinics are generating an increased demand for the high-field systems. Patel says that 1.5T systems have become the bread-and-butter MRI scanners, as they account for two thirds of installations, replacing older units in both hospital and nonhospital settings. Eventually, users will shift to a higher strength. Weber reports that 3T is quickly becoming a mainstream clinical scanner already, but he adds that the 1.5T systems continue to dominate the field. Still, the shift toward 3T is inevitable. "The interesting dynamic is that the shift is actually happening much faster than expected," he says, adding that he expects GE Healthcare's 3T business to exceed 25% of its 1.5T business by next year, which will represent a growth rate of 30%–40%.

As the mid- and high-field scanners experience a higher adoption rate, sales in low-field scanners are certainly on the decline, Patel says. However, they're not expected to completely disappear, as some customers—like certain specialists and smaller freestanding centers—still will seek the more affordable MR equipment. Weber notes, "We have a healthy and steady market in the lower fields. It's not growing as much as it once was, but it's not shrinking either."



These images, taken with GE Healthcare's Excite 3T, demonstrate good off-center imaging in a shoulder study (left), increased resolution in renal MRA (center), and more precise spectroscopy imaging (right).

Emerging Applications

Patel address another important factor that drives new installations: the need of some facilities for additional MRI scanners to handle greater utilization resulting from the increased adoption of MRI by nonradiology departments, such as cardiology and orthopedics, as well emerging applications that increase the versatility of MRI. Some emerging applications include contrast-enhanced MR angiography, interactive cardiac MR, interventional MR, and breast MR.

Weber says the core applications still generate the highest volume of procedures, albeit at a single-digit growth rate. Double-digit growth rate is demonstrated in areas of body, vascular, and MR breast imaging. To put these figures in perspective, Patel says, "Cardiac and vascular applications are the fastest growing applications in the market. [But] in terms of absolute numbers, they still represent only a fraction of MRI studies performed. MRI continues to be used frequently for neurological and orthopedic procedures, and these uses currently outweigh the use for cardiovascular procedures."

Weber feels that cardiac imaging is too low volume right now to even show up on the radar screen. Still, he is enthusiastic about its potential. "We think this emerging application is one that will take hold," he says.

The key to its success, he thinks, is real-time imaging. Weber reports that GE Healthcare is working on a real-time cardiac exam that essentially would run the MR scanner like a cardiac ultrasound, but without any gating or breath holding.

Another application that Weber is excited about is functional MRI (fMRI)—one of the most fascinating MRI techniques developed to date. Traditionally, Weber says, fMRI has

been the province of researchers working at major academic institutions. However, fMRI has a recognized potential value to a basic clinical workup, particularly for any surgical or interventional planning. But widespread clinical use of fMRI is still down the road, and Weber says the key to clinical application will be its ease of use. GE Healthcare, he reports, has developed a new fMRI technique focused on that element.

Meditations on fMRI

Academic researchers who have been using fMRI are helping to unlock many of the secrets about the brain's higher functions. That's why it has become an object of such fascination, even outside the medical industry. So far, the technology has uncovered clues about why we experience certain emotions and pain, and it has been applied toward diverse purposes—finding the underlying causes of obesity, for example, and developing better ways of managing troubling and complex mental conditions, such as autism and attention-deficit hyperactivity disorder (ADHD).

In one particularly compelling area of research, scientists have been using fMRI to validate the efficacy of such contemporary and alternative medicine techniques as transcendental meditation (TM), yoga, and acupuncture.

Alarik Arenander, PhD, director of the Brain Research Institute at the Institute of Science, Technology, and Public Policy of Maharishi University of Management (Fairfield, Iowa), sees a harmonic convergence that could lead to greater understanding of the most mysterious of the body's organs. This convergence involves the concurrent technological advances in neuroimaging (such as fMRI) and the increasing interest in the fundamental states of the brain, demonstrated by the resurgence of interest in mental disciplines, such as TM. At the Institute, Arenander has been involved in research concerned with applying TM to the treatment of traumatic brain injury patients and to children with ADHD.

David Orme-Johnson, PhD, adjunct faculty of the Center for Natural Medicine and Prevention at Maharishi University, has been involved in some of most compelling research in this area. Together with Zang Hee Cho, PhD, professor of radiological sciences and of psychiatry and human behavior at the Functional Brain Imaging Laboratory at the University of California, Irvine, Orme-Johnson has developed an ongoing study involving the functional neuroimaging of acute stress responses in TM practitioners. The collaborators want to study the brain mechanisms that might mediate the reported beneficial effects of the TM program on stress and the response of the heart to stress. In the study, conducted at Irvine, Orme-Johnson and Cho are using fMRI to examine the reaction to pain in TM practitioners compared to nonmeditating controls. After the initial imaging, the controls learn TM and then are imaged again after 4 months of TM practice. The imaging technique employed is fMRI using a Philips 1.5T Intera MRI system.

Entering the study, Orme-Johnson and Cho hypothesized that long-term TM practice develops inner stability and lower levels of anxiety, so that the reaction to pain is not amplified by subsequent distress reactions. They speculated that the brain response to stress in the long-term TM-practicing subjects would be less than in nonpracticing subjects.

In the study, which initially involved eight subjects aged 55 to 65 years old (four long-term TM practitioners and four nonmeditating subjects), hot water was the pain stressor. The fMRI allowed the researchers to measure the hemodynamics, or the flow of blood and oxygen, into areas of the brain (aka, the BOLD effect). Heart-rate measurements also were taken. The subjects, who were imaged twice a day (morning and evening), placed their fingers in the water for 30 seconds three times over a 7.5-minute period. During evening sessions, the TM subjects showed significantly less response across all brain regions than the four controls. Heart rate increased in controls during the pain stimulation in both sessions but did not increase significantly in the TM group in either session.

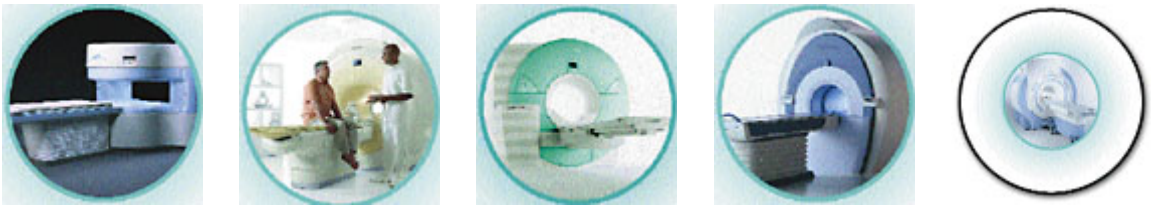
The fMRI images revealed less activity in the brain of meditators during pain stimulation than in the controls. Researchers concluded that the results showed that both the brain and heart responded less to pain stimulation in the TM group than in the control group. Moreover, they said the increased heart rate revealed a defensive reaction of elevated sympathetic arousal (commonly called the "fight-or-flight response") that can actually damage the body by leading to cardiovascular disease and possibly nutritional deficiencies. Their results concurred with other evidence suggesting that TM practice increases cardiovascular health and can change an individual's response to stress.

The experiment wasn't conducted during an actual meditation period, which has a significant implication: The results suggest that greater relaxation does not occur during meditation only. It seems that by practicing TM, the meditators have actually evolved into less stressed, more relaxed individuals. Arenander commented that this apparent transformation has a holistically beneficial effect, and people who practice TM are physically and psychologically healthy individuals.

"We feel there is much more to the story," Arenander says. "When people continue to meditate, they have better health. They live longer, have less cardiovascular disease and mortality, and their management of cancer and asthma are better. How does it change peoples' physiologies so remarkably? Now there's an interest to find out."

One organization that is particularly interested in answering that question is the National Institutes of Health, and the Brain Institute has applied for grants to continue neurological studies involving fMRI and TM.

As their own study progresses, Orme-Johnson and Cho are increasing the number of subjects to gain better statistical reliability. They also will try to determine the specific regions of the brain involved. In addition, the research team is converting from a 1.5T to a 3T system.



From left to right are MR systems from Hitachi Medical Systems (the Airis Elite 0.3T), Philips Medical Systems (the Intera Achieva 3T), Siemens Medical Solutions (the Magnatom Avanto 1.5T featuring the Total Imaging Matrix), Toshiba America Medical Systems (the Vantage 1.5T), and GE Healthcare (Signa Excite 3T).

The Angiography Alternative

MR angiography (MRA) is another area of great interest, but mainly because of the challenges it presents as well as the potential it provides. Essentially, MRA is used to assess vascular occlusive diseases. Conventional angiography remains the gold standard, but MRA provides an effective alternative for certain angiographic procedures.

Unlike conventional angiography, MRA is noninvasive: It doesn't require contrast agents and catheters. (However, contrast-enhanced MRA is generating increasing interest.) Also, the patient is not exposed to any radiation. In addition, it is less expensive, quicker, and involves a shorter recovery period.

According to Matthew Budoff, MD, associate professor of medicine at Harbor-UCLA Research and Education Institute (Los Angeles), MRA is most useful for renal artery disease, carotid disease, and aneurysms. But it's not as useful for coronary disease. "Coronary MRA is still currently thought of as being experimental rather than a useful procedure for clinical practice in most labs, just because the success rate and the ability to interpret the vessels are still very limited," he says.

The main problem is that the heart is a moving organ, and this creates many artifacts. "That is the biggest limitation," Budoff explains. "That's why it works much better for the carotid and renal arteries rather than in the coronaries themselves."

One area where MRA has proven especially useful is in orthopedics. This recognized value is due, in large part, to Hollis Potter, MD, chief of the division of MRI at the Hospital for Special Surgery (HSS of New York). She works in the newly opened MR center that includes five MRI units (one 0.7T, three 1.5T, and one 3T), all dedicated to orthopedic imaging.

On first mention, it might not seem that orthopedics and MR make a good match. But the coupling is just one example of Potter's renowned effective unorthodoxy. During her career, she has developed a reputation as one of medicine's most innovative thinkers. Early on, she had the notion that MRI would be an outstanding diagnostic tool in orthopedics. Using the nontraditional small coils and pulse sequence parameters she developed at HSS, Potter has been able to generate startlingly clear images of tendons, ligaments, and cartilage.

The use of MRA in orthopedics came as a result of necessity, she relates. "We're an orthopedic hospital, so we don't have an angiography suite. We don't do conventional contrast angiography. So we have been, to some extent, forced into MRA," Potter explains. "But I think it has been very helpful in that we've come up with noninvasive ways to image

the blood vessels and to push the envelope a bit in the orthopedic applications of MRA. We have used MRA to supplant conventional angiography in various categories."

One such category is pelvic trauma. "All patients at the hospital for Special Surgery with pelvic and/or acetabular trauma undergo an MRI and have an MR venogram of their pelvis 24 hours prior to stabilization in the operating room," Potter says. "We're trying to identify clots in the pelvis that are not well seen by any other type of imaging technique."

Potter and colleagues have found MRA to be quite sensitive in picking up pelvic clots, which can help prevent sudden postsurgical death from an unexpected pulmonary embolism. Previously, physicians used contrast venography but found several significant problems—pain, risk of contrast reaction, and contrast dilution, the latter of which makes it hard to see the pelvic veins and, thus, resulted in missed clots. "The beauty about MRA is that it's noninvasive, and we have great visualization of pelvic clots," Potter says. "At the same time, we use MRI to diagnose cartilage injuries—injuries to the nerve and other things that might affect the immediate management of the patient."

Other uses at HSS include joint dislocations, particularly the knee, which causes injuries to the veins and arteries right behind the knee. "The patient is first referred for an MRI, and that is used as a surgical planning technique," Potter explains. "Then, using an additional 5 minutes of MR scan time, we do a contrast-enhanced MR arteriogram."

Potter calls it "one-stop shopping" for the patient. "The patients really like it, because they get all of the information at the same time," she says. "All of their questions are answered."

Physicians at HSS also use the ortho/MRA techniques for patients with lupus and mixed collagen vascular disease. "Their renal function has been compromised, and they can't undergo conventional angiography because the contrast could potentially damage their kidneys even more," she points out.

Potter now finds that there's increasing interest from the imaging companies in supporting orthopedic research and development. Also, many orthopedic surgeons are starting to demand more from MRI. "The types of procedures they're doing are becoming much more complex," she says.

More Directions for MRI

The 89th Scientific Assembly and Annual Meeting of RSNA held last November provided a forum for researchers to present new uses for MRI that could enhance diagnosis and treatment for a range of disorders. These are some of the highlights:

• Oded Gonen, PhD, professor of radiology at the New York University School of Medicine, reported on a new method involving MR spectroscopy, which could provide better diagnosis and treatment of multiple sclerosis (MS). Gonen and colleagues used MR spectroscopy to look at the loss of brain tissue and brain cells to determine the root cause of the disease. Using a method they developed called whole brain N-acetylaspartate

(WBNAA), the researchers found that brain-cell loss precedes brain atrophy, or brain-volume loss. Because WBNAA is an earlier and more specific measure of MS, the researchers feel it could be more useful in monitoring early disease and developing new drugs.

• Jonathan H. Gillard, MD, a lecturer and honorary consultant neuroradiologist at Addenbrooke's Hospital at the University of Cambridge in England, discussed an ongoing study involving stroke patients imaged with new MRI technology—a multichannel MRI machine with eight phased-array brain coils. Gillard reported that it can produce the same number of images as the older, two-coil machines and reduces scan time from 20 minutes to just 3. He added that results show the 3-minute scan to be just as good as a 20-minute scan. Further, the new technology is an advance over both the older machines and CT.

• Jonathan H. Burdette, MD, assistant professor of neuroradiology and associate in the department of bioengineering at Wake Forest University (Winston-Salem, NC), reported on the first study to ever use fMRI to study multisensory processing in people with dyslexia. The study yielded what might be an important clue as to why dyslexics have trouble reading: They process auditory and visual sensory cues differently than do normal readers.

Final Thoughts

Product manufacturers continue researching and developing new technology that pushes the MRI envelope. For instance, GE Healthcare is working with a technique called MR-guided focused ultrasound. "The idea is to use MR for guidance in a very noninvasive way," Weber explains. "We build an ultrasound transducer into the existing MR table to focus the ultrasound energy to a pinpoint inside the body. We use the MR to visualize where that pinpoint is, and we guide the transducer to ablate various structures in the body. We're using it to noninvasively ablate uterine fibroids." He thinks that it also will be useful for cancers of the breast, prostate, and brain.

In short, when looking at the developments of MRI and how researchers surmounted various challenges to attain these developments, one can't help but sense a "won't say die" attitude.

Weber concurs: "Through MRI's history, a lot of pessimists have stood at podiums and said, 'You can never do this with MR.' And I think we've checked them off, one by one, through the years. A great example of that was the launch of the 1.5T scanner. A number of people said it couldn't be done, and MR found a way to do it. Next came 3T. With each year, new technical challenges are solved."

Buying and Selling

Michael Brandt of Philips Medical Systems indicates that most of the purchases in the current MRI market, particularly for the high-field systems, are coming from the hospitals and imaging centers, as they're in a very competitive imaging environment. David Weber of GE Healthcare reports that his company sees the majority of its purchases by hospitals; still, he notes that the current higher growth rate is in imaging centers.

As far as costs go, Monali Patel of Frost & Sullivan expects to see slight annual increases for the next several years due to the increased functionality offered by newer equipment. "While the high prices could act as a deterrent to some smaller facilities, most larger facilities have high enough utilization rates that the price does not ultimately affect their decision to purchase a high-end scanner," she says.

New equipment provides faster image scanning, new coil technology, more channels, and more bandwidth performance. The most significant trend is the emergence of 3 Tesla (T) MRI systems. These offer improved signal and speed over 1.5T systems. Some newer systems provide increasing numbers of coils and systems to enable whole-body imaging. State-of-the-art products include:

GE Healthcare's Signa Excite 1.5T is currently supplied with 8-channel coils for parallel imaging and is expanding this year to 16- and 32-channel capability. "Our biggest investment over the past 3 to 5 years has been in our Excite platform, and we continue to develop its fundamental capability and application breadth," Weber says. One example is in GE Healthcare's breast MRI technique, Vibrant, which is built on Excite technology. Vibrant enhances the ease of use and the quality of the MR breast exam and has opened the door for a larger breast imaging patient population. "Your typical MR breast exam is a 2-day affair, because it requires an injection of a contrast agent," Weber explains. "You do one breast one day, and you have to wait until the following day to reinject and do the other breast. Vibrant does it all in one sitting and is more geared for the technologist, making it sort of a push-button exam."

Hitachi Medical Systems America (Twinsburg, Ohio) offers the Airis Elite 0.3T, an open system with a higher gradient specification with gradient strengths of 21 mT/m and a slew rate of 55 mT/m/s. It also features a higher specification host computer.

The Intera Achieva 3T from Philips Medical Systems has the shortest bore of any 3T system on the market. "It comes with the highest gradient performance and power, and it leads the industry in image reconstruction speed performance," Brandt says. The Achieva has an 8- or 16-channel RF system that will be expandable to 32 channels.

Siemens Medical Solutions (Malvern, Pa) offers the new Total Imaging Matrix (TIM), which allows for whole-body imaging without the need for repositioning the coils or the patient. It features a total of 76 individual coil elements. Some of these include seven coils covering the whole body; five coils covering the anterior body (head coil, neck coil, two body coils, and peripheral leg coils); and two coils covering the posterior body (cervical spine and whole spine).

And the Vantage from Toshiba America Medical Systems (Tustin, Calif) has a magnet measuring 140 cm in length, the shortest available on the market. The system comes with standard 4-channel coils, with an 8-channel option.

—DH