SODIUM MR IMAGING

In clinical MR imaging, signals derived from protons attached to oxygen in water and to carbon in fat provide exquisite anatomic detail, enabling clinicians to detect disease and injury through anatomical changes. As medical imaging progressed into the early 21st century, clinicians have gained a greater understanding of the molecular and biological processes behind many of the most prevalent—and costly—diseases, including cancer, cardiovascular disease, and neurodegenerative disease.

According to Keith Thulborn, MD, PhD, Professor of Radiology, Physiology, and Biophysics and the Director of the Center for MR Research at the University of Illinois-Chicago, one of the issues with looking only at anatomy and physiology is that clinicians are assessing disease by the distortion of anatomy after the disease is already well-developed and progressing. “Rather than looking at anatomy and physiology, we have started to investigate the metabolism of pathology to see if this approach will tell us more directly about earlier disease,” he explains. “This could provide the opportunity to intervene much earlier if we can see and quantitatively measure the progression of a pathological process from its earliest stages.”

At the University of Illinois, this quest has led Dr. Thulborn to pursue quantitative metabolic MR imaging, of which sodium MR imaging is the most advanced for clinical applications. Sodium (Na+) is an important ion in maintaining the health of cells. Energy-consuming sodium-potassium ion pumps maintain tightly controlled sodium and potassium ion gradients across the cell membranes to control water balance between the interstitial and intracellular environments, and therefore cell volume. Many other cellular transport systems are also coupled to these sodium-potassium...
ion gradients. Any disease that affects energy production in the cell or membrane permeability compromises the function of these ion pumps, leading to cell swelling and ultimately to cell death. The sodium concentration is high outside, but low inside cells. A measurement of tissue sodium concentration allows the cell density to be derived. It turns out that cell density is a fundamental property of brain structure, having a very narrow range for individuals with normal cognitive function, irrespective of age. Although the brain loses cells with increasing age, the brain shrinks to maintain a near constant cell density.

Sodium MR imaging can measure the cell density, explains Dr. Thulborn.1,2,3 “Whereas proton MR imaging is a qualitative descriptive picture of a disease, sodium metabolic MR imaging can quantify the cell density and any changes that may occur during the progression of that disease.”

In patients with cancer, radiation therapy protocols are based on population statistics from clinical trials using survival as the outcome measure. These protocols are designed to kill tumor cells, while avoiding complications in surrounding brain tissue. The result of these clinical trials is that every patient receives the same radiation dose (fractionated over time), regardless of treatment response. In Dr. Thulborn’s opinion, sodium MR imaging satisfies a yet unmet medical need of measuring tumor response in real-time by measuring cell density to serve as a quantitative indicator or bioscale of the death of tumor cells. “By measuring sodium concentrations during a patient’s treatment on a weekly basis, we can determine not only if the therapy is working, but also how well it is working and where it is working, as some tumors respond in some regions, but not in others,” he adds. Oncologists can use this information to determine how well a treatment is working for a particular patient and how to adapt the course of therapy to improve response where there is no change in cell density.

In cases of neurodegenerative disease, such as Alzheimer’s disease, changes in cell density occur in the hippocampus decades prior to the appearance of symptoms. The measurement of hippocampal cell density could have an impact on future clinical trials. Dr. Thulborn explains, “The clinical manifestation of Alzheimer’s disease occurs only after several decades of progression of the pathological process that begins in the hippocampus before spreading to the rest of the brain. Clinical trials that take decades to complete are not feasible. However, if we can identify people at high risk, such as those with a family history of Alzheimer’s disease, and use sodium imaging to determine if their cell density in the hippocampus is progressively decreasing from normal, then that would suggest that they may be good candidates for a clinical trial.”
Keith Thulborn, MD, PhD, is Professor of Radiology, Physiology, and Biophysics and the Director of the Center for MR Research at the University of Illinois-Chicago. Dr. Thulborn is a leading clinical researcher in the field of MR neuro imaging and has received several awards for his work in neuroradiology. He earned his bachelor’s degree in chemistry and biochemistry and doctor’s of philosophy in biochemistry at the University of Melbourne and his doctor of medicine from Washington University (St. Louis). Dr. Thulborn’s research entails the development of MR imaging technology for functional, physiological, and metabolic investigations of the normal human brain and in the setting of pathology. He has published over 100 articles, nearly 200 abstracts, and has been invited to speak at numerous medical meetings and events.

The Center for Magnetic Resonance Research at the University of Illinois at Chicago has the mandate to develop advanced MR imaging techniques for human neuroimaging using a 9.4T GE magnet and both brain and body MR imaging on a 3.0T GE Discovery® MR750 scanner. The Center houses the world’s first 9.4T scanner specializing in quantitative metabolic MR imaging of the human brain along with laboratories for non-human primate physiology, electronics development, computer software, and pulse sequence development as well as faculty offices and conference room for educational and clinical activities. The Center has three full-time faculty with support staff and students.

References

Figure 2. One partition of the 3D TCF bioscale maps of a patient with a high grade brain tumor in the left frontal lobe after resection and fractionated radiation treatment and now undergoing Temodar chemotherapy showing resection cavity (blue-black fluid space) with a surrounding margin of abnormal decreased TCF that was stable over multiple chemotherapy cycles (left map) but then after the last cycle (right map), expanded along the posterior margin (white arrow), indicative of tumor recurrence that was confirmed by subsequent proton MR imaging at 3.0T. Sodium MR imaging was performed as in Figure 1 after each cycle of Temodar and TCF remained stable, suggesting little response. Figure supplied by Ian Atkinson, PhD, UIC.

Images courtesy of University of Illinois-Chicago, College of Medicine, Center for MR Research.
SILENT MR TECHNOLOGY: MOVING BEYOND T1

Creating an entire silent brain exam is integral to GE Healthcare’s Humanizing MR mission

During the past two years, GE Healthcare has announced groundbreaking developments in MR that provide quality, affordable care to more people worldwide—underscoring the guiding principle of Humanizing MR.

The buzz now is about the introduction of Silent Scan®, innovative technology designed to address one of the most significant impediments to patient comfort—excessive acoustic noise generated during an MR scan. But GE Healthcare is not stopping there, as the company is in the process of moving beyond T1 to develop an entire silent (i.e. near ambient noise levels) brain exam incorporating all MR imaging contrasts.

“The goal, explains Bryan Mock, MR Product Manager at GE Healthcare, is to provide clinicians with the tools for a routine, complete brain exam using T1, T2, FLAIR, MRA, and Diffusion, but make it silent.

Yet, according to Dawei Gui, PSD Engineer for GE Healthcare, applying the current Silenz acquisition technology to T2 sequences isn’t straightforward. “The commercial product is a gradient echo approach,” he says. “So we are currently studying how the concept works in a spin.
Doctors need the ability to visualize the vasculature to eliminate problems that may be present in those structures. GE Healthcare is developing a silent MR angiography acquisition that is based on arterial spin labeling preparation pulses, explains Sun. The current technology is based on time of flight (very fast imaging where “unsaturated blood” flows into the slab and appears “bright” compared with surrounding tissue) or contrast-enhanced fast gradient echo imaging (very fast imaging where the contrast is derived from the change in T1 of the blood due to the gadolinium).

While both techniques generate images of the brain’s vasculature, both sequences often exceed 100 dB of acoustic noise.

echo approach. We want to reduce noise but maintain SNR, resolution, and image quality.” As such, the company is actively pursuing silent T2 contrast by manipulation of sequences to optimize gradient waveforms. “We’re interrogating all aspects of conventional MR, and we’re looking at innovative ways to obtain T2 contrast like physicians are used to seeing in a silent acquisition,” comments Polzin.

GE Healthcare’s efforts include leveraging PROPELLER, a fast-spin echo based T2 technique that has excellent motion-insensitive properties and can help eliminate subtle motion artifacts. However, this sequence is still quite loud. Gui and Wei Sun, Senior PSD/Applications Engineer at GE Healthcare, are taking a hard look at all aspects of these conventional sequences to optimize the gradient waveforms, the fundamental source of noise, to reduce the acoustic signature. This includes eliminating larger crusher gradients, minimizing gradient transitions where unnecessary, and avoiding mechanical frequencies of the magnet/gradient system. “By careful optimization, we are looking at ways to reduce the acoustic noise while maintaining high image quality,” offers Gui.

The design goals include the ability to image the vasculature in the brain to look for occlusions and malformations. Doctors need the ability to visualize the vasculature to eliminate problems that may be present in those structures. GE Healthcare is developing a silent MR angiography acquisition that is based on arterial spin labeling preparation pulses, explains Sun. The current technology is based on time of flight (very fast imaging where “unsaturated blood” flows into the slab and appears “bright” compared with surrounding tissue) or contrast-enhanced fast gradient echo imaging (very fast imaging where the contrast is derived from the change in T1 of the blood due to the gadolinium).
In the silent technique, the blood within the carotid arteries is “tagged” using a long RF inversion pulse commonly referred to as a “labeling” pulse. Once the blood is tagged, it is allowed to flow into the vasculature and captured by the Silenz acquisition. This is followed by the collection of a control dataset where a “labeling” pulse is applied above the head to minimize magnetization transfer effects and to control artifacts. These two datasets are subtracted to eliminate the background, leaving a depiction of the entire vascular tree.

An additional benefit of a conventional or silent ASL technique is the absence of exogenous contrast, adds Mock. “Since the Silenz sequence is a radial 3D acquisition, the data produced is isotropic and can be reformatted into any plane without loss of resolution. In addition, the radial acquisition enjoys a very short TE (~8 ms), so the sequence does not suffer from in-plane, intra-voxel flow dephasing.”

Going farther

According to Mock, GE Healthcare’s next goal is to move outside of the brain. “Silent imaging requires stable power electronics, unique acquisition technologies, and extremely fast RF switching technology in the RF receive coils. Once we have the complete neuro exam validated, then we’ll evaluate RF coils to determine which ones can switch fast enough between transmit and receive for high SNR and high artifact-free data outside of the brain.” Mock continues, “Our continued research and development includes an evaluation of the hardware, coils, or how it translates to MSK or body, for example. At that point, we expect to also look at adding respiratory gating, navigators, and other motion compensation techniques to enable free-breathing silent body imaging.”

Adds Polzin, “These silent sequences are expected to become another tool for radiologists. They could be used for patients intolerant of noise, just as PROPELLER is used for patients who move. There may be tradeoffs, but physicians are seeking solutions that can help them achieve results. Our investment in developing these silent sequences is one element of our commitment to Humanizing MR.”

Acknowledgement:
The editor sincerely acknowledges the direction and input of GE Healthcare’s Dawei Gui, Senior PSD/Application Engineer; Bryan Mock, MR Product Manager; Jason Polzin, Chief Technology Leader, Software & Applications; and Wei Sun, PSD Engineer.
Brown Adipose Fat

A type of tissue found in a number of mammals—including mice, bears, and infant humans—and previously thought to have regressed in adult humans is generating excitement in the research community. Brown adipose tissue (BAT), called “brown” due its appearance under a microscope, regulates thermogenesis—it metabolizes fatty acids and carbohydrates to create heat. It’s what keeps mice and rats warm when it is cold outside.

According to Scott Reeder, MD, PhD, Section Chief of MRI and Cardiovascular Imaging, and Director of the UW clinical MRI fellowship, University of Wisconsin-Madison, the presence of BAT in adults was noticed in the late 1990s and early 2000s with widespread use of PET/CT for cancer staging. “Some patients had abnormal uptake in the interscapular region and also along the spine, particularly the cervical spine, and even in the heart—this was found to be activated BAT.” This became problematic for PET/CT imaging in cancer patients as the uptake mimicked deposits of metastatic cancer. Dr. Reeder and his colleagues were often asked to image these patients with MRI to determine if the area of uptake was metastatic cancer or BAT.

“What is most interesting is that scientists realized that since adults have BAT, it could be an excellent, potential target for drug therapy to treat obesity,” Dr. Reeder explains. “So imagine if you could give a drug that would turn on the BAT and make it more active, and therefore burn more calories, then you could potentially treat metabolic syndrome and obesity by giving a pill.”

This interest extends to the National Institutes of Health (NIH) for new biomarkers to identify, quantify, and measure or detect activation of BAT. Additionally, the NIH has a request for applications (RFA) for developing non-PET-based biomarkers of BAT, such as MRI.

Most of the research work performed to date on BAT has been in animal studies. “The challenge in adult humans is having the ability to validate it with a reference standard, which ultimately will be histology,” Dr. Reeder
Scott B. Reeder, MD, PhD is the Section Chief of MRI and Cardiovascular Imaging, and Director of the UW clinical MRI fellowship at the University of Wisconsin-Madison.

Dr. Reeder adds, “The T2* of BAT in wild type mice is lower than the T2* in obese mice, which means researchers may be able to characterize BAT and different metabolic state based on T2* and fat fraction.”

Even with the research data available and the discovery of BAT in adult humans, Dr. Reeder stresses there is a need for further study. “One interesting technique would be to fuse MR and PET for a correlative study of the activation of BAT,” he explains. PET is accepted as a biomarker of the activation of BAT, and Dr. Reeder sees potential for a study that would use MR chemical shift encoded fat quantification methods to identify the location, followed by PET to characterize the BAT as a reference standard. He adds that a study presented at the ISMRM Fat/Water conference in 2012 by Rosa Tamara Branca, PhD, demonstrated the ability of hyperpolarized Xenon imaging (Xenon 129) to locate and activate BAT.

“The studies being conducted on BAT are very exciting, and while this is still research-based, I see great potential in future clinical use,” Dr. Reeder concludes.

References

Animal studies have also shown that obese mice have a higher concentration of triglycerides in BAT than wild mice.

Dr. Reeder says. As researchers begin to translate the work in animal studies to humans, MR-based chemical shift encoded fat quantification methods are being utilized, he adds.

“Using this MR technique, it has been found that the proton density fat fraction is lower in BAT, as opposed to white adipose tissue (WAT). BAT has a higher number of organelles, such as mitochondria, as well as higher density of blood vessels and other water containing structure, that lower the overall concentration of triglycerides compared to WAT,” Dr. Reeder explains.

“Using methods developed by our group, several other groups have demonstrated in mice that we can distinguish BAT from white adipose tissue using fat fraction as a threshold. Early human studies have also shown exciting preliminary results.”

Animal studies have also shown that obese mice have a higher concentration of triglycerides in BAT than wild mice.
MR elastography (MRE) is a technique developed by Richard Ehman, MD, and colleagues at Mayo Clinic (Rochester, Minn.) that uses low-frequency mechanical waves to probe the elastic properties of tissue. These mechanical waves are generated in the body through an external acoustic driver and are then imaged using a special phase-contrast MR sequence. Using a sophisticated mathematical algorithm, the mechanical wave data collected by the MR scanner are then used to generate a diagnostic image that depicts tissue stiffness, called an “elastogram.” Several studies have demonstrated the clinical accuracy of MRE for assessing hepatic fibrosis in patients.1

According to John Huston III, MD, a neuroradiologist at the Mayo Clinic, in the early development stages of MRE, Dr. Ehman and Joel Felmlee, PhD, felt that the technology could also be applied to brain imaging. As MRE became a commercial product for the liver, research began at Mayo Clinic on the potential application in the brain.

The first step was to develop a driver to transmit waves through the skull that was comfortable yet effective; next was to select the optimal pulse sequence—a single shot spin-echo echo planar pulse sequence.

There was another hurdle to overcome. “Typically the wave propagation through the liver is relatively uniform and the stiffness can be determined with a two-dimensional inversion. The wave fields in the brain, however, are extremely complicated due to the curved skull and fixed structures like the falx, and the inversion methods used in the liver didn’t work intracranially.”

To address the need for 3D imaging of the brain using MRE, Dr. Huston worked with Matt Murphy, PhD, and Armando Manduca, PhD, mathematician at Mayo Clinic. Together they developed a method for performing 3D inversions with MRE. With all three pieces in place, brain MRE studies began.

Dr. Huston first focused on a diffuse disease, working with Clifford Jack, Jr., MD, and a world-renowned imager in the study of Alzheimer’s Disease (AD) at Mayo Clinic, to measure brain stiffness in a mouse model of AD. In their studies, they found that MRE could detect the brain to be softer in these mice who produce many amyloid plaques compared to age-matched wild-type mice.2 With this initial success, they moved to patient studies and found the same thing. “With the progression of Alzheimer’s, the patient’s brain becomes softer due to degeneration.”3

While much remains to be completed, Dr. Huston is hopeful that by combining MRE with other MR imaging techniques—hippocampal volume, MR spectroscopy, and diffusion—there is potential to make a differential diagnosis in the setting of cognitive decline. The real challenge, he says, is how to differentiate the various dementias and distinguish someone with mild dementia that will lead to Alzheimer’s versus vascular dementia or mild cognitive impairment that will not progress to dementia.

This article discusses ongoing research being conducted at Mayo Clinic and the ongoing research is being conducted with support from GE Healthcare.
After studying a diffuse disease, Dr. Huston next turned his attention to a focal disease—meningiomas. Meningiomas can present as a hard tumor that involves a tedious, lengthy, and more risky surgery or as a soft tumor that is easier to dissect. However, Dr. Huston says 90% of meningiomas appear very similar when imaged by traditional MR sequences, so it is difficult for the neurosurgeon to know prior to the surgery which tumor type he/she will face.

A published study authored by Dr. Huston and his colleagues at Mayo Clinic found that throughout the spectrum of tumor stiffness there was a good correlation between the surgeon’s assessment of tumor stiffness at the time of resection and the pre-surgical measurement with MRE. “The information regarding the stiffness of a meningioma provided by MR Elastography enables the neurosurgeon to more confidently communicate with the patient the risks and difficulty of an operation and also provides the surgical team the ability to allocate the appropriate time and resources to perform the case,” explains Fred Meyer, MD, Chair Department of Neurosurgery at Mayo Clinic.

“I believe we have reached a point where we have developed a very good tool,” Dr. Huston says. A key factor in the success of his research is the acoustic driver. “This soft pillow driver has been well accepted by our patients and it provides a MRE exam with whole brain coverage. We are very excited where we are right now,” he adds, “and we hope that in the future, anyone who has MR Touch and the brain driver will be able to do these studies.”

References

John Huston III, MD, is a neuroradiologist at Mayo Clinic. He attended medical school at the University of Iowa College of Medicine in Iowa City, Iowa and performed his residency at Diagnostic Radiology, Mayo Graduate School of Medicine, Mayo Clinic, Rochester, Minn. Dr. Huston’s fellowships took place in neuroradiology and diagnostic radiology, Mayo Graduate School of Medicine. His certifications include the American Board of Radiology - Neuroradiology and the American Board of Radiology. Dr. Huston is also a Professor of Radiology and he is widely published. His research interests include cerebrovascular disease, including carotid atherosclerosis and intracranial aneurysm; high field MR clinical imaging; and MR angiography.

Fredric B. Meyer, MD, is the Chair of Neurosurgery at Mayo Clinic. He attended medical school at Boston University in Boston, Mass., and performed his residency at Mayo Graduate School of Medicine, Mayo Clinic, Rochester, Minn. Dr. Meyer is also a Professor of Neurosurgery who has been widely published. His interests include the following types of surgery: brain tumor and aneurysm; epilepsy; pituitary; hemifacial spasm; trigeminal neuralgia; awake brain; Moyamoya disease; spinal cord tumor; and pediatric brain tumor.

Mayo Clinic is a nonprofit worldwide leader in medical care, research, and education for people from all walks of life. Doctors from every medical specialty work together to care for patients, joined by common systems and a philosophy of “the needs of the patient come first.” Mayo Clinic is governed by a 33-member Board of Trustees.
Ultra high-field MRI, i.e., 7 tesla and beyond, is becoming progressively more available for fundamental and clinical research involving human subjects. At the 2012 Radiological Society of North America annual meeting, Kohsuke Kudo, MD, PhD, Division of Ultra High-Field MRI at Iwate Medical University in Japan, was lead author on poster LL-NRE1309, “7.0T MRI is Now Ready for Clinical Neuroimaging: Current Concepts and Applications of Ultrahigh Field.” Following is a review of the poster.

7.0T MRI is labeled as an investigative device and cannot be used for clinical diagnosis. Instead, it can be used for clinical research under the approval of an institutional review board and informed consent.

The 7.0T MR environment

For the 7.0T MR clinical trial, Dr. Kudo and his team used a Discovery* MR950† from GE Healthcare. The magnet arrived in March 2010. Because it was not actively shielded, about 400 tonnes of room shielding was required. The installation process lasted one year, with some delay due to the severe earthquake in Japan. After system completion, human scanning commenced starting in April of 2011.

In the MRI scanner room, the fMRI tools included a headphone and goggles, airline-style headphones, and a response pad. The head coils were two channel quadrature transmit, 32-channel receive, and the power injector (Nemoto, Sonic Shot GX) worked well, even close to the magnet—so it was located nearby where dynamic Gadolinium (Gd) administration could be easily performed. The patient monitor (Schiller, Maglife C Plus), anesthetic

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Figure 1. In spite of B1 field inhomogeneity in 7.0T, uniform suppression of CSF signal by inversion pulse is achieved. Good contrast is observed for the white matter lesions (red arrows) and iron deposits in the basal ganglia (blue arrows), with minimum blurring on MRP images.

Images were obtained using an investigational device.
The longer T1 improved quality of MR angiography, including greater inflow-effect and better suppression of brain signal. Additionally, duration of tagged spin became longer in arterial spin labeling; however, T1 contrast on SE/FSE T1WI was lower than 3.0T and R1 relaxivities of Gd in 7.0T were lower than 3.0T.

In a normal subject, small perforating arteries and anterior choroidal arteries were better seen in 7.0T MRA as well as the periphery of cortical branches. In a glioblastoma subject, strong enhancement of tumor was seen in 7.0T, with better suppression of parenchymal signal. The margin of ring-enhanced tumor was clearer in 7.0T because of increased spatial resolution.

With T2 shortening (the susceptibility effect), T2* decreased as the square of static magnetic field (B0) - 22 times larger than 1.5T and 5.4 times larger than 3.0T. T2* shortening yielded better contrast for susceptibility-based imaging, such as T2* weighted imaging (WI), functional MRI (fMRI, BOLD) and dynamic susceptibility contrast (DSC) weighted imaging. However, it caused image distortion and artifact, especially for GRE and EPI scans.

Additionally, in a normal subject, the cerebral veins and iron deposit in the basal ganglia were better seen in T2* WI at 7.0T than 3.0T. Furthermore, susceptibility artifact from the skull base was more remarkable in 7.0T T2* WI and phase shift was linear to static magnetic field (B0): 4.7 times greater than 1.5T and 2.3 times greater than 3.0T.

Safety and workflow

Safety of MRI depends on the strength of the main magnetic field, gradient, volume (dB), and specific absorption rate (SAR). Although a main field less than 8.0T (or 4.0T for neonates) is classified as “non-significant risk device” by the FDA, 7.0T MRI is not approved for clinical use.

Vertigo was the most common complaint, but it occurred mostly during table movement (due to dB/dt change). The rate of vertigo was smaller in our institute compared with previous reports, likely due to the slower table speed of the system (2 cm/s). Other complaints were rare (less than 5%) and all were transient. More than 400 subjects were scanned at Iwate Medical University without any severe adverse effects.

Our workflow for a 7.0T scan includes (in this order) prescreening, informed consent, changing clothes, a metal survey, the 7.0T scan, changing clothes, and a questionnaire. Particular attention was paid to potential metallic objects. Our staff included two MDs, three PhDs, two post-doc fellows, one research fellow, one programmer, one MR technologist, two nurses, and one administrative assistant.

Imaging characteristics

Here are some characteristics of a higher signal-to-noise (SNR) ratio of ultra high-field MR such as 7.0T:

- SNR was linear to static magnetic field (B0)
- 4.7 times greater than 1.5T
- 2.3 times greater than 3.0T
- Higher SNR allowed flexible tradeoff between parameters of interest
- Higher spatial resolution
- Shorter scan time
- Wider receive bandwidth
- Increased parallel acquisition factor
- Multi-nuclei imaging (1H, 19F, 31P, 23Na, 13C, 17O...)

Higher spatial resolution was achieved by higher SNR:

- 2D: < 0.2 mm in plane, < 2.0 mm thick
- 3D: < 0.5 mm isotropic
- Acquisition matrix was increased up to 1024 for 2D, and 512 for 3D sequences without interpolation
- Margins of MS plaques were clearly seen as well as the medullary veins in the plaque—even with an FSE image
With a Multiple Sclerosis (MS) subject, ring hypointensity of MS plaque was observed on phase images, possibly due to iron deposits in the periphery of MS plaque. Penetrating vein in the MS plaque was also seen on phase image. With 200μm quantitative susceptibility mapping (QSM) (a novel method to quantify local susceptibility) which reflected tissue iron, deoxy-Hb, and other paramagnetic or diamagnetic materials. For DWI/DTI of the tuberculum sellae meningioma, to reduce image distortion and susceptibility artifacts, a larger parallel factor or smaller matrix size should be used for 7.0T diffusion weighted imaging (DWI) and diffusion tensor imaging (DTI). Only mild distortion was noted on this skull base tumor. Additionally, regarding volume DWI of a normal subject, although image distortion was noted near the skull base, whole-brain coverage was possible for DWI. For TOF-MRA of the left MCA stenosis (leptomeningeal anastomosis) and Moyamoya disease (transdural anastomosis), due to longer T1 relaxation time, time-of-flight effect persisted even in the periphery of cerebral arteries.
in 7.0T. Leptomeningeal anastomosis (distal ACA) was seen in 7.0T MRA, which corresponded well to digital subtraction angiography (DSA). Transdural anastomosis (from the middle meningeal artery) could be also visualized in Moyamoya patients. For high grade glioma, fine tumor vessels as well as the feeding arteries were seen on 7.0T MRA, utilizing longer T1 relaxation and higher SNR.

Furthermore, with 200μm TOF-MRA of a normal subject, a lot of perforating arteries were seen on 7.0T MRA, including lateral striate arteries, medial striate arteries, and recurrent artery of Heubner. These perforating arteries on 7.0T MRA were comparable with histological specimen. Because of the limitation in receive coil sensitivity, it was difficult to obtain high SNR image in the posterior fossa; however, pontine arteries and paramedian artery were seen with high-resolution MRA. With a ruptured arterio-venous malformation (AVM) subject, not only feeding arteries, draining veins of AVM were observed without Gd administration.

Regarding PC MRA of a normal subject, whole-brain coverage was achieved with phase contrast MRA. In a 3D FIESTA of tuberculum sellae meningioma, because of the SAR limit, a large flip angle couldn’t be used in FIESTA; however, good contrast was achieved with a mild range flip angle. Although banding artifacts were noted on skull base tumor in the sagittal image, those artifacts were not seen on axial acquisition. With Gd-Enhanced SPGR, because of the difficulty in obtaining good contrast on SE/FSE T1WI, SPGR was an alternative sequence that provided high resolution post-Gd images. In addition to the tumor itself, many tiny vessels were seen. For Gd-enhanced Cube T1WI of tuberculum sellae meningioma, post-Gd Cube T1WI was useful for the evaluation of skull base tumor while SPGR had strong image distortion or artifact in this area.

For DSC of high-grade glioma, SE-EPI was more sensitive to micro vessels than large vessels compared with GRE-EPI; however, SNR of SE-EPI was inadequate, even with 3.0T. SE-EPI on 7.0T had better SNR, and a high SNR cerebral blood volume (CBV) image could be obtained. A ring-like area of increased CBV corresponded well to micro tumor vessels on MRA. With ASL of Moyamoya Disease, due to longer T1 relaxation time, efficacy of tagged spin continued in the ischemic area, which contributed to better quantification of CBF in ASL.

With oxygen extraction fraction (OEF) map, a relative change in OEF was quantified by OEF map using T2* phase image (9 sec). Regarding the right middle cerebral artery occlusion, absolute quantification of OEF was achieved using QSM, based on susceptibility measurement of deoxy-Hb in the veins. OEF increase in the right side corresponded well to PET-OEF. For MRS of glioblastoma (G4), separation of metabolite’s peak was improved in 7.0T MRI and necrosis patterns were observed in the tumor. With fMRI of a glioblastoma preoperative study, localization of motor and speech area was done before the surgery.

Additionally, regarding Parkinson’s Disease, neuromelanin imaging was achieved with magnetization transfer (MT) contrast, although it was difficult to limit SAR. High signal intensities were identified in substantia nigra pars compacta and locus coeruleus.

**Summary**

7.0T MR is proving to be a very useful research tool. It can provide great insight and physicians are learning many new, innovative things. As a result of this clinical study, more physicians and facilities will likely pursue 7.0T clinical research.

**References**


‡ Investigational device not commercially available. Limited by law to investigational use in compliance with applicable local ethics and research requirements.
In 2011, Charles (Chuck) Dumoulin, PhD, Director of the Imaging Research Center at Cincinnati Children’s, spearheaded the development of a new type of neonatal MRI scanner. The Cincinnati researchers launched a pilot safety study in February, 2012 and commenced using the investigational MR scanner for clinical research imaging in May, 2012. Since starting clinical research imaging on the NICU MR, Dr. Kline-Fath has been able to evaluate the posterior fossa and the brainstem, identify swelling in the brain, determine if a hemorrhage was acute or chronic, and define abnormal development of the cells in the brainstem.

Infection is always a concern when we move them out of the NICU,” explains Dr. Kline-Fath. Armed with research that demonstrates improved outcomes for neonates when a disorder of the brain, spine, lung or abdomen is properly diagnosed, Dr. Kline-Fath felt that MR was the answer. “Ultrasound remains a mainstay for imaging neonates; it is efficient, portable and provides good resolution with no radiation. However, it does not provide the soft tissue detail, 3D anatomy or visualization of structures behind bone or air that we can obtain from MR.”

Figure 1. Coronal SSFSE T2 image in a 36 wk infant with history of prematurity. There is an evolving left grade 4 hemorrhage with porencephalic cyst and low T2 signal inferior consistent with evolving hemorrhage.

In 2011, Charles (Chuck) Dumoulin, PhD, Director of the Imaging Research Center at Cincinnati Children’s, spearheaded the development of a new type of neonatal MRI scanner. The Cincinnati researchers launched a pilot safety study in February, 2012 and commenced using the investigational MR scanner for clinical research imaging in May, 2012.

Since starting clinical research imaging on the NICU MR, Dr. Kline-Fath has been able to evaluate the posterior fossa and the brainstem, identify swelling in the brain, determine if a hemorrhage was acute or chronic, and define abnormal development of the cells in
Figure 2 A. Fetus born at term with multiple anomalies. Figure A is a 2D Sagittal Fiesta showing absence of the corpus callosum and complex interhemispheric cyst (arrows). Figure B is an Axial FSE T2 image showing the complex interhemispheric cyst (solid arrow) and abnormal appearance of the sulci along the right parasagittal frontal lobe (dotted arrows) consistent with migrational abnormality.

Images were obtained using an investigational device and courtesy of Cincinnati Children’s Hospital Medical Center.

Figure 3. Term infant with meningitis. Image A is a diffusion image showing restricted diffusion in the left frontal lobe (arrow). Figure B is a Coronal SSFSE T2 with loss of the cortical ribbon and sulci (arrows) consistent with cerebritis.

Images were obtained using an investigational device and courtesy of Cincinnati Children’s Hospital Medical Center.
Figure 4. Neonate born premature with multiple episodes of necrotizing enterocolitis. Coronal 2D Fiesta shows multiple abnormally dilated bowel loops (arrows). Neonate clinically has feeding intolerance.

Images were obtained using an investigational device and courtesy of Cincinnati Children’s Hospital Medical Center.

Figure 5. Term infant with mass on thigh. Figure A is a Coronal STIR and Figure B is fat saturated SSFSE T2 image showing large heterogeneous mass (solid arrow) extending into the muscles (dotted arrows) along the medial thigh.

Images were obtained using an investigational device and courtesy of Cincinnati Children’s Hospital Medical Center.
the brain. MR sequences, such as DWI, provide information in cases of ischemia while MR spectroscopy measures important metabolites in the neonatal brain, such as lactate.

“We see improvements in survival rates for neonates when appropriate therapy is applied,” Dr. Kline-Fath explains. Her department is using MR to help research common neonatal issues, including neonatal bowel pathologies, airway disorders, hypoxic ischemic disease, and premature white matter injury. In the case of white matter disease, Dr. Kline-Fath is using MR to better understand what is occurring in the brain to cause the destruction of white matter.

For Dr. Kline-Fath, the future is bright for MR imaging of neonates. “If we can diagnose common disorders in neonates that are detrimental to a child in their later years, then we are making a huge difference in their life,” she says. “I think this is a necessary change for the future...to improve child health, we need to start when they are neonates.”

With the MR in the NICU, Dr. Kline-Fath is working with her colleagues to improve the care for the tiniest, most fragile patients.

Beth M Kline-Fath, MD, is Associate Professor of Radiology, Pediatric Neuroradiologist, and Chief of the Fetal Imaging Division at Cincinnati Children's Hospital Medical Center in Cincinnati, Ohio. Dr. Kline-Fath received her undergraduate and medical degrees from the University of Cincinnati. After completing a residency in Radiology at the University of Cincinnati, she completed a fellowship in Pediatric Radiology at Cincinnati Children’s. Dr. Kline-Fath worked in private practice for several years before returning to Cincinnati Children’s for fellowship training in Pediatric Neuroradiology. Since joining the Neuroradiology Staff, Dr. Kline-Fath has developed the Fetal Imaging Program for the department and is a staff member of the Fetal Care Center of Cincinnati. In addition to general Pediatric Neuroradiology, her areas of interest include fetal imaging and MR spectroscopy.

Cincinnati Children’s Hospital Medical Center ranks third in the nation among all Honor Roll hospitals in U.S. News and World Report’s 2012 Best Children's Hospitals ranking. It is ranked #1 for neonatology and in the top 10 for all pediatric specialties. Cincinnati Children’s is one of the top two recipients of pediatric research grants from the National Institutes of Health. It is internationally recognized for improving child health and transforming delivery of care through fully integrated, globally recognized research, education, and innovation. Additional information can be found at www.cincinnatichildrens.org.
In healthcare today, patients are not only looking for an accurate diagnosis, but for a positive diagnostic imaging experience as well. After all, it’s bad enough to be sick. Patients shouldn’t have to leave their self-respect in the changing room or be fearful about not feeling in control. At GE Healthcare, we want patients to feel safe and at ease, while helping to make their MR experience more pleasant and comfortable.

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