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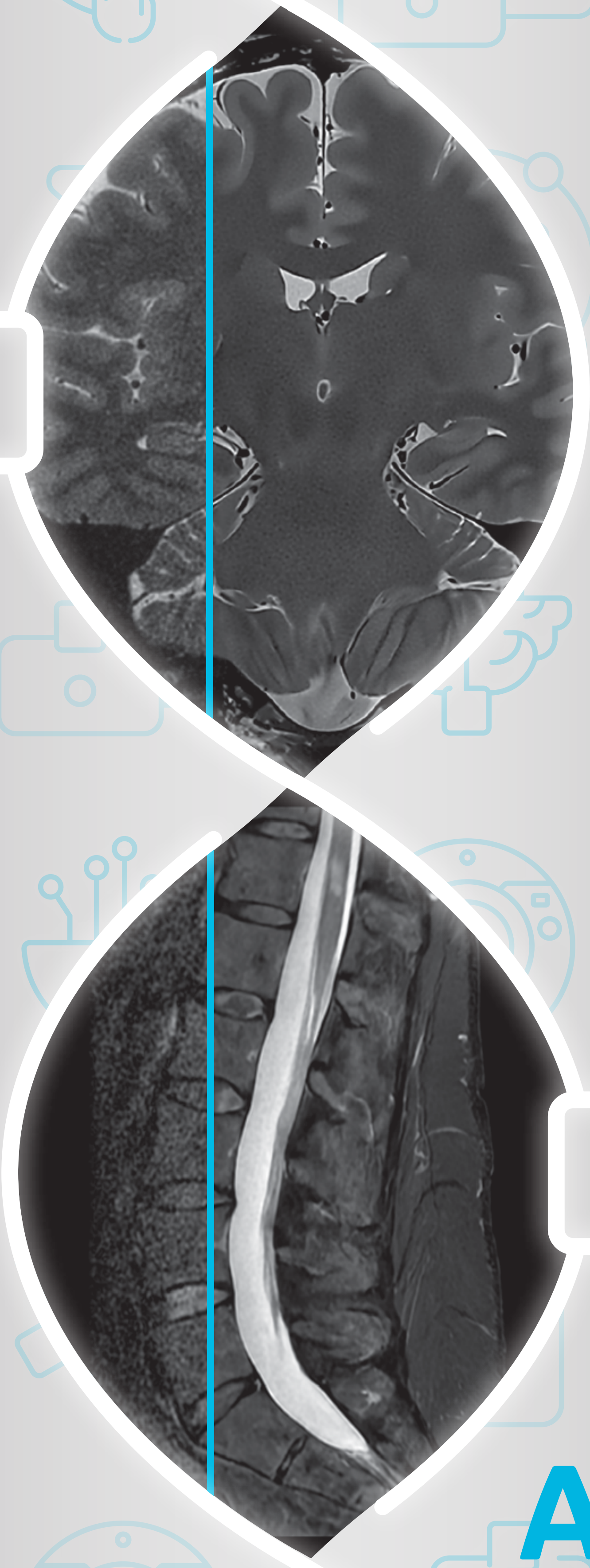

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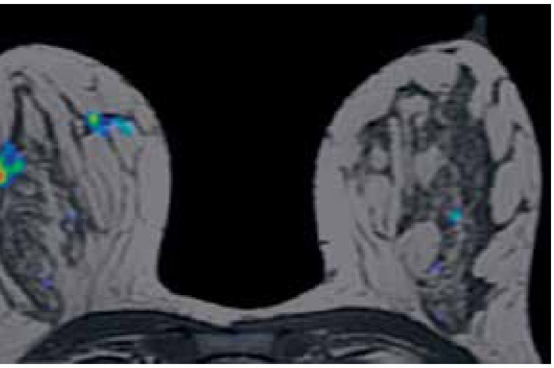

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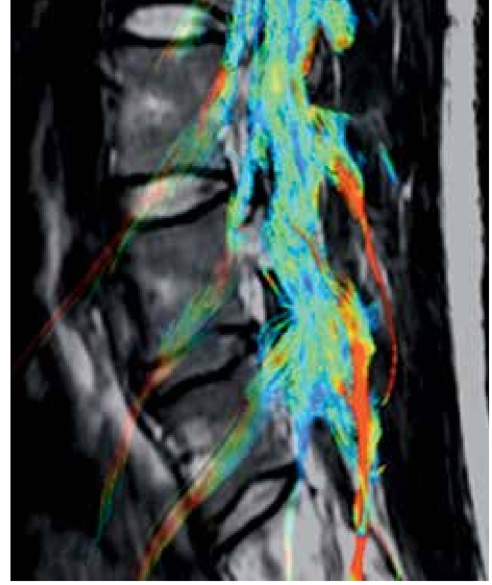

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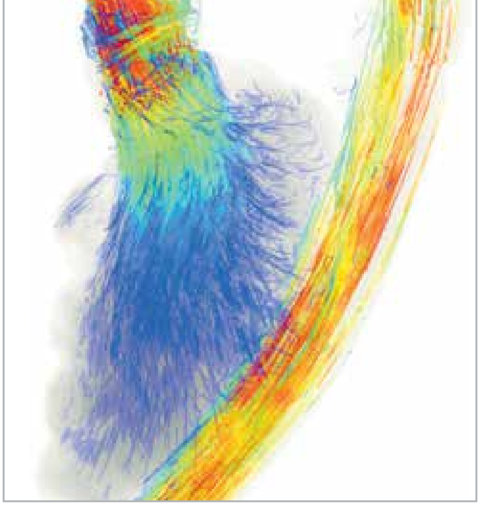

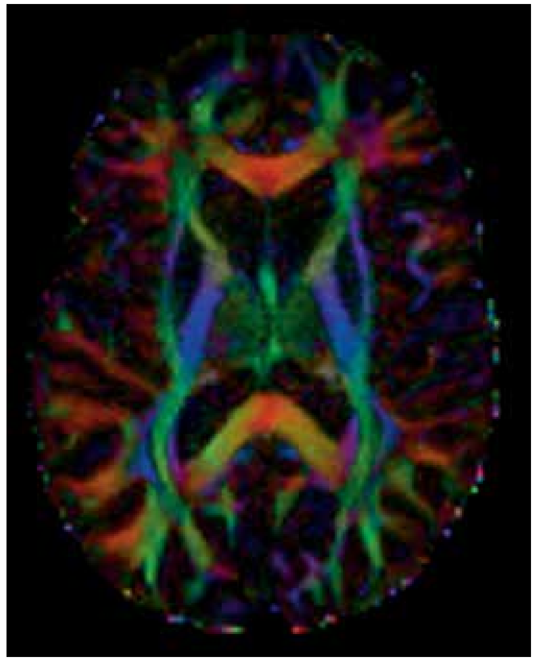

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Supercharging MR with AI

As we enter a new era of healthcare defined by the emergence of AI, it's imperative that we rethink not just the technologies that make up our AI solutions, but how we implement these tools. That means developing technology fully integrated with AI from the beginning, embedded into systems and software so it's a seamless clinical experience.

At GE Healthcare, we're aiming to become the center of gravity for this AI innovation. We're evolving our mindset around AI as a set of technologies and productivity tools that have the power to help you transform patient outcomes. We're powering breakthroughs using AI that can improve workflow so you can maximize productivity and save lives in the moments that matter.

We're also creating an ecosystem of technical and clinical knowledge, starting with the clinicians who use these systems every day. The best way to understand how to reduce costs, increase access and improve quality are to talk to the clinicians who live this reality. That's why GE partners with clinical experts at academic institutions and leading healthcare facilities around the world. These connections help us live in your workflows, understand your pain points and then apply this powerful technology to drive better outcomes.

These partnerships have powered advancements like our Edison intelligence platform. Edison helps accelerate the development and adoption of AI technology and empower providers to deliver faster, more precise care. Embedded within existing workflows, Edison applications can integrate and assimilate data from disparate sources and apply analytics or advanced algorithms to transform the data and generate clinical, operational and financial insights.

For example, AIR x™, which stands for Artificial Intelligence Prescription, is built on Edison as an AI-based, automated workflow tool. It uses deep-learning (DL) algorithms built right into the MR technologist's workflow to automatically identify anatomical structures to "prescribe" slices for neurological exams, delivering consistent results to facilitate quantitative analysis.

Another example is a new MR image reconstruction method, AIR™ Recon DL‡, representing an evolution in digital image reconstruction for reducing traditional image artifacts. It is a DL-based, convolutional neural network to intelligently reconstruct a final MR image with a high signal-to-noise ratio and image sharpness. AIR™ Recon DL is not a post-processing technique, rather it is embedded directly in the reconstruction pipeline, where the neural network model is applied to acquired input data to remove noise and ringing artifacts prior to final image formation. By operating on raw data within the online reconstruction pipeline, AIR™ Recon DL benefits from access to the full set of acquired source data to generate an image, compared to after DICOM image conversion where important information may be lost.

To accelerate our AI journey, we have developed strong strategic alliances with several leading AI-related global technology companies. With Amazon Web Services, leveraging SageMaker data science tools helps our GE data scientists build best-in-class AI solutions. The alliances with Intel®, Hewlett Packard Enterprise and NVIDIA® help bring the most sophisticated AI technology to our 500,000 imaging devices globally and accelerate the speed at which healthcare data can be processed, allowing clinicians to review critical findings at the point of care to accelerate patient diagnosis.

We believe AI should feel invisible while it works silently in the background to make life easier for clinicians. It's like a driverless car — we're not excited because it's built with AI. We're excited because it gives us a more relaxing commute, improves safety on the roads and allows us to do more in a day.

That's our vision for AI in healthcare. It's why we strive to access and provide unbiased data science that's integrated straight into your workflow, while delivering a greater impact in patient care pathways.

Karley M. Yoder
VP & GM, Edison AI
GE Healthcare Digital

‡510(k) pending at the US FDA. Not yet CE marked. Not available for sale.

Passing the baton

Allen Song, PhD, Professor of Radiology, Duke University School of Medicine and Director, Duke-UNC Brain Imaging and Analysis Center (BIAC)

What an exciting year for GE Healthcare MR! Now equipped with the most complete and advanced lineup of clinical systems and research scanners, as well as imaging software that enables seamless workflows to achieve the most accurate and efficient diagnosis throughout the body, GE MR is positioned better than ever in its continued quest to elevate radiology.

As usual, the advances presented in this issue, based on the state-of-the-art imaging hardware and software, are just some of the “HyperSense” sampling of how GE MR is expanding the role of radiology in healthcare. Not only are we improving the accuracy of our diagnoses, we are also enabling early detection of various diseases, and helping to plan new treatment options. Specifically, GE continues to innovate its AIR™ family of products… and it’s not just the remarkable AIR™ Coils, including the new AIR™ Multi-Purpose Coils*. You can read how AIR x™ is making a difference in imaging workflow and radiology reading and learn about the new AIR™ Recon DL‡, a deep learning-based convolutional neural network that delivers amazing image quality.

In this issue, you can also read how GE customers are reaping the rewards of the SIGNA™ Continuum™ from the US to Africa to Japan and New Zealand. There is something for everyone in the world of radiology in this edition — literally. From the head to the toe, GE has you covered.

To me personally, it was an incredible experience to have had the opportunity to work with the most talented and dedicated editorial staff, along with fellow scientists and engineers, to bring some of the clinical and research highlights to our community. They work tirelessly behind the scenes so users such as you and me can be in the spotlight. I am also extremely pleased and excited to announce that Dr. Scott Reeder from the University of Wisconsin Madison will take on the honor as the guest editor for the coming year. I look forward to learning the continued success and excitement from our vibrant MR community for many years to come.

It is with our warmest appreciation that we thank Dr. Allen Song for his guidance and leadership as the first SIGNA™ Pulse of MR Guest Editor. He has shared ideas and topics that we’ve covered in 2019 and has helped us to think bigger and broader on the global impact of MR imaging. We are indebted to him for his passion and expertise in furthering MR education throughout our community and beyond.

– The SIGNA™ Pulse of MR Editorial Board

*Not yet CE marked. Not available for sale in all regions.
‡510(k) pending at the US FDA. Not yet CE marked. Not available for sale.

Scott B. Reeder, MD, PhD, Professor, H.I. Romnes Faculty Fellow, Vice Chair of Research and Chief of MRI at the University of Wisconsin School of Medicine and Public Health

Originally from Canada, Dr. Reeder has made Madison, Wisconsin, his home since he joined the University of Wisconsin in 2005. It’s not just that close proximity to GE Healthcare that has made him a valued research partner. Since his graduate days at Johns Hopkins University and Stanford University, he developed friendships with many MR experts who have spent their careers at GE.

While studying for his undergraduate degree in Engineering Physics at Queen’s University in Ontario, Dr. Reeder participated in a summer research project using “magnetic flux leakage devices” for detection of corrosion pits in the Trans-Canada oil pipeline. It was there that he discovered his passion for engineering, physics and non-invasive testing. Yet, the human connections that are inherent in medicine continued to draw him in and MR was the perfect combination for him to explore his interests in engineering and medicine.

“The best part of my job is mentoring a diverse group of graduate students, post-doctoral fellows, residents, clinical fellows, visiting scholars and junior faculty.” Dr. Reeder says. “I'm also lucky to have had many opportunities in MR imaging, but perhaps my proudest achievement is the development of IDEAL IQ for quantitative liver fat and iron imaging.”

Looking back on the last 20 years that he’s collaborated with GE, his most memorable moment was working with the MR clinical and engineering teams to perform the first clinical validation of the Discovery™ MR750 3.0T system.

When asked what he believes will be the most significant advancement in MR in the next five years, he jokes, “If I knew that, I’d be writing a grant on that idea right now.” Seriously, though, he sees the potential for machine learning to unleash the future of image reconstruction, image analysis, workflow and computer-assisted diagnosis in MR.

Dr. Reeder adds, “The potential for machine learning to transform how we perform MR cannot be understated.”

After 35 years with GE, I have decided to retire. I came to GE MR from GE Aerospace in 1996, and now I have the honor and privilege to close out my career leading the MR business. Working with clinicians and researchers like you, who are molding the future of patient care, has been the most inspiring part of this job.

MR and its nearly endless potential will play a critical role in enabling precision medicine. Your vision of that future is powering the development of faster, smarter, more adaptable and consistently repeatable MR technologies. Technologies like AIR™ Coils, which adapt to patients — unlike traditional coils that require patients to adapt — are setting new industry standards for patient comfort and consistently better image quality. And technologies like deep learning-based AI are automating scan prescriptions, enabling faster acquisitions, and reconstructing better images. Thank you for inspiring us.

As you've heard me say at ISMRM meetings, many of the innovations in our products are invented by you or with you. We need you to advance MR. That's what makes MR truly unique. Thank you for 36 years of collaboration, especially on innovations that have made their way into publications, product and clinical use. Thank you for your passion for invention to improve patient care, and thank you for partnering with GE to push MR technology beyond its former limits.

And on a personal note, I've cherished every interaction with you. Thank you for inspiring me, challenging me and making my GE Healthcare career truly gratifying. I have come to know many of you as friends and will dearly miss you as well as this business.

I'm excited to introduce Jie Xue as the new President & CEO of GE MR — many of you may know her already from her time leading the 1.5T MR product segment. She most recently led our X-Ray business and has over 20 years of GE Healthcare experience, beginning as an Edison Engineer. She helped build our portfolio of SIGNA™ scanners, which she will now lead and advance to new heights. I'm confident Jie will foster a culture of strong partnership with you to deliver tomorrow's game-changing innovations.

The changes we've seen in imaging over the decades and its impact on the quality of healthcare is astounding, and I know MR will continue to shape the future of patient care. I can't wait to see where you, Jie and the GE MR team will take MR.

Let's stay in touch,

Eric Stahre

I'm thrilled to be coming back to GE MR and this great modality. The five years I spent in MR were some of the most rewarding and illuminating of my career. I continue to be amazed by the power of MR and its potential to push the boundaries of what's possible in imaging. I look forward to getting to know you, the researchers and clinicians who are challenging what's possible today to create the MR of tomorrow.

Collaboration is a critical component of what makes GE MR successful and I thank you for working with us to make our products better, smarter, faster and more comfortable. MR holds a unique spot in imaging — by paving the future of imaging through cutting-edge research. It is fascinating to imagine where MR and healthcare as a whole will go with the potential of AI becoming a reality.

Thank you to Eric for the warm welcome. I look forward to working with you all and bringing MR technology to more people and places around the world.

Very truly yours,

Jie Xue

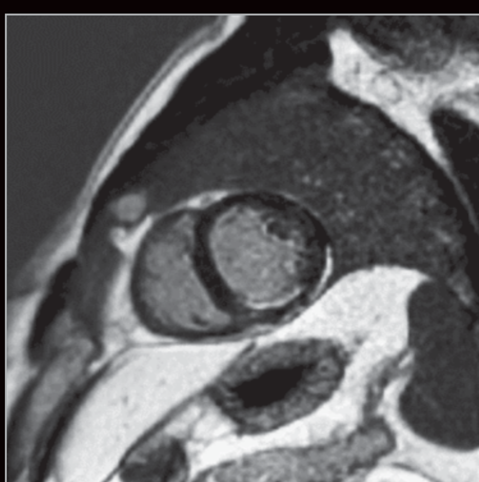
Exablate Neuro cleared for SIGNA Premier

GE Healthcare and Insightec®, a global medical innovator of incisionless surgery, announced US and EU regulatory approval for Exablate Neuro™ compatible with the SIGNA™ Premier MR system. Exablate Neuro™ is a focused ultrasound platform for treating the brain with no surgical incisions. MR imaging provides a comprehensive anatomical survey of the treatment area, patient-specific planning and real-time thermal monitoring throughout the treatment.

Exablate Neuro™ has FDA approval for the treatment of medication-refractory essential tremor and tremor-dominant Parkinson's disease and CE marked for the treatment of essential tremor, tremor dominant Parkinson's Disease-Unilateral and neuropathic pain.

"We're excited to continue expanding MR-guided focused ultrasound offerings with Insightec®," said Baldev Ahluwalia, General Manager, MR Beyond Segment at GE Healthcare.

Gadavist cleared as first contrast agent for cardiac MR



Hyper-intense signal difference between black blood and MDE defines area at risk. Image acquired on an Optima™ MR450 1.5T system.

Image Courtesy of Centro Cardiologico Monzino, Milano, Italy.

Bayer's Gadavist® is the first MR imaging agent approved by the FDA to assess myocardial perfusion, both stress and rest, and late gadolinium enhancement in adult patients with known or suspected coronary artery disease (CAD).

According to the company, the approval was based on two multinational, non-randomized, blinded-read Phase 3 studies of almost 1,000 adults with suspected or known CAD based on signs and symptoms. Nearly 800 of those patients were evaluated for efficacy.

The use of Gadavist® in a cardiac MR exam can provide the information clinicians need to assess perfusion and late gadolinium enhancement in less than one hour, which can help with patient management. Using the imaging agent, it is possible to get a clear picture of the blood supply serving the heart muscle, together with how well the blood flows or perfuses through the muscle at rest and during exercise.

Approximately 16.5 million Americans are affected by CAD, making it the most common form of heart disease.

2019 Minnies Best New Radiology Device

GE Healthcare proudly announces that the AIR™ family of flexible RF Coils is the AuntMinnie.com 2019 Minnies winner for Best New Radiology Device. The AIR™ Coils were one of 18 semi-finalists and one of two finalists selected by an expert panel of radiology luminaries and AuntMinnie.com editors. The Minnies have been recognizing excellence in radiology for the past 20 years.

"This external recognition by one of the premier radiology publications demonstrates what we at GE have all known since the inception of AIR™ Coils — it's a game changer," says Eric Stahre, President and CEO of GE MR. "We are only limited by our imagination and our customers' imagination to come up with new and different designs. The sky is the limit... we're just getting started."

Twenty years of 3.0T

In 1999, GE received FDA 510(k) clearance of its first 3.0T MR scanner, making this the 20th anniversary of 3.0T scanning on a GE MR system. GE's first cleared scanner was installed at Beth Israel Deaconess Medical Center in Boston.

While 1.5T remains the dominant Tesla strength for high-field scanners, 3.0T has distinct advantages, such as extremely clear and vivid images and shorter overall scan times. 3.0T is also ideal for imaging neurological, musculoskeletal, breast and vascular, where the minute details are especially crucial for diagnosis.

A fond farewell

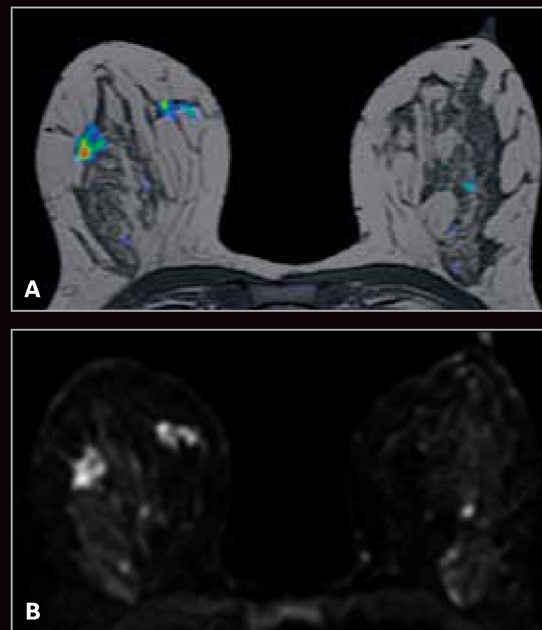
It is with great sadness that SIGNA™ Pulse of MR informs you of the passing of Jim Sedorovich, a dedicated Advanced Clinical Expert for GE MR for over 20 years and a frequent contributor to our publication. Jim created a passionate fan base of customers and colleagues with his incredible MR knowledge, which was only surpassed by his kindness.

Jim's commitment to our customers has left an indelible mark on GE and on our magazine. He will be missed as a colleague, a friend and an educator. GE has dedicated an MR bay at its global headquarters with a plaque to further memorialize Jim and his impact on GE MR customers.

"Everything that we do here at our site, your touch is all over it and so we will carry you in our hearts forever and ever. We love you, Jim!"

Longtime GE customer

DWI can streamline breast MR exams



(A) Overlay of MUSE DWI on T1w images, (B) MUSE DWI (b800).

Breast MR is the most sensitive test for breast lesion detection and outperforms conventional imaging with mammography, digital breast tomosynthesis or ultrasound.[1] However, the long scan time and relatively high costs limit its widespread use. That's why a joint German-Austrian study published in *European Radiology* revealed some good news for women undergoing breast MR. The study reported that diffusion-weighted imaging (DWI) can be used to streamline breast MR protocols, which could translate into shorter exams. The team led by Matthias Dietzel, a radiologist from University Hospital Erlangen in Germany, found the protocol can be safely abbreviated by using DWI instead of delayed-phase enhancement.

"As DWI is typically used as an add-on to the initial phase and delayed phase, our findings have a potential clinical impact," the group concluded. "They provide a rationale to shorten and to simplify current breast MR practice without losing diagnostic information."

1. Leithner D, et al. Abbreviated MRI of the Breast: Does It Provide Value? J Magn Reson Imaging. 2019 Jun; 49(7): e85–e100.

We need your feedback

What's on your mind? The editors at SIGNA™ Pulse of MR want to know. Help us improve the content of our magazine by taking our survey at: http://tinyurl.com/sps191

Darryl Sneag, MD
The Hospital for Special Surgery
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Hollis Potter, MD
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A new era of deep-learning image reconstruction

Radiologists and technologists are intimately familiar with the traditional compromise in MR between image quality and scan time. Higher image quality — through higher SNR and/or spatial resolution needed to resolve anatomical detail — necessitates long scan times, whereas faster scans — desired for patient comfort and productivity — compromise image quality and diagnostic confidence. AIR™ Recon DL‡, an innovative new reconstruction technology from GE Healthcare based on deep learning, offers a fundamental shift in this balance between image quality and scan time, resulting in TrueFidelity™ MR images that elevate the science of image reconstruction for clinical excellence without conventional compromises.

Conventional MR image reconstruction gives rise to well-known image artifacts as a direct result of the data acquisition and reconstruction process. For example, thermal and electrical noise during data sampling translates into random image noise that reduces SNR, while incomplete sampling of high spatial frequencies creates partial volume and edge ringing (i.e., Gibbs ringing) artifacts in the final reconstructed image.

Traditional methods to address these artifacts include hardware, software and acquisition approaches. Hardware solutions such as higher field strength magnets and more RF coil elements can improve SNR. Software filters are commonly applied in the data reconstruction pipeline to mitigate noise and ringing; however, these are only partially effective and can have the undesired impact of reducing effective spatial resolution. In the acquisition protocol, scan parameters can be adjusted to improve image quality, but this comes at a high cost. For example, SNR can be improved by increasing the number of signal averages (NEX) with a proportional increase in scan time; truncation artifacts can be mitigated by increasing spatial resolution, which in turn typically increases scan time and also reduces SNR. This costly SNR/spatial resolution/scan time interdependency forces clinicians to make difficult trade-offs between image quality and scan time for a given patient and clinical need.

Though there has been some success easing this MR trade-off with existing technologies, the reality is that many images today still suffer from low SNR and artifacts, which can lead to decreased diagnostic confidence and reduced radiologist productivity. Patients may be called back for re-scans, which leads to fewer daily scan slots

‡510(k) pending at the US FDA. Not yet CE marked. Not available for sale.

Pascal Roux, MD

Centre Cardiologique du Nord
Paris, France

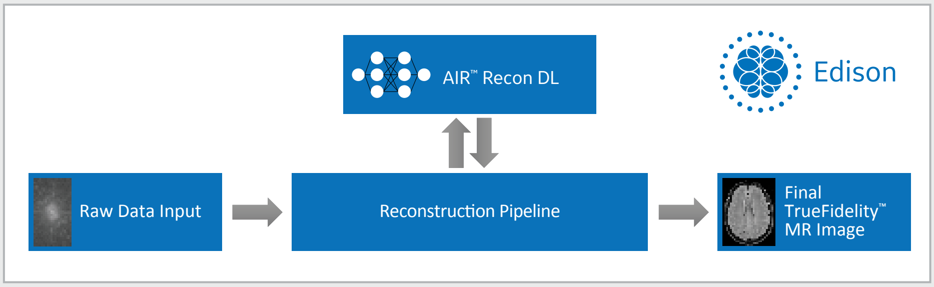


Figure 1. AIR™ Recon DL is integrated directly into the MR image reconstruction pipeline to intelligently reconstruct a final image with high SNR and sharpness.

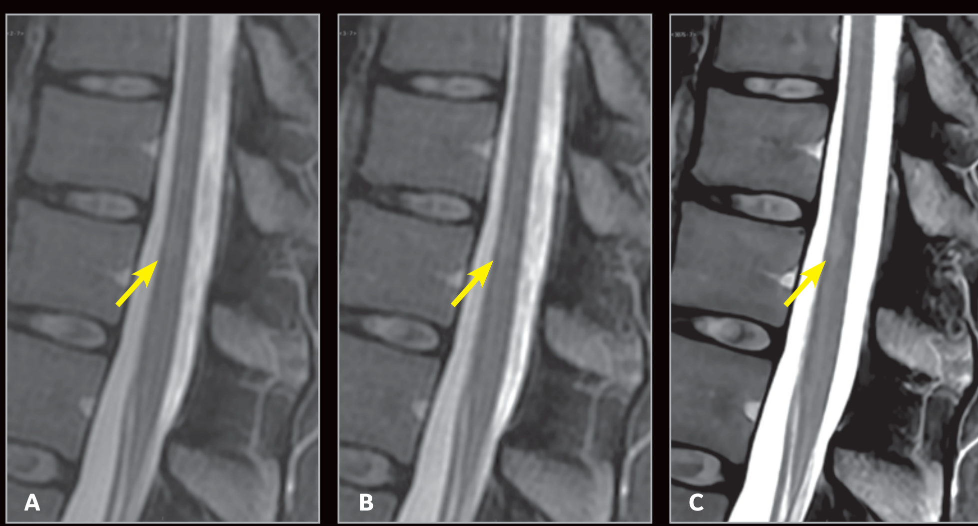


Figure 2. AIR™ Recon DL improves SNR to help depict lesions. (A) Existing protocol: sagittal T2 FSE, 0.9 x 1.0 x 3.5 mm, 4 NEX, 2:50 min. (B) Revised protocol: sagittal T2 FSE, 0.9 x 1.0 x 3.5 mm, 2 NEX, 1:28 min. (C) Image in 2B reconstructed with AIR™ Recon DL at maximum noise reduction to enable shorter scan time without sacrificing SNR.

Images courtesy of CCN

available for scheduling new patients. It can also lead to lower patient throughput due to repeated scans during the exam, further backlogging the schedule and leading to a poorer patient experience.

Artificial intelligence now offers an exciting new means to mitigate traditional image artifacts and generate clearer, higher-quality images than previously obtainable from the same MR data.

AIR™ Recon DL represents a revolution in MR image reconstruction by introducing a deep learning-based convolutional neural network to intelligently reconstruct a final MR image with high SNR and image sharpness. AIR™ Recon DL is not a post-processing technique but rather is embedded directly in the reconstruction pipeline, where the neural network model is applied to acquired input data to remove noise and ringing artifacts prior to final image formation (Figure 1).

By operating on raw data within the online reconstruction pipeline, AIR™ Recon DL benefits from access to the full set of acquired source data to generate an image, compared to post DICOM image conversion where important information has been lost.

AIR™ Recon DL uses a feed-forward deep convolutional neural network trained on over 10,000 images using GE's Edison AI Platform. Supervised learning was performed by using data pairs of high SNR, high-resolution

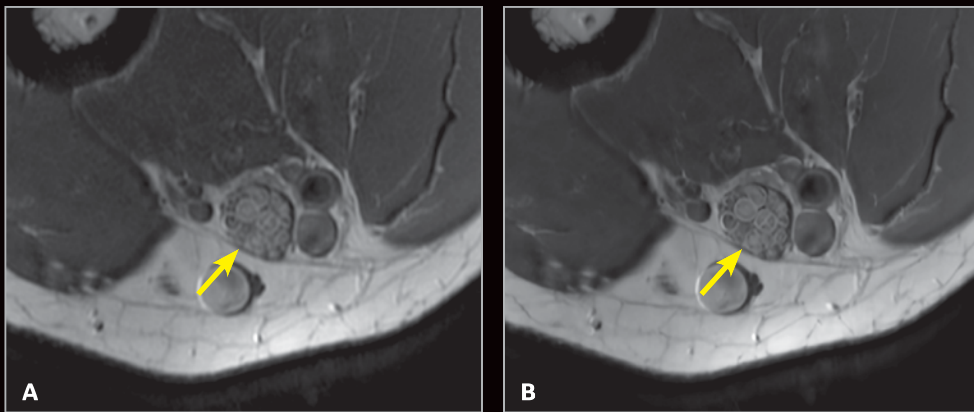


Figure 3. Spontaneous median neuropathy of the elbow. Axial PD 2D FSE. (A) Image acquired with standard protocol, 512 x 352, 12 cm FOV, 2 NEX; (B) image reconstructed with AIR™ Recon DL at maximum SNR improvement. Note the clarity of the median nerve in the AIR™ Recon DL image.

Images courtesy of HSS

images and low-SNR, low-resolution images. The trained network employs a cascade of over 100,000 unique filters that recognize patterns characteristic of noise and low resolution to reconstruct only the ideal object image. The network includes a tunable SNR improvement level expressed as mild, medium and maximum to accommodate user preference. AIR™ Recon DL includes an innovative ringing suppression technology: rather than simply removing Gibbs ringing, the network recognizes where ringing occurs and recasts this former artifact into improved image detail. The result is an image with high SNR and spatial resolution that is virtually free of truncation artifacts.

With AIR™ Recon DL, the potential is for technologists to acquire higher SNR without a time penalty and for radiologists to have more consistency and quality in the images they interpret. Alternatively, scan time may be reduced without compromising detail or SNR.

For example, if an MR technologist decreases slice thickness or in-plane pixel size, the amount of signal is proportionately reduced, which typically leads to noisier images. With AIR™ Recon DL, the result is higher SNR images and this may enable radiologists to be more confident in their reading and reporting.

The best of both worlds

Pascal Roux, a radiologist at Centre Cardiologique du Nord (CCN), one of the first global clinical sites to evaluate AIR™ Recon DL for GE, believes that AIR™ Recon DL is a solution that offers a dramatic improvement over existing image reconstruction techniques. "In my experience, AIR™ Recon DL demonstrated high-resolution images with no truncation artifact, imperceptible noise and depiction of sharp structure," Dr. Roux says. As of the end of August 2019, CCN had performed nearly 1,000 exams with a prototype version of AIR™ Recon DL.

In one case, he was able to detect a lesion on a spinal cord exam that was difficult to appreciate on the images processed without AIR™ Recon DL. In Dr. Roux's opinion, the lesion was more clearly visible on the images processed with AIR™Recon DL (Figure 2).

> "Anytime a new technology can help improve resolution, it will help us to better analyze lesions."
>
> *Dr. Pascal Roux*

Reading an AIR™ Recon DL image is very natural and comfortable for Dr. Roux. He expects to be more confident in his diagnosis because AIR™ Recon DL is designed to help improve SNR and image sharpness, which can enhance spatial resolution as well as help remove artifacts and reduce acquisition time.

"I have the best of both worlds. I do not have to choose between improving the quality of the exam and shortening the exam time," he says.

AIR™ Recon DL is an excellent tool to improve workflow. If Dr. Roux's department can increase the number of exams even by a fraction each hour, the cumulative result at the end of the day could be significant. With a three-exam-each-hour schedule, Dr. Roux believes it is possible to add five to six more patients in a 12-hour day.

The shorter acquisition time also means that when he needs to capture an additional image for a difficult case, he can do it without worrying about the schedule.

"Sometimes a sequence fails, or you get great information and want to add something," Dr. Roux explains. "It is hard to do that when an MR exam is 20-30 minutes. However, if we can go faster because we can reconstruct it with a deep-learning solution such as AIR™ Recon DL, then we have sufficient time to do this in the scan room."

Figure 4. Coronal PD 2D FSE image of the elbow depicts normal ulnotrochlear cartilage. (A) Standard protocol, 512 x 352, 14 cm FOV, 1 NEX; (B) AIR™ Recon DL at maximum SNR improvement more clearly demonstrates the superficial cartilage layer (lamina splendens) and subchondral bone.

Images courtesy of HSS

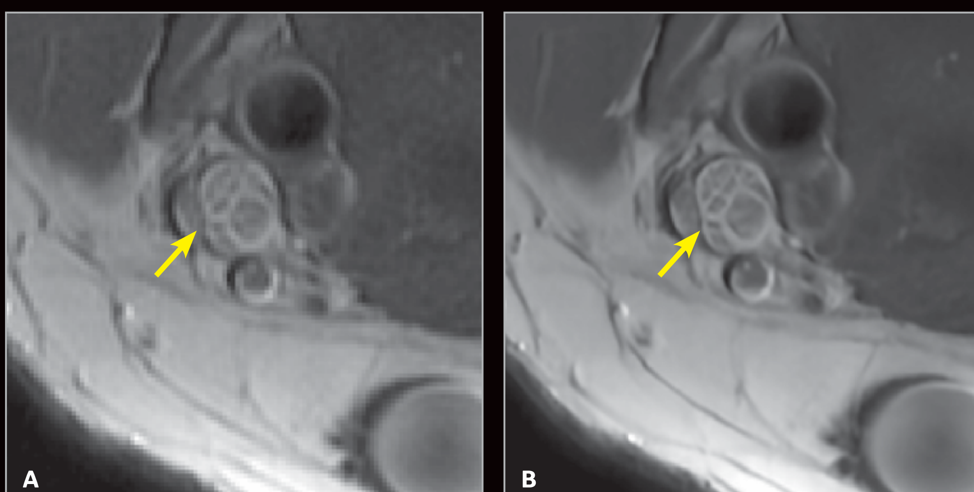


Figure 5.Axial PD 2D FSE image through the arm in a patient with a severe, spontaneous median neuropathy. (A) 512 x 352, 12 cm FOV, 2 NEX; (B) AIR™ Recon DL at maximum SNR improvement more clearly depicts fascicular detail and enlargement.

Images courtesy of HSS

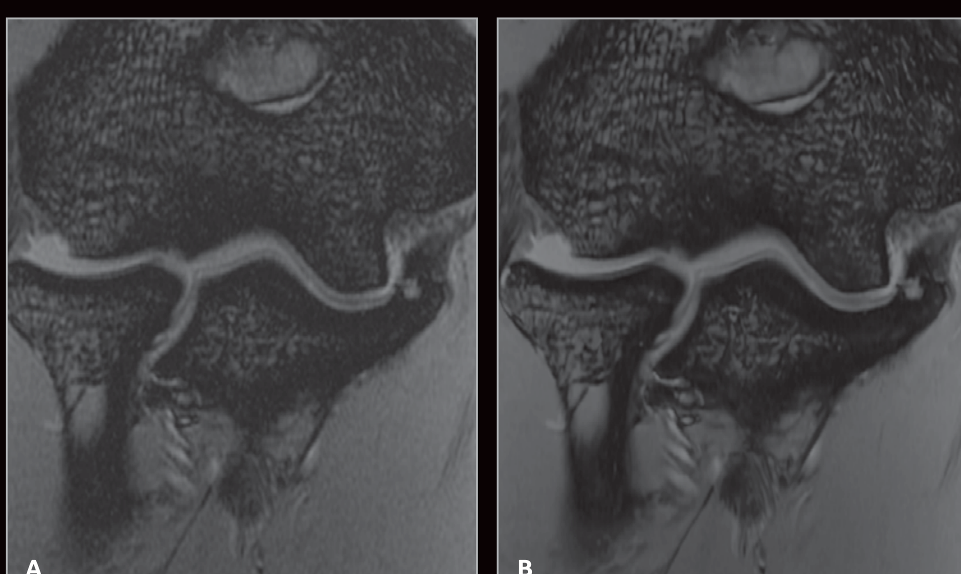


Figure 6. (A) Standard protocol. Coronal T2* GRE, 0.3 x 0.6 x 1.7 mm; (B) AIR™ Recon DL at maximum SNR improvement.

Images courtesy of HSS

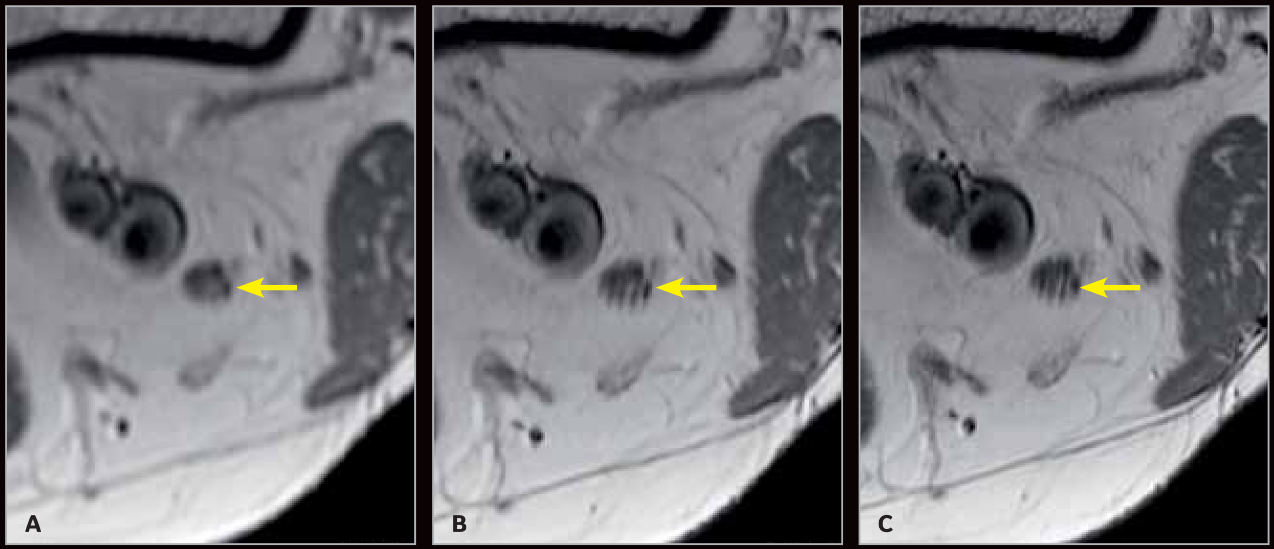


Figure 7. Elbow. (A) Unfiltered, axial 2D FSE, 256 x 180, 1 NEX, 1:10 min. (B) AIR™ Recon DL at maximum-plus SNR improvement, 256 x 180, 1 NEX, 1:10 min. (C) Reference unfiltered, 512 x 352, 2 NEX, 4:09 min.

Images courtesy of HSS

Finding the "sweet spot"

The Hospital for Special Surgery (HSS) is another of several global sites evaluating AIR™ Recon DL and its impact on image quality, spatial resolution and acquisition scan time. Darryl Sneag, MD, Director of Peripheral Nerve MRI, Erin Argentieri, senior lead research specialist and Hollis Potter, MD, Chairman, Department of Radiology and Imaging, examined the use of AIR™ Recon DL in peripheral nerve and musculoskeletal (MSK) imaging.

"AIR™ Recon DL provides the added resolution that we need when looking at musculoskeletal structures, such as ligaments, tendons, nerves and the trabecular detail of the bones," says Dr. Sneag.

The difference is like 'night and day' for Dr. Potter, particularly when using a 512 x 512 matrix with one excitation (1 NEX). With AIR™ Recon DL, trabecular detail is not blurred and the individual nerve fascicles are clearly demonstrated (Figures 3 and 4). Previously, at a 512 x 512 matrix, SNR would be a challenge, but with AIR™ Recon DL, Drs. Potter and Sneag can push the MR system to a higher matrix and achieve impressive imaging results.

"In our experience, this tool enables us to back off on the number of averages or achieve a higher matrix, to either save on scan time or achieve a higher resolution image."

Dr. Hollis Potter

"There is more detail in the image, especially at a lower matrix. In some conventionally-processed MR images, the trabecular pattern is poor, the nerves are blurred and there is a lot of noise in the image. With AIR™ Recon DL, the difference is striking," Dr. Potter says (Figure 7).

Dr. Potter adds that with the high-resolution AIR™ Recon DL images, she can confidently evaluate the internal architecture of the nerve — something she couldn't routinely see before.

"In my opinion, we are seeing better image quality and faster radiology reads. This will help us be more confident in our diagnosis," she adds.

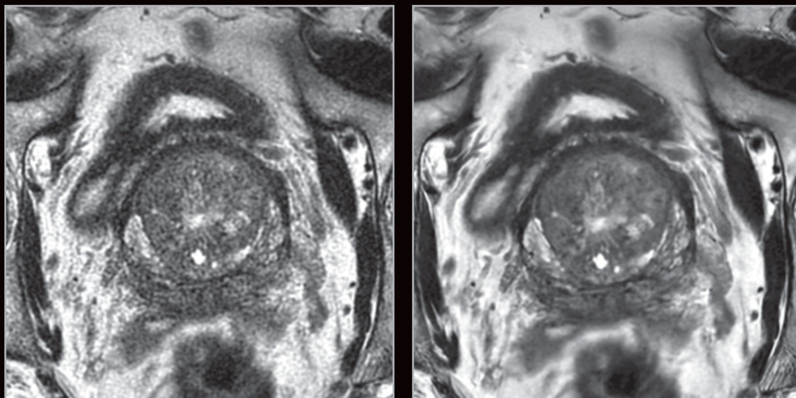
With AIR™ Recon DL, the power of deep learning and neural networks is unleashed in MR image reconstruction. AIR™ Recon DL was designed to improve SNR and image sharpness, thereby improving image quality in MR exams.

Beyond enhancing image quality, AIR™ Recon DL complements GE's AIR x™ automatic prescription and AIR Touch™ workflow tools to help improve scan consistency and usability, and potentially help facilitate shorter scan times.

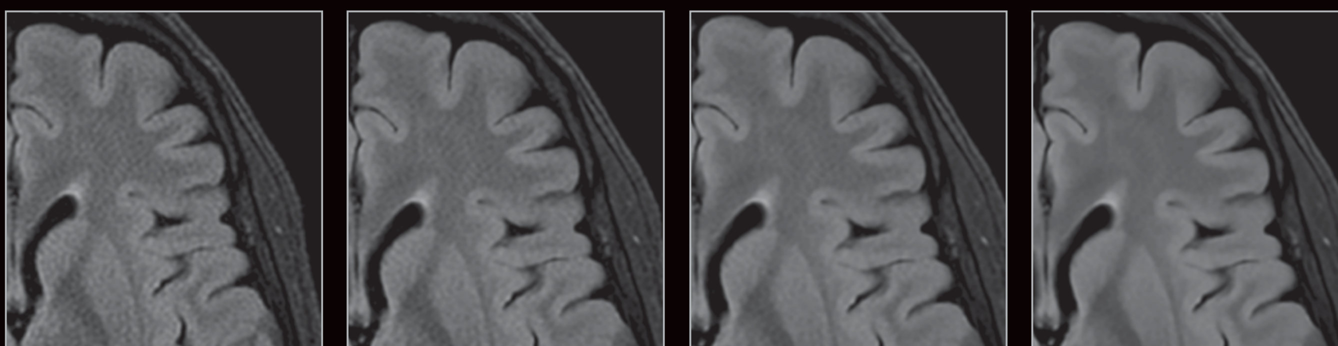
Based on initial evaluations at HSS and CCN, AIR™ Recon DL demonstrates that it can provide high-quality images across a variety of anatomies and scan protocols and has the potential to reduce scan times while preserving high image quality for more efficient exams. S

Editor's note: The editors gratefully acknowledge the assistance of R. Marc Lebel, PhD, Lead Scientist, Julie Poujol, PhD, Research Scientist and Anja C.S. Brau, PhD, General Manager, MR Collaboration & Development, in the development of this article.

AIR™ Recon DL gallery

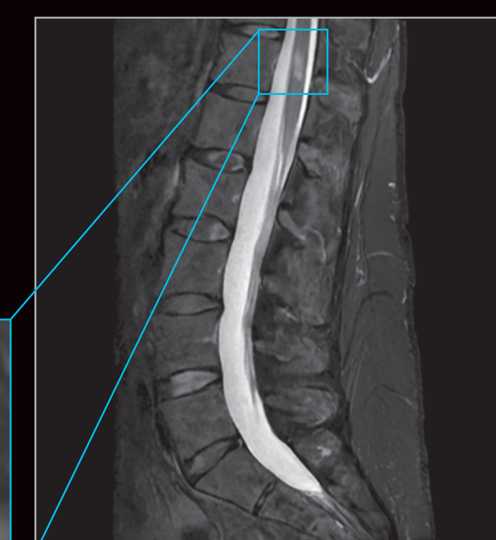


AIR™ Recon DL‡ recovers a high-quality image from an otherwise noisy thin-slice axial T2 prostate image acquired in only 1:07 min.



Original image | Mild SNR improvement | Medium SNR improvement | Maximum SNR improvement

With AIR™ Recon DL, images can be reconstructed with mild, medium or maximum SNR improvement for visibly improved image quality compared to the original image.



Sagittal STIR lumbar spine reconstructed without (left) and with (right) AIR™ Recon DL. Image quality in the spinal cord is clearly improved through reduced noise and ringing.
0.8 x 0.9 x 1.5 mm
2:47 min.

‡510(k) pending at the US FDA. Not yet CE marked. Not available for sale.

Abstracts accepted at RSNA 2019

GE Healthcare is pleased to announce that four abstracts on AIR™ Recon DL[‡] have been accepted for presentations at the 2019 Annual Meeting of the Radiological Society of North America (RSNA).

Congratulations to these clinicians and institutions, and a heartfelt thank you to all who submitted an abstract on AIR™ Recon DL for consideration at this year's meeting.

Sunday, Dec. 1
10:45 AM – 12:15 PM
SSA22-06

Session: Physics (MRI – New Techniques and Image Quality)

Improvement of Late Gadolinium Enhancement Image Quality Using a Novel, Deep Learning Based, Reconstruction Algorithm and its Influence on Myocardial Scar Quantification

Van der Velde N, Bakker B, Hassing C, Wielopolski PA, Lebel RM, Janich MA, Budde RP, Hirsch A
Erasmus Medical Center, Rotterdam, Netherlands

Monday, Dec. 2
12:15 – 12:45 PM
R370-SD-MOA1

Session: Neuroradiology Monday Poster Discussions

Deep-Learning Reconstruction Improves Quality of Clinical Brain and Spine MR Imaging

Bash SC, Thomas M, Fung M, Lebel RM, Tanenbaum LN
RadNet, Inc., Baltimore, MD

Tuesday, Dec. 3
10:30 AM – 12:00 PM
SSG08-08

Session: Musculoskeletal (Machine Learning and Artificial Intelligence)

Performance of a Deep Learning-Based MR Reconstruction Algorithm for the Evaluation of Peripheral Nerves

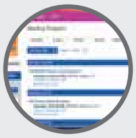
Argentieri EC, Zochowski KC, Potter HG, Shin J, Lebel RM, Sneag DB
Hospital for Special Surgery, New York, NY

Thursday, Dec. 5
10:30 AM – 12:00 PM
SSQ15-08

Session: Neuroradiology/Head and Neck (Artificial Intelligence)

Denoising MR Images of the Cervical Spine: Multi-Reader Assessment of a Deep Learning Approach

Villaneueva-Meyer J, Shin D, Li Y, Leon III PA, Banerjee S, Brau AC, Lebel RM, Glastonbury CM
University of California San Francisco



To read the full abstracts online, visit: meeting.rsna.org/program/

[‡]510(k) pending at the US FDA. Not yet CE marked. Not available for sale.

Ahmet Kemal Firat, MD
Emsey Hospital
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A simply better MR experience

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In patient neuro MR follow-up studies, consistency of image slices is crucial for determining response to therapy or progression of disease. The quality of the exam is also often dependent upon the technologist's experience. AIR x™ is an AI-based automated workflow tool for MR neuro exams that increases consistency and productivity in slice prescriptions for less variability between technologists and between exams.

As one of Turkey's leading private hospitals, Emsey Hospital provides high-quality healthcare to residents of Istanbul, as well as patients from throughout the region. The radiology department provides a full complement of imaging and interventional services and relies on the advanced technology found across the breadth of GE Healthcare systems. As the hospital embarked on its vision to expand services to international patients, it became apparent that a new 3.0T MR system was needed to complement its existing Brivo™ MR355 1.5T.

To fill this need, the department installed a 3.0T SIGNA™ Pioneer. According to Huseyin Cagil, MD, radiologist, a key factor in selecting the system was the foundation of innovative technologies — from Total Digital Imaging to the AIR™ Coils and AIR x™ to the SIGNA™Works productivity platform of advanced applications. Today, SIGNA™ Pioneer is the first choice for MR imaging at Emsey Hospital, especially for prostate, liver, MSK and neuro.

"AIR x™ has become one of the favorite applications for the technologists and neuroradiologists," Dr. Cagil explains. "This deep-learning automatic slice prescription tool has brought standardized improvement for almost all our head exams today."

In addition to automatically prescribing slices for routine brain exams, AIR x™ is also being used for MR exams of the temporal lobe, internal auditory canal, orbits, optic nerves, pituitary gland and the Circle of Willis.

AIR x™ also enables the department to improve the patient experience. Dr. Cagil and Mahmut Erol, MD, radiologist, explain that if the patient needs to move their head or take a break during the exam, they can. That's because AIR x™ automatically detects anatomy and prescribes the slices to produce images with less variability between scans and technologists. After the technologist performs a scan localizer, AIR x™ handles the rest for reproducible slice planning.

"We see consistently correct slices regardless of the technologist's experience, which contributes to an easier and more reliable evaluation of head exams by the radiologists," Dr. Cagil adds.

Neuroimaging is often dependent upon the technologist's experience in slice prescription. Dr. Erol explains, "This is also important for patients who we follow longitudinally to evaluate the course of their neurological disease. Patients have unique morphologies and we need robust algorithms for these challenging clinical needs. We believe that our decision to implement AIR x™ and SIGNA™ Pioneer now will help with patient follow-up well into the future."

Dr. Erol adds that patients with neurological or neurodegenerative diseases are often assessed for signal changes in brain structures bilaterally with symmetrical evaluations. He believes the consistency in slices provided by AIR x™ will further improve patient management.

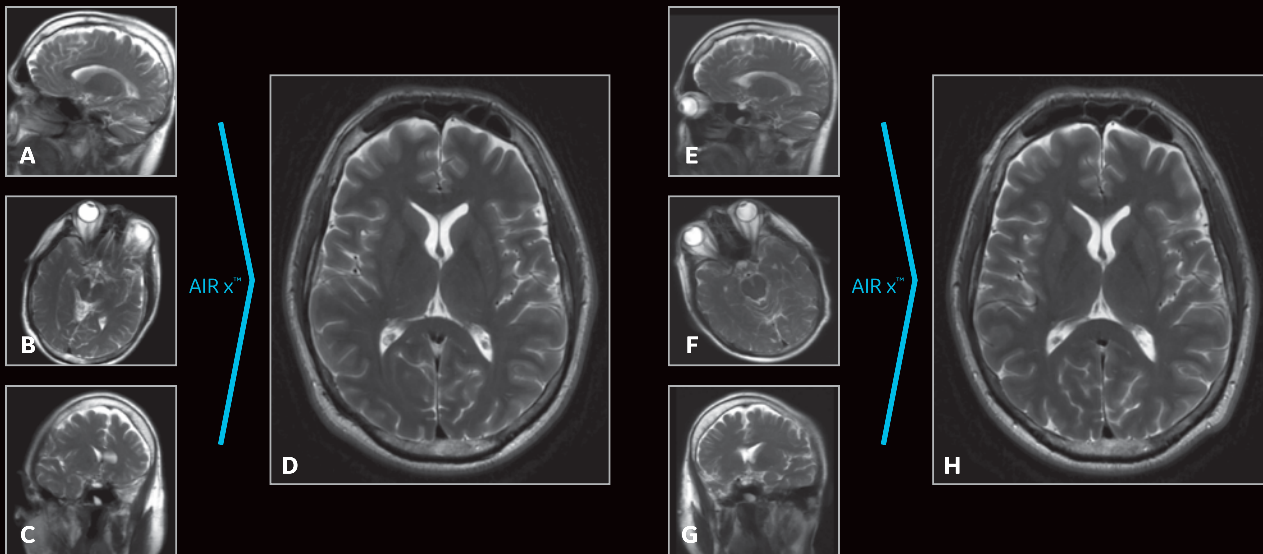
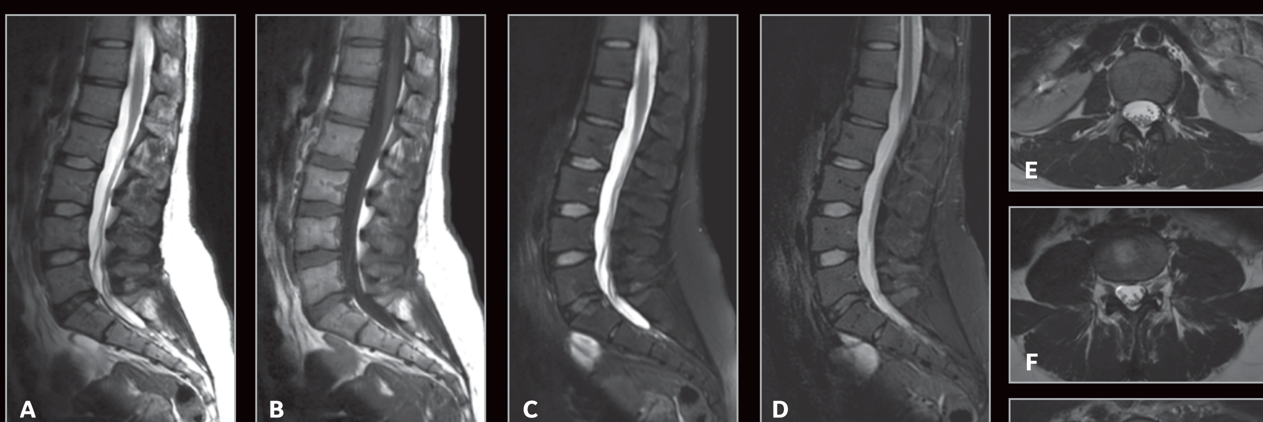


Figure 1. AIR x™ provides excellent accuracy in slice prescription and reproducible slice planning even in extreme conditions. (A-C) 3-plane localizer helps determine (D) image slice/orientation in the first position so that it matches (E-G) 3-plane localizer and (H) image slice/orientation in the second position.

Images courtesy of Emsey Hospital



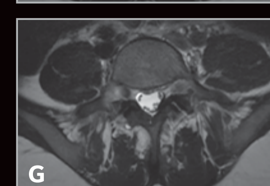


Figure 2. Lumbar spine exam on a patient scanned in the lateral decubitus position performed with only the AIR™ AA Coil for high-quality imaging results. (A) T2 FSE; (B) T1 FSE; (C) T2 ASPIR; (D) T2 STIR PROPELLER; and (E-G) T2 FSE.

Images courtesy of Emsey Hospital

It's not just AIR x™ that is making a difference in patient care. Emsey Hospital also acquired the AIR™ Anterior Array (AA) Coil with the SIGNA™ Pioneer. Although the AIR™ AA Coil was not yet commercially available when the new system was installed, the radiologists believed the concept of MR coils that conform to the body like a blanket would transform patient comfort and improve image quality.

"The AIR™ AA Coil has significantly improved our SNR and we can use it for many imaging exams, from large to small fields of view and it never disappoints us," Dr. Cagil says. "In patients who are difficult to position or where traditional coils cannot sufficiently cover their anatomy, the AIR™ AA Coil resolves these situations."

For example, patients with severe back pain could only be positioned in the decubitus position in lumbar spine exams. Now, the AIR™ AA Coil is placed on the back of these patients. In long bone scans where no dedicated coil was available, the large coverage and proximity to the anatomy with the AIR™ AA Coil provides better images for patient management. In MSK imaging, combining the Posterior Array (PA) Coil with the AIR™ AA Coil enables the technologist to scan both knees simultaneously with excellent resolution from the approximately 30 active

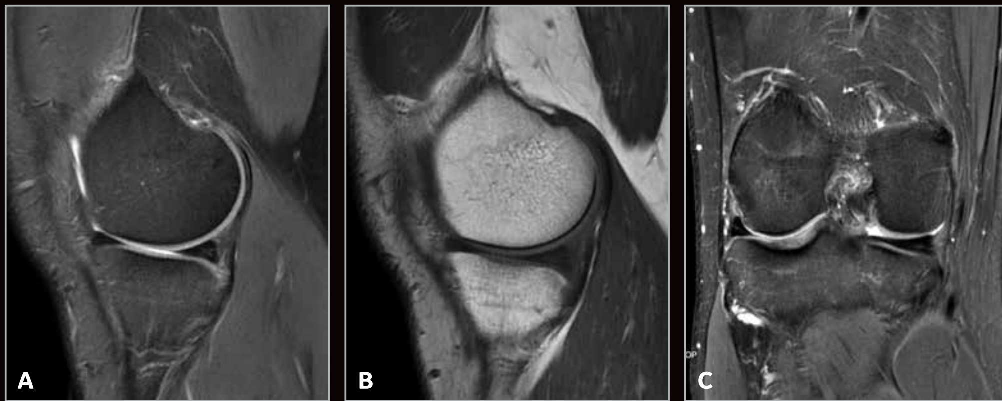


Figure 3. Knee imaging with the AIR™ AA Coil. (A) PD FatSat PROPELLER; (B) T1 PROPELLER; and (C) PD FatSat PROPELLER. All sequences acquired with a pixel size of 0.7 x 0.7 x 3.5 mm.

Images courtesy of Emsey Hospital

channels (between both coils). This approach also helps save exam time by eliminating patient re-positioning.

"Signal uniformity has significantly improved across all anatomies and coil combinations," Dr. Cagil adds. "We've seen impressive results in dedicated organ studies requiring a small FOV, such as the prostate, female pelvis, pancreas, etc."

AIR™ AA Coils are also impressive in large FOV exams, particularly in abdominal-pelvic oncology cases. According to Dr. Erol, two traditional hard shell AA coils were previously needed for the large coverage on some patients.

"Now, patients are much more comfortable with the AIR™ AA Coil because it helps them tolerate the exam — and that impacts image quality," Dr. Erol says. "Also, having acceleration techniques available with the sequences, especially SSFSE, provides clearer imaging results due to less motion captured during the acquisition."

The feedback from the technologists further supports the radiologists' view on improved patient comfort. Dr. Erol says they are very positive about the easier patient positioning and flexibility of coverage. They can even slide the AIR™ AA Coil up and down on the patient while they are still inside the bore.

Beyond the benefits of AIR™, Emsey Hospital is also exploring the use of MR Touch, IDEAL IQ and StarMap for a comprehensive liver health program.

According to Ahmet Kemal Firat, MD, Associate Professor of Radiology and an interventional radiologist, these sequences enable the department to tackle the growing incidence of fatty liver diseases.

"We are currently treating approximately 200 patients each year with interventional radio/chemo-embolization," Professor Firat explains. "We are planning to use these imaging techniques to address liver disease in a larger cohort of patients."

Professor Firat also anticipates participating in research exploring the use of 3D MR elastography techniques in collaboration with other institutions worldwide.

Reproducibility in slice prescription

Kremlin-Bicêtre Hospital is one of three hospitals in the Paris-Sud University Hospitals that provides comprehensive healthcare within the framework of a teaching and research environment. The hospital is renowned for specializing in neurosurgery, interventional neuroradiology, neuro-oncology and polytrauma cases.

In 2017, the hospital implemented SIGNA™ Architect and the AIR™ 48-channel Head Coil to further support neuroimaging for surgery, interventions, radiation therapy and head trauma cases. Recently, AIR x™ was added as part of a SIGNA™Works AIR™ Edition productivity platform upgrade at the hospital.

Many patients receiving a neuro MR exam at Kremlin-Bicêtre Hospital are undergoing some type of therapy or intervention for a neuro disease or injury. According to Farida Benoudiba-Bataille, MD, neuroradiologist, AIR x™ saves time for the patient, technologist and the radiologist.

"We have found that AIR x™ can help save time in the patient set-up and that means less time that they are immobilized and in the scanner," Dr. Benoudiba-Bataille explains.

Adds Laure Cacheux, RT(R), technologist, "AIR x™ is very fast in the slice positioning regardless of the required plan. That saves us time because we just need to check the slice prescription from AIR x™." As a result, the technologists can spend more time addressing any patient concerns, anxiety or stress.

More importantly, since the slice prescription is no longer technologist-dependent, there is greater reproducibility and similarity of the MR slices (images) across studies. This is very important for patient follow-up in oncology, including primary and secondary tumors, neurodegenerative diseases, such as multiple sclerosis, and arteriovenous malformation or other neurosurgery cases.

"In the case of a patient follow-up for tumor assessment, the slice positioning must be as identical as possible to the prior exams in both the axis and the coverage," says Antony Morel, RT(R), technologist. "While AIR x™ is clearly

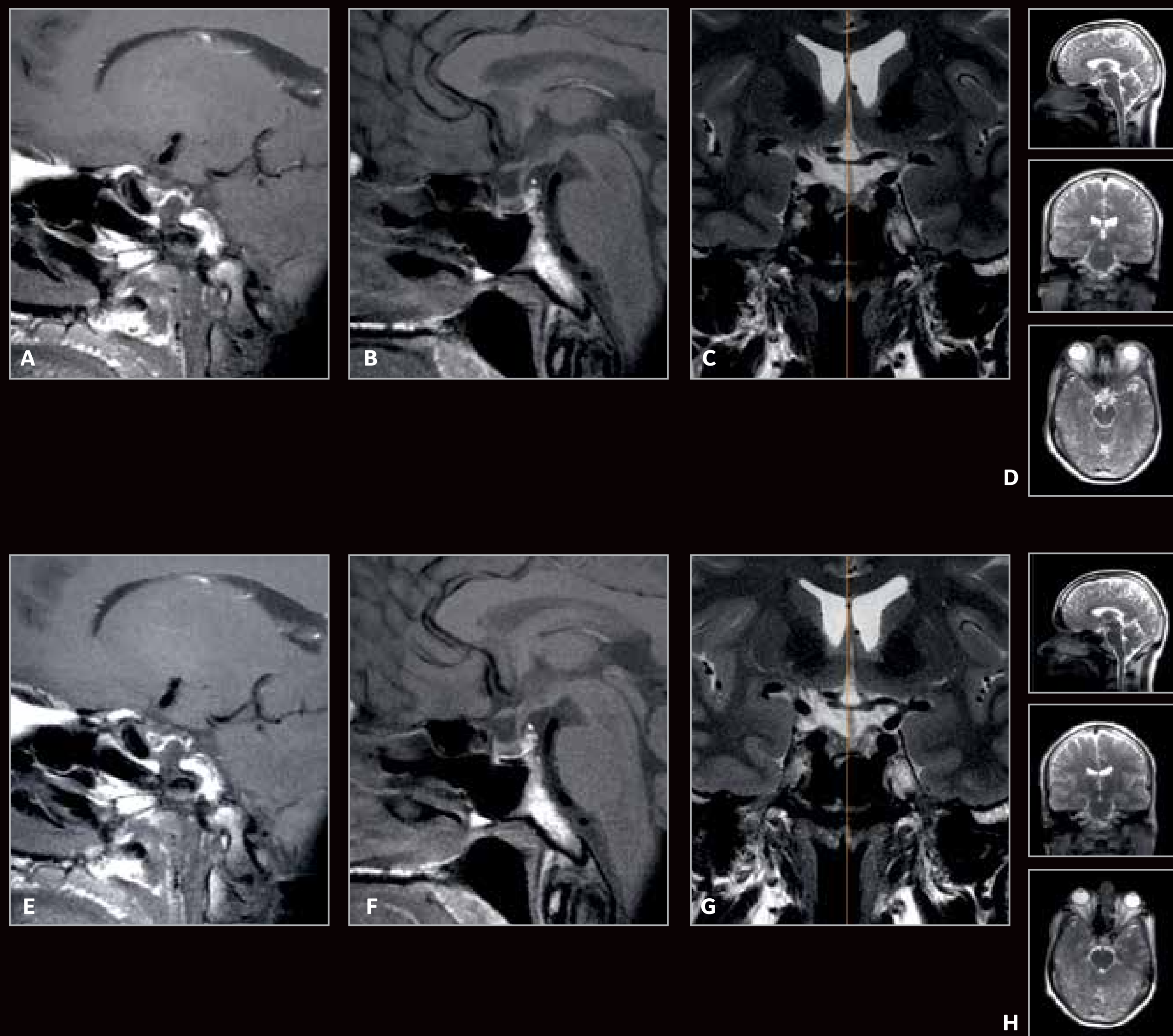


Figure 4. Patient underwent MR imaging of the pituitary on two different days. With AIR x™, the technologist was able to start and finish the acquisition at the same anatomic position to obtain identical coverage and slice positioning data for comparison of the two studies. (A-C) First day exam with (D) 3-plane localizer and (E-G) the second day exam with (H) 3-plane localizer. Notice the slightly different translation and rotation in the 3-plane localizer images between the first and second day.

Images courtesy of Kremlin-Bicetre Hospital

useful for a newer technologist, even the most experienced technologists may not be able to achieve this precision with every follow-up exam."

Dr. Benoudiba-Bataille explains, "With the same slice prescription and patient position, we are more confident that we can detect a residual tumor in our follow-up MR study, for example. It also assists with precise contouring and reliable measurements needed for therapy planning independent of the radiology reviewer."

The reliable and reproducible measurement of tumors is a requirement of the Response Evaluation Criteria in Solid Tumors (RECIST), a set of published rules that define when patients respond, stay the same or worsen during treatment. RECIST is used in many cancer trials to evaluate the efficacy of treatments.

"The reproducibility in imaging that we can obtain with AIR x™ enhances my confidence in patient follow-up cases, and that allows me to better support my colleagues in oncology and surgery."

Dr. Farida Benoudiba-Bataille

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Hollis Potter, MD
The Hospital for Special Surgery
New York, New York

Darryl Sneag, MD
The Hospital for Special Surgery
New York, New York

A coil for all joints in MSK imaging

Patients come in all shapes and sizes. However, traditional hard shell MR coils do not fit all patients, all the time, and this can lead to poor signal and poor image quality. The lack of dedicated coils for orthopedic imaging presents challenges in patient positioning and often leads to longer scan times and lower signal-to-noise ratio. Coupled with the high-performance gradient of the wide bore SIGNA™ Premier system, AIR™ Multi-Purpose (MP) Coils‡ provide flexibility and comfort in positioning, larger Z-coverage of the body and consistent and excellent image quality. Together, they aid in patient diagnosis and surgical planning at the Hospital for Special Surgery in New York.

AIR™ MP Coils were designed to address the need for total positioning freedom with 360-degree coverage in patients of all shapes and sizes. With an adaptive design and both 20- and 21-channel coils that are 38 percent lighter per channel compared to conventional technology, AIR™ MP Coils deliver the coverage needed for a variety of orthopedic, body and cardiac exams.

"The challenge in orthopedic imaging is the lack of dedicated coils," says Hollis Potter, MD, Chairman, Department of Radiology and Imaging at the Hospital for Special Surgery (HSS). As a result, coils designed for other body parts are often used in orthopedic MR imaging.

Take for example the elbow. There is a tremendous degree of rotation in the forearm; however, above the elbow joint, the arm has less rotation. Positioning is very important to obtain high-quality images without the need for a "superman" position where the patient's arms are extended straight up above their head, creating traction on the shoulder and brachial plexus.

With traditional coils, Dr. Potter would regularly see evidence of B_1 inhomogeneities, degradation in the images and a lack of homogeneous fat suppression on elbow images. These were often the result of air gaps between the skin and coils and the inability to completely "wrap" the elbow or overlapping of coil elements due to poor fit.

Positioning the orthopedic patient with a traditional coil is not only more difficult due to its rigid structure, but often requires additional time for localization during scanning. According to Dr. Potter, it would not be unusual to see four different localizer MR scans as the technologist tried to obtain the ideal position for optimal image quality, and often positioning a patient in a hard-shell-cased coil is a difficult task. This is not the case with the AIR™ MP Coils.

‡Not yet CE marked. Not available for sale in all regions.

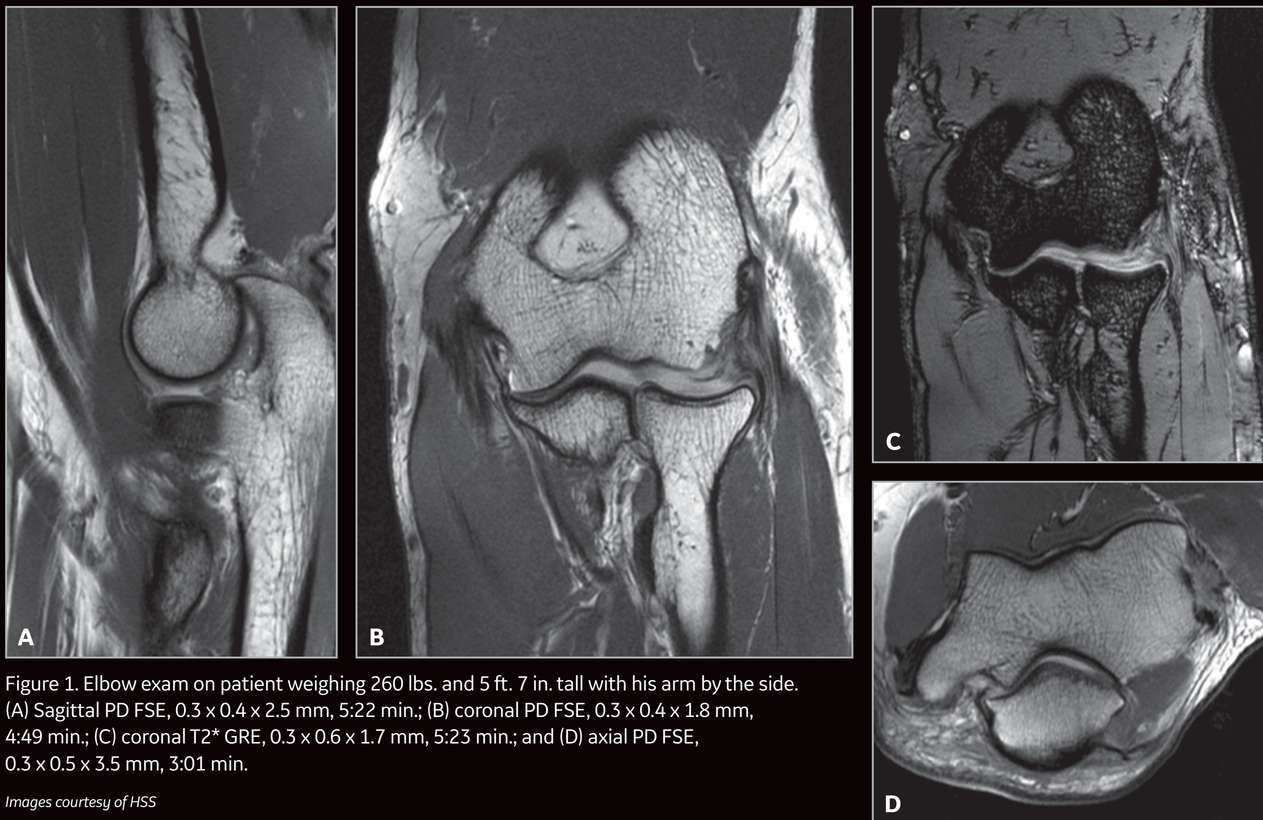

Figure 1. Elbow exam on patient weighing 260 lbs. and 5 ft. 7 in. tall with his arm by the side. (A) Sagittal PD FSE, 0.3 x 0.4 x 2.5 mm, 5:22 min.; (B) coronal PD FSE, 0.3 x 0.4 x 1.8 mm, 4:49 min.; (C) coronal T2* GRE, 0.3 x 0.6 x 1.7 mm, 5:23 min.; and (D) axial PD FSE, 0.3 x 0.5 x 3.5 mm, 3:01 min.

Images courtesy of HSS

"The AIR™ Coils have been great for us," Dr. Potter says. "They are like fabric, so it doesn't matter how big our patient's elbow or arm is. We can wrap the coil around the elbow and overlap elements without perceivable interference or any negative impact on image quality."

In addition to added patient comfort, the technologist can place the AIR™ MP Coil in areas that were previously difficult to access, such as around the neck for a brachial plexus study. "Traditional flex coils are not completely flexible, can be uncomfortable and may impact image quality," says Darryl Sneag, MD, radiologist at HSS.

The AIR™ MP Coils provide larger Z-coverage of the body area and are particularly useful when imaging an extremity.

"To image a large tumor or to evaluate nerves from the shoulder to the wrist, our technologist had to reposition the coil three to four times to cover the entire anatomy," explains Dr. Sneag. "Now, we only have two position changes. From my perspective, the biggest advantage is the increase in Z-coverage while still achieving the equivalent in-plane spatial resolution."

Although GE Healthcare's Discovery™ MR750w with GEM had an integrated posterior array providing added flexibility in coil positioning, the SIGNA™ Premier with the integrated AIR™ Posterior Array (PA), AIR™ Anterior Array (AA) and the newly launched AIR™ MP Coils, which come in two different channel counts, deliver added flexibility and coil combinations. With the AIR™ Coils, patients are more comfortable and this leads to a better patient experience.

Patient comfort also impacts image quality and study reproducibility by helping to reduce patient movement. According to Dr. Potter, having high-quality images that are reproducible across MR exams can reduce radiologist fatigue when reading.

"When we have consistent, superior image quality, it is hard not to get excited," says Dr. Potter.

"The superior gradient performance of the SIGNA™ Premier system with solid gradient linearity off of isocenter, combined with the flexibility of the AIR™ Coils, provides us with some of the best and most consistent images that I have encountered across platforms."

Dr. Hollis Potter

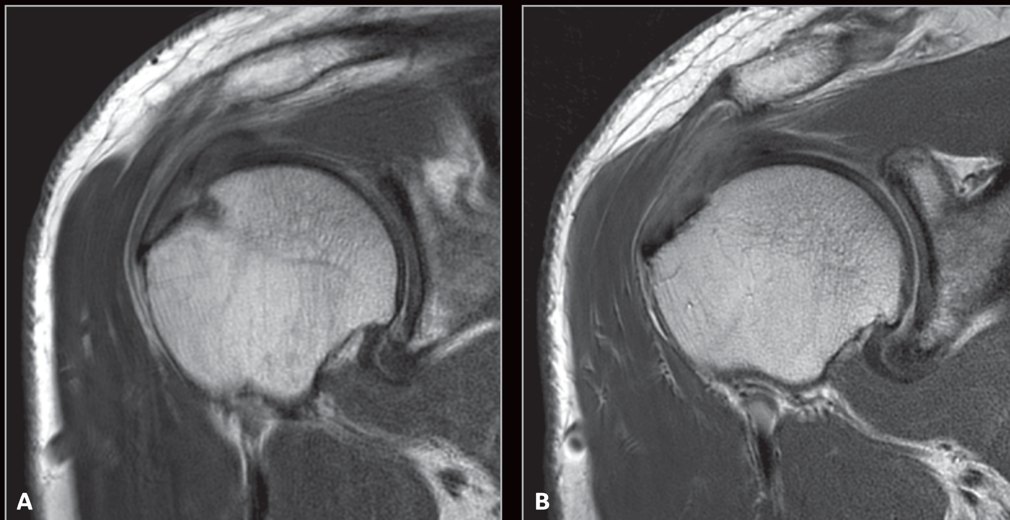

Figure 2. Coronal PD FSE shoulder exam (A) without PROPELLER, 0.3 x 0.4 x 3 mm, 4:04 min., and (B) with PROPELLER, 0.3 x 0.3 x 3 mm, 3:43 min.

Images courtesy of HSS

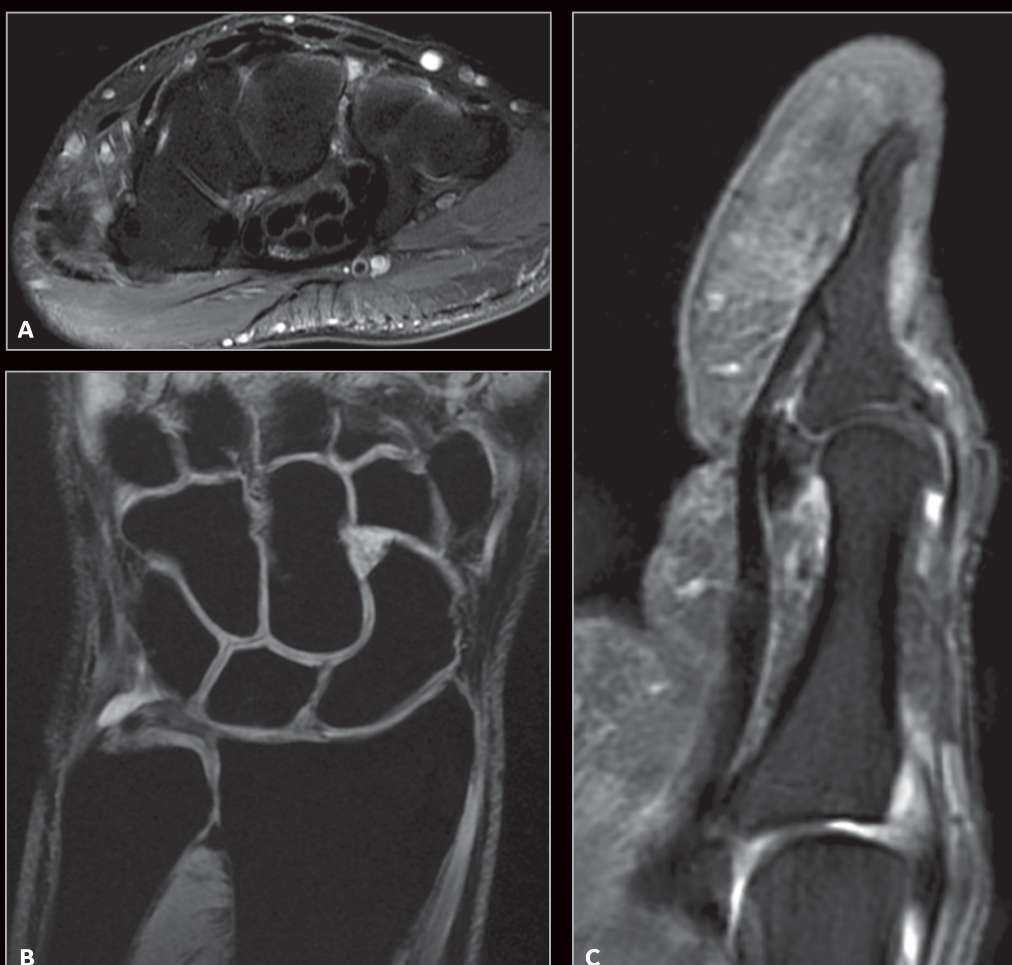

Figure 3. (A) Hand image, axial PD FatSat, 0.3 x 0.3 x 3 mm, 8 cm FOV, 3:36 min.; (B) wrist image, coronal PD, 0.3 x 0.4 x 2 mm; and (C) finger image, sagittal PD FSE Flex, 0.3 x 0.4 x 2.5 mm, 2:17 min.

FOV (cm)	RBW (± kHz)	ESP % change from Discovery™ MR750 to SIGNA™ Premier
10	31.25	-9.3
	62.5	-13.7
	83.3	-13.7
	100	-18.4
	111.11	N/A on MR750
	125	N/A on MR750
8	31.25	-8.0
	62.5	-12.5
	83.3	-13.3
	100	N/A on MR750
	111.11	N/A on MR750
7	31.25	-7.4
	62.5	-8.7
	83.3	N/A on MR750
	100	N/A on MR750
6	31.25	-6.8
	62.5	-7.4
	83.3	N/A on MR750

Table 1. Echo spacing (ESP) reductions with a standard 2D FSE acquisition on Discovery™ MR750 and SIGNA™ Premier, as a function of FOV and receive bandwidth (RBW). In several circumstances, the prescription could not be scanned on Discovery™ MR750, as noted. The protocol used for this comparison was a 2D FSE, 512 x 488 matrix, 2 mm slice thickness.

For Dr. Sneag, the ability to precisely visualize lesions and nerves, and identify structural changes in peripheral nerves to give patients a reason why they are in pain or weak, is the most significant impact of the combined improvements from AIR™ MP Coils, new pulse sequences and higher performance gradients on SIGNA™ Premier.

"These improvements are not to be taken lightly — these technologies are making a strong impact," adds Dr. Potter. "It is not just the ability to provide the information we need to confidently diagnose conditions that were previously considered a diagnosis of exclusion, but we now find focal lesions that are amenable to surgery. These images provide an essential roadmap to refine the surgical exposure."

The impact is not just in diagnosis, but also in surgical planning. Drs. Sneag and Potter can deliver a more targeted approach to answer the clinical question, such as pinpointing precisely where the abnormality is located. This approach can help reduce serial imaging, as well as the length of time for the surgical procedure.

In several instances, Dr. Sneag has marked areas on patient scans that have taken a lot of the guesswork out of the procedure for surgeons. In many cases, the surgeon has been able to reduce the incision size significantly because they knew exactly where to operate.

From a research perspective, the results have been equally impressive with AIR™ Coils and SIGNA™ Premier.

"With SIGNA™ Premier, we now have the ability to actively use 120 elements," says Dr. Sneag. "That allows us to think outside the box — previously we only had 32 channels. As we are looking at higher channel coils or combining coils, there are so many more options."

SIGNA™ Premier has gradient performance advantages over the Discovery™ MR750, as evidenced by shorter echo spacing, which leads to sharper images (Table 1). In addition, SIGNA™ Premier has the capacity for more elements, as well as more receivers. By adding the high-density AIR™ Coils, HSS can now scan with the densest coil packing per volume, enabling the use of the highest independent channels for each imaging volume. And that is a benefit for clinicians and patients alike. S

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David Rogers,
MBChB, FRANZCR
Ascot Radiology
Auckland, New Zealand

Lexie Nelson, MRT
Ascot Radiology
Auckland, New Zealand

AIR a true asset in the land of Kiwis

Be the best that you can be is the motto for AUT Millennium, a charitable trust created to help New Zealanders live longer, healthier lives that is home to several sports clubs and national sporting organizations. The same can be said for Ascot Radiology, the radiology group that provides imaging services at AUT Millennium and seven other sites, including Ascot Hospital and the multi-modality clinic Ascot Central.

In 2018, Ascot Radiology upgraded its Discovery™ MR750w wide bore system with SIGNA™Works. One year later, the practice completed a SIGNA™ Lift to bring the system up to a SIGNA™ Architect and the latest SIGNA™Works productivity platform featuring some of GE Healthcare's most advanced MR applications.

"The imaging was good, previously, but naturally we are very happy for any improvement in image quality," says David Rogers, MBChB, FRANZCR, Managing Director for Ascot Radiology. He noticed the improvement in signal-to-noise ratio (SNR) with the system upgrade and, of course, the new AIR™ Coils.

"The AIR™ Coils are the lightest and most flexible coils available today," he explains. As a body radiologist specializing in female pelvic imaging, he sees the difference.

Traditional body arrays are heavy, rigid and fixed. "Almost crushing for the patient, and that makes it more difficult for them to regulate their breathing," Dr. Rogers adds. "The patient would breathe very shallow and then gasp for a deep breath. That, in particular, can ruin the quality of abdominal and pelvic imaging."

Now, with AIR™ Coils, the patient breathing and related body movement is more regular, and that has led to better image quality with fewer artifacts. Patients are not complaining about the heavy weight on them, which makes for a much better patient experience too.

"We are also seeing superb results in joint imaging with the larger coverage afforded by the AIR™ Coils," he says. Since the SIGNA™ Architect is in the Ascot Radiology clinic within the AUT Millennium facility, there are many patients who are professional or semi-professional athletes with large forearms and broad shoulders.

The larger coverage also impacts abdominal imaging, such as in the commonly used coronal SSFSE sequence. With the AIR™ Anterior Array (AA) Coil, the coverage is from the diaphragm through the pelvis, whereas with traditional abdominal coils the coverage stopped before the pelvis. That makes a difference in the reading of the exam, as Dr. Rogers can now report from one sequence versus two.

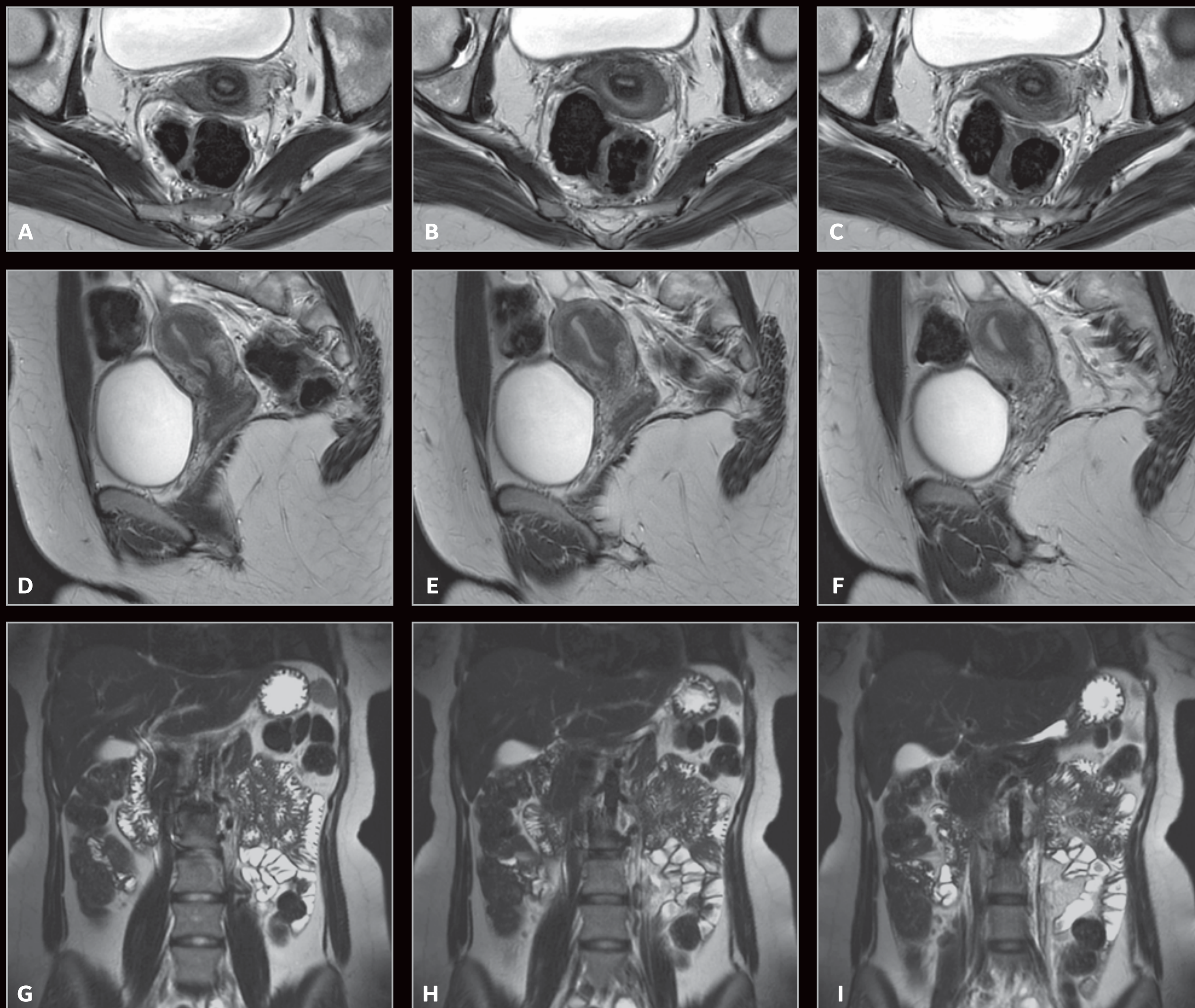


Figure 1. Female pelvis imaging with AIR™ AA Coil and PROPELLER MB. (A-C) T2 axial PROPELLER MB; (D-F) T2 sagittal PROPELLER MB; (G-I) T2 coronal SSFSE.

Images courtesy of Ascot Radiology

Dr. Rogers has also found that the dynamic range in the images, or the difference between the darkest and lightest tones, is much better in the abdomen and pelvis with the new system and AIR™ Coils. Specifically, the PROPELLER MB motion insensitive sequence now allows more flexible parameter tailoring, and when used in T2 imaging, the endometrium tissue is brighter and the uterus is a darker shade of gray.

"There is much better conspicuity of lesions in these images. I've also reviewed several spine exams and found that both the signal and the resolution were improved. Certainly the imaging performance in these areas has increased dramatically. We are more confident diagnostically when we can consistently perform MR exams at a high standard."

Dr. David Rogers

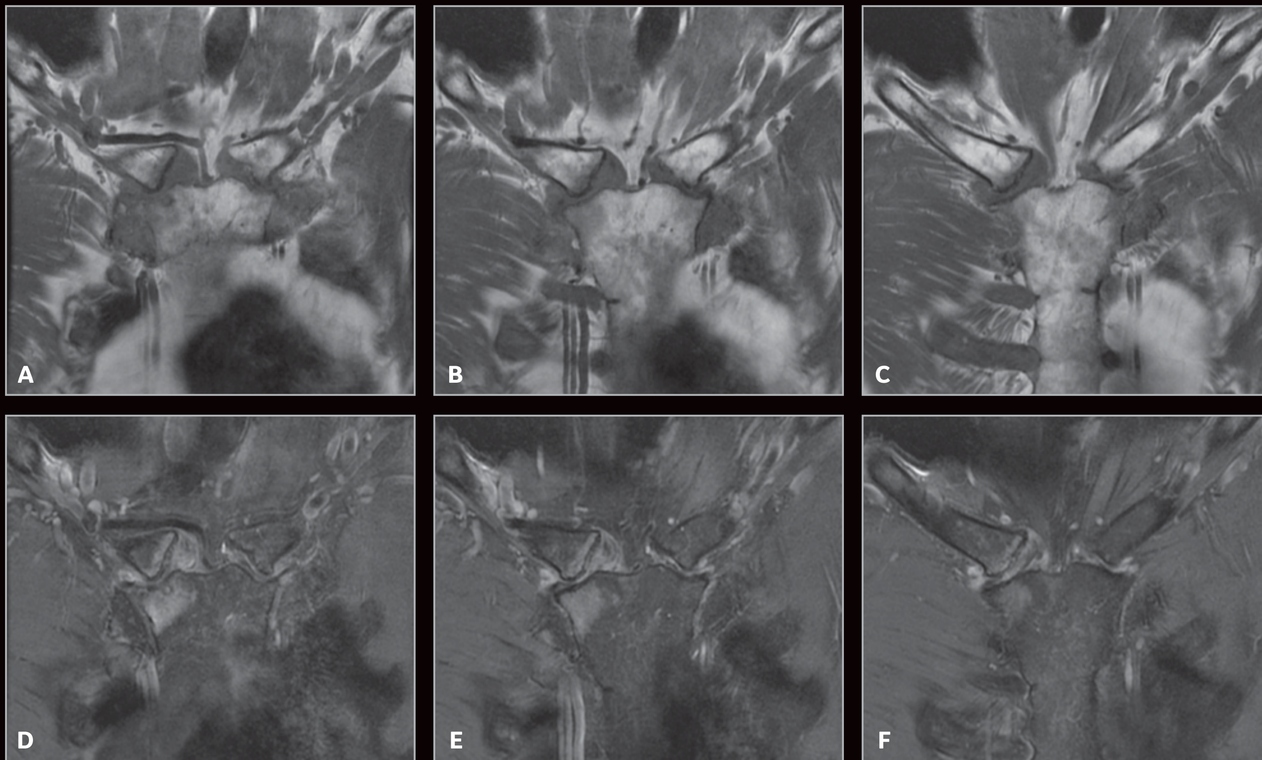


Figure 2. Sternoclavicular joint imaging with AIR™ AA Coil. (A-C) T1 coronal and (D-F) T2 coronal FatSat.

Images courtesy of Ascot Radiology

He recalls a patient who had a spine MR exam on three different occasions: the first on the Discovery™ MR750w, the second on the SIGNA™Works upgrade and a third recently on the SIGNA™ Architect Lift with AIR™ Coils. There is an obvious difference in signal and resolution, he adds, and the different exams of the same patient are a clear demonstration of the increased image quality of the new system and coils.

Patient workflow

Although it is difficult to know whether the improvements are from the upgraded system, new sequences, AIR™ Coils, or a combination of these new technologies, Dr. Rogers notices the shorter scan times with the ARC, HyperSense and HyperCube acceleration techniques and a reduction in motion artifacts with the enhanced PROPELLER MB.

"Having these acceleration techniques available gives us the freedom to choose between the same resolution and a faster scan or better resolution at the same exam time," Dr. Rogers says. "We are getting better imaging per minute from the scanner." That ability to save time in a routine exam is important, he adds, because then in difficult cases he can spend the extra time acquiring another view or sequence.

> "The AIR™ Coils are really game-changing and make a huge difference in the flexibility of the system."
>
> *Dr. David Rogers*

That difference in flexibility is also positively impacting the technologists' daily workflow and productivity at Ascot Radiology. Lexie Nelson, MRT, (MR radiographer), has found she needs to change fewer coils to get the MR study completed, even when imaging large-sized professional athletes. It also means she is not taking precious scanner time trying to find a coil that fits, which can also delay the next exam(s).

"We have a lot of different-sized patients, from very thin runners to the broad and muscular weight lifters," Nelson says. "These people would sometimes not fit in a traditional hard shell coil. We would waste time trying two to three different coils and the patient might get embarrassed. Now, we can just wrap the AIR™ Coil around their body part or area, and that gives us a more efficient workflow. Plus, the coil is not so confining or scary-looking, so in some cases it helps us coax the patient into the scanner for their exam."

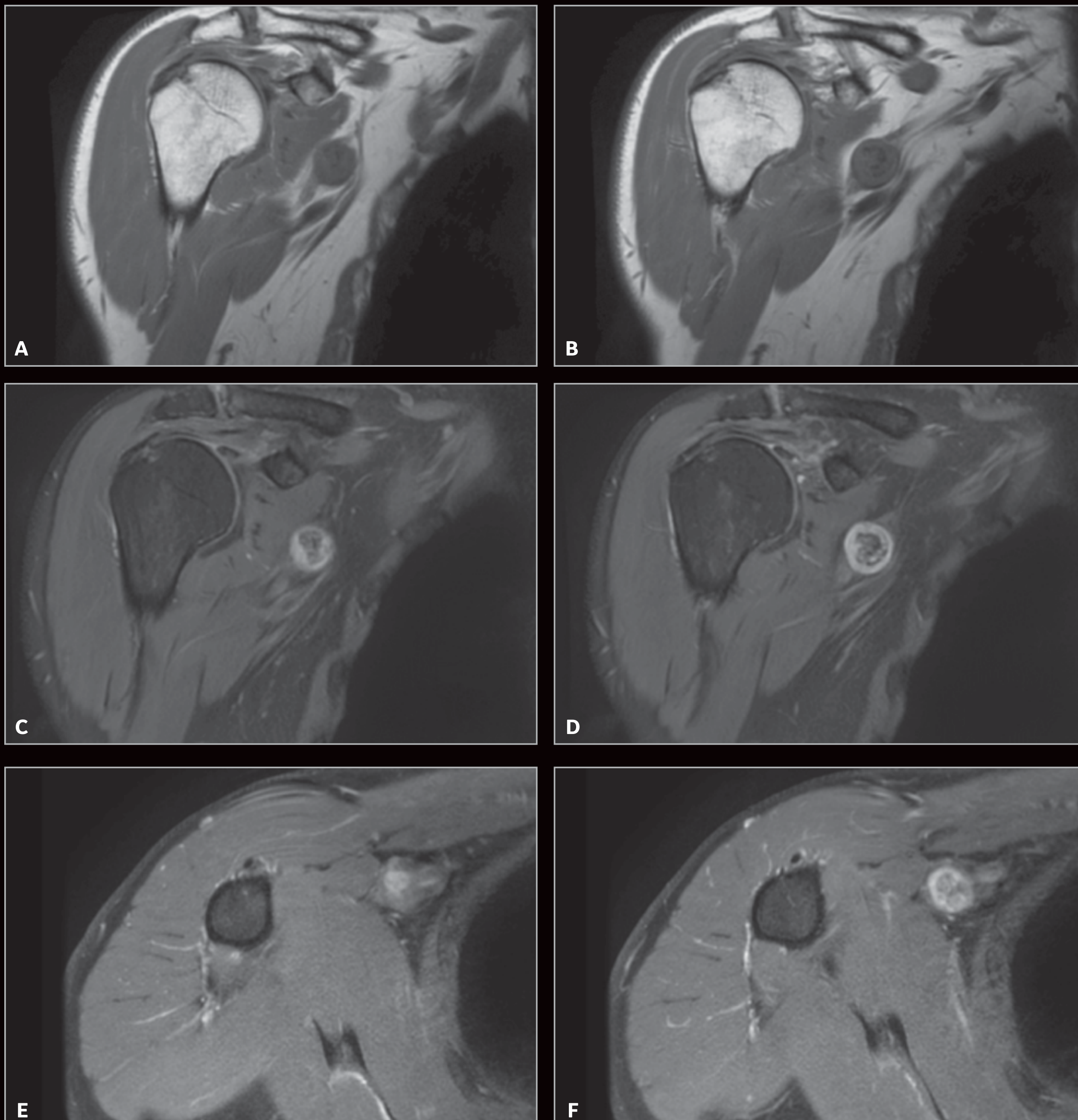


Figure 3. Pectoral area imaging with AIR™ AA Coil. (A-B) T1 coronal; (C-D) PD coronal FatSat; and (E-F) PD axial FatSat.

Images courtesy of Ascot Radiology

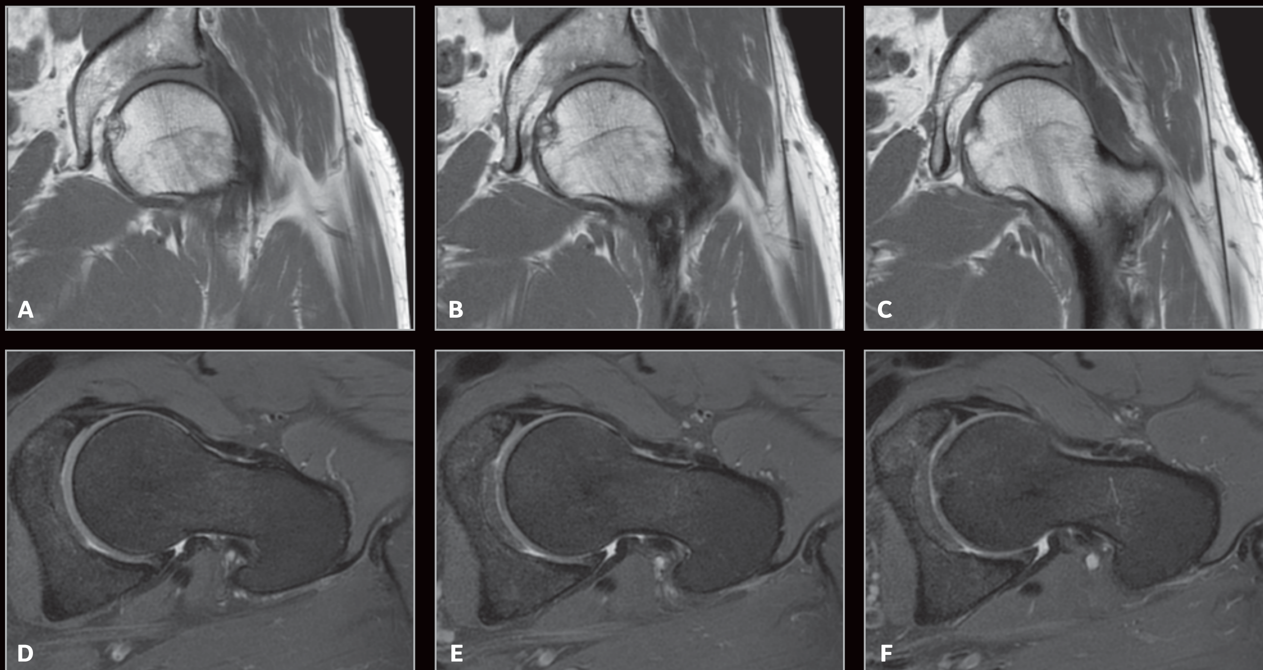


Figure 4. Unilateral hip imaging with AIR™ AA Coil. (A-C) T1 coronal and (D-F) PD axial FatSat.

Images courtesy of Ascot Radiology

With the excellent coil coverage and SNR, Nelson doesn't have to manipulate the patient's position as much as before. The flexible, blanket-like design enables her to more easily wrap the coils around the patient and get them in the correct position for imaging. Plus, the larger field of view (FOV) means she can capture the anatomy in one scan versus having to move the coil and scan again.

For example, the technologists will often perform an exam covering the shoulder, clavicle and pectoral area in athletes who are suspected of tearing a muscle in one of these areas.

"I can wrap the AIR™ Coil from the sternum to the arm and get all the information our radiologists need without losing signal or hurting the patient," Nelson explains. "I don't have to use two coils. Or, if I'm scanning the shoulder, I can image from the tip of the scapula right down to the midline of the clavicle." The AIR™ Coil is also used for smaller FOV sternoclavicular joint imaging.

She has the same experience imaging the hips and female pelvis. Nelson will use both the embedded AIR™ Posterior Array (PA) Coil in the table and then wrap the AIR™ AA Coil on top of the patient without moving them.

"It's good for workflow and the patient, and the images are beautiful. There is no image fallout on the sides, given the large surface area we are scanning," Nelson adds.

The largest coverage and FOV that Nelson has imaged so far is a full femur of a patient who tore their hamstring muscles. She scanned from the crest of the pelvis all the way to the knee — something she could not do with traditional coils and get the necessary coverage.

Several of the newer sequences in SIGNA™Works are also making an impact on the technologist's workflow and imaging from the SIGNA™ Architect. Nelson can easily change a sequence to PROPELLER MB if a patient is moving, which she says is amazing and improves workflow. When using the FSE Flex sequence in more challenging areas, she doesn't lose resolution when compared with FSE FatSat acquisitions.

Yet, it's the AIR™ Coils that are life changing.

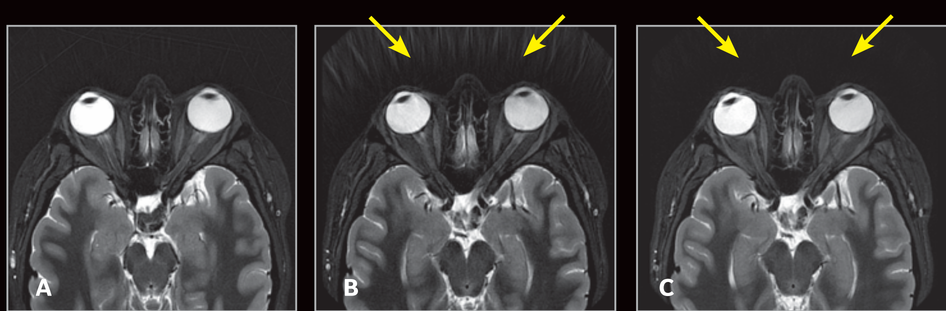
"The AIR™ Coils are a true asset. I would tell others to get one if they can, and better yet, get two, because they are fabulous."

Lexie Nelson

A software package that helps you do more with less

Learn more about what you can do with AIR™: gehealthcare.com/air

The new SIGNA™Works AIR™ Edition from GE Healthcare packs innovations that deliver versatility, productivity and consistent quality, empowering any technologist to deliver images with remarkable clarity. From new applications to enhancements to existing technologies, the new software release is just simply better.



(A) Typical scanning reconstruction requires significant oversampling (NPW) to prevent out-of-FOV artifacts. This causes the user to scan more than is needed, which has a direct impact on scan time. (B) If we reduce the over oversampling factor (NPW), we're able to lower the scan time but introduce out-of-FOV artifacts (arrows). (C) With AIR™ Recon, we can achieve shorter scan times and remove the out-of-FOV artifacts and improve the quality.

AIR™ workflow and image quality

Intelligent workflow applications powered by AIR™ automate the scan process to drive consistency. When paired with advanced imaging applications, AIR x™, AIR Touch™ and AIR™ Recon deliver simply better versatility and productivity gains along with industry-leading image quality.

AIR x™, a revolutionary workflow tool for brain exams, automatically prescribes slices to help eliminate error-prone, manual slice placements. Studies have shown 5x faster set-up time and 4x fewer clicks with AIR x™. So no matter who is scanning you get consistent and precise prescription set up for patients regardless of their age, pathology or position in the magnet.

AIR Touch™ accelerates the scanning process through automated coil selection and landmarking. Just use IntelliTouch™, GE's 1-touch landmarking tool, to activate an optimized set of coils that is selected based on the patient's anatomy. With the anatomical-based protocol optimization, AIR Touch™ optimizes the protocol parameters with a single touch, delivering a 59%** productivity gain from plan to scan. Realize further scan savings with Flexible No Phase Wrap (NPW) to scan only what you need so you can focus on the patient not the scanner.

AIR™ Recon, GE's new reconstruction algorithm available on several key applications like PROPELLER, Cube, FSE and Flex, helps reduce background noise and out-of-FOV artifacts while improving SNR. The result is cleaner, crisper images without having to overcompensate in your scanning protocol.

Existing app enhancements

MAVRIC SL‡, GE's industry-leading application for imaging in the presence of MR-Conditional implants, now includes T2-weighting (in addition to T1, PD and STIR), NPW and an automated-parameter setting for streamlined workflow. Want to get there faster? **HyperMAVRIC SL** a 3D isotropic acquisition that enables 40 percent shorter scan times by automatically tailoring the acquisition to the patient's implant.

There's even more in the SIGNA™Works AIR™ Edition to make everyday scans exceptional. New standard and expanded advanced applications simply improve your MR imaging capabilities from scan setup to patient comfort to image reconstruction. Ⓢ

** Results may vary.

‡ MAVRIC SL should only be used with MR-Conditional implants and within the MR conditions specified for those implants.

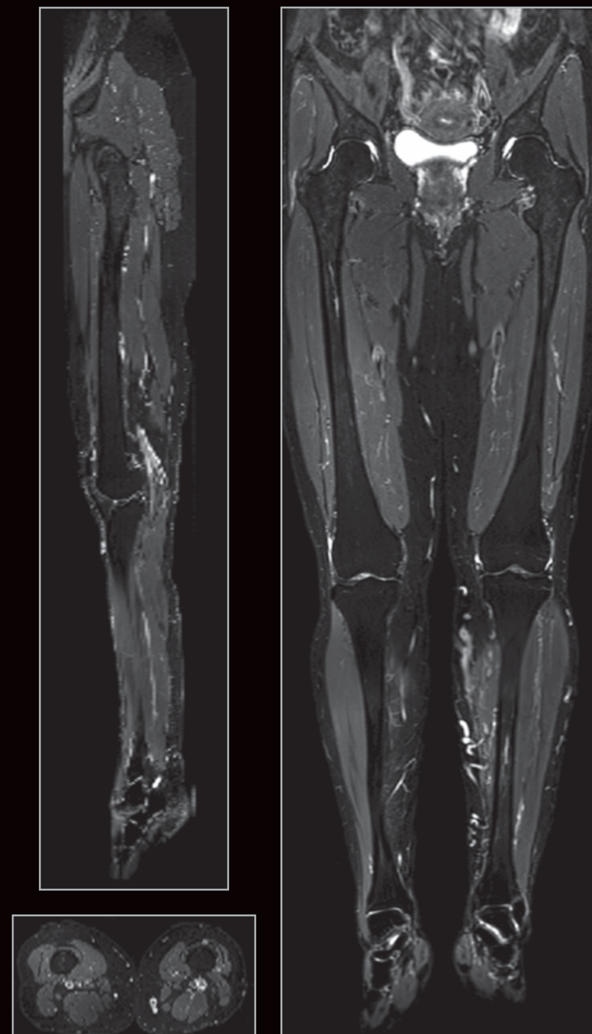
SIGNA™Works AIR™ Edition is not available on all systems. Please contact your local GE representative for more information.
AIR™ is not available in all regions.

AuntMinnie.com
THE BEST OF RADIOLOGY
WINNER

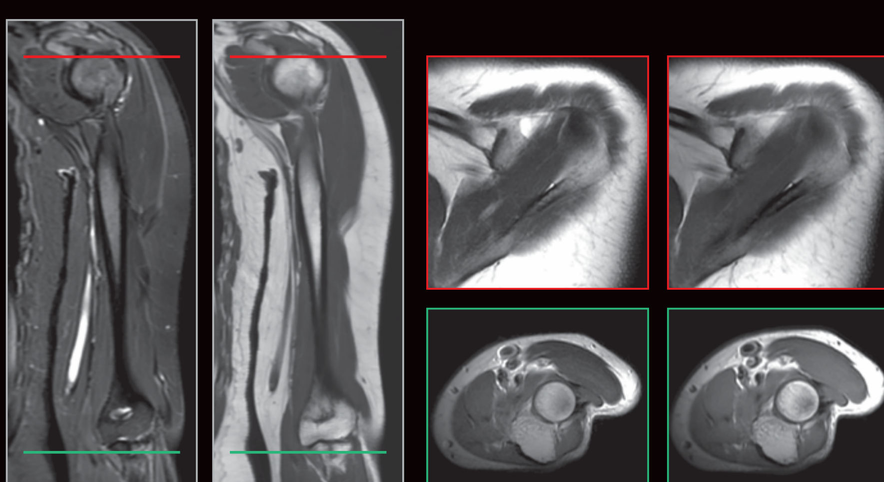
SIGNA™ Works AIR™ Edition gallery:
Coil combinations with AIR Touch™

All images in this gallery were acquired using AIR™

Two-station chest/abdomen/pelvis (above) and the upper extremity (below) demonstrate the coverage of the AIR™ Anterior Array Coil. The coil was not repositioned, allowing flexibility in imaging while maintaining versatility, comfort and quality.

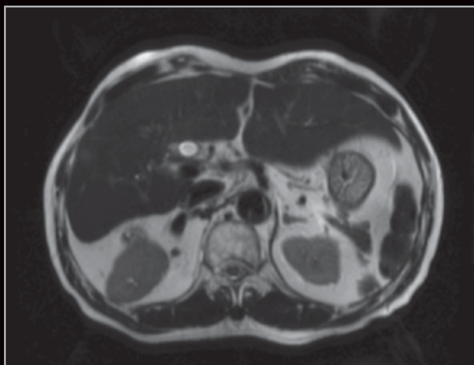
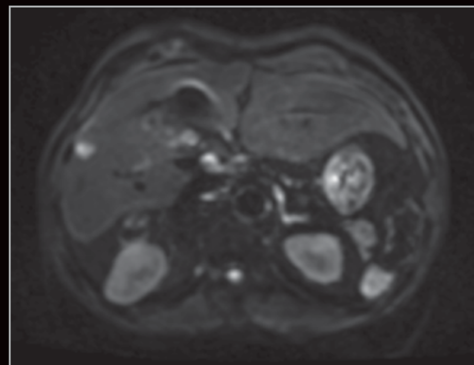


With two AIR™ AA Coils wrapped around the lower extremities, a multi-station exam (above) can be performed with ease. AIR Touch™ automated coil selection allows for improved workflow while optimizing parallel imaging performance with minimal interaction from the user.



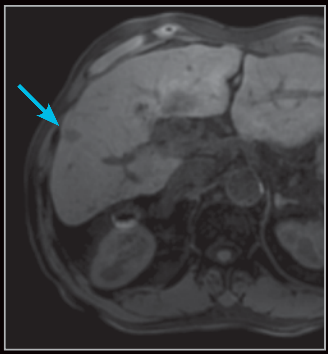
All images courtesy of Emsey Hospital, Istanbul, Turkey

SIGNA™ Works AIR™ Edition gallery:
Abdominal imaging

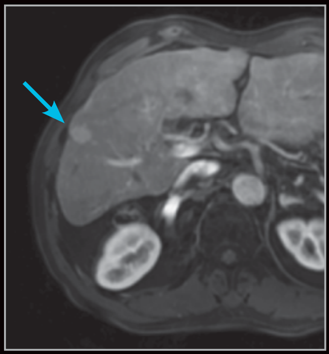



T2 SSFSE, DWI and dynamic LAVA depict a rapidly enhancing liver lesion.

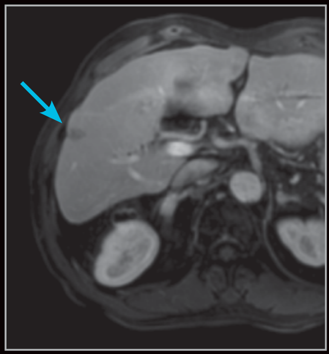
Images courtesy of Hospital Universitario Quirón Salud, Madrid, Spain



Pre-contrast enhancement

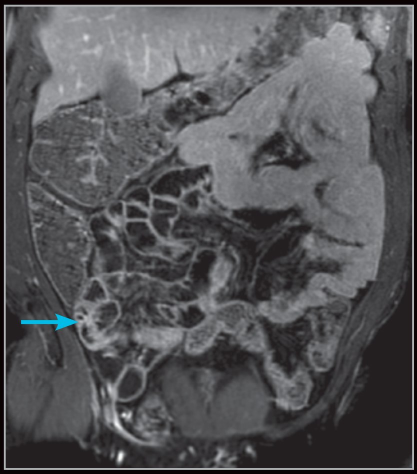


Arterial phase



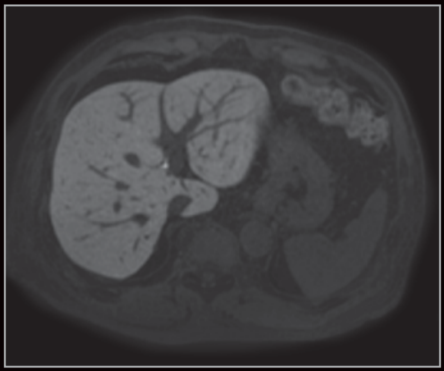
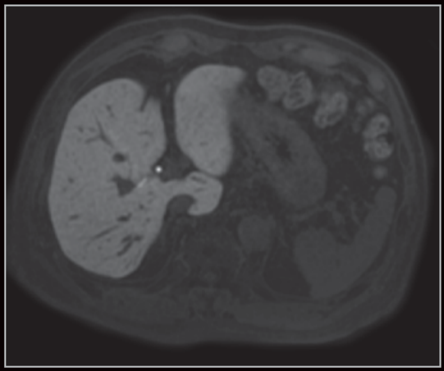
Portal phase

Late phase

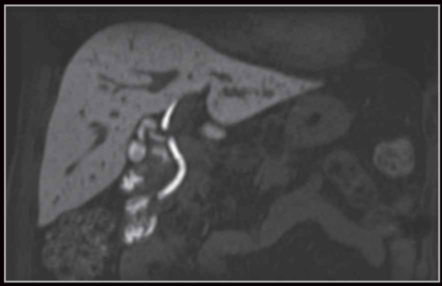



Patient with Crohn's disease demonstrating post-contrast enhancement of the terminal ileum. MRA was obtained in the same exam during the early arterial phase of a DISCO LAVA sequence.

Images courtesy of Hospital Universitario Quirón Salud, Madrid, Spain

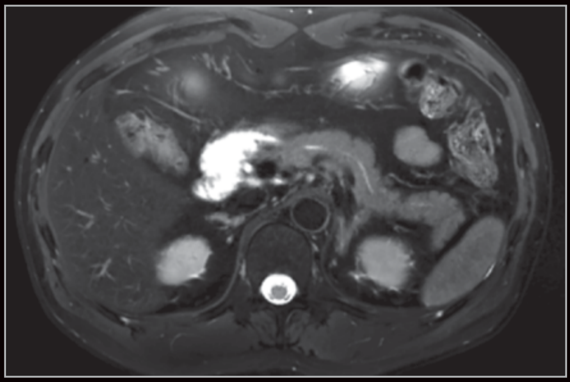
Delayed phase axial LAVA acquisition 15 min. post Gd-EOB-DTPA. Scan time was 0:20 min.

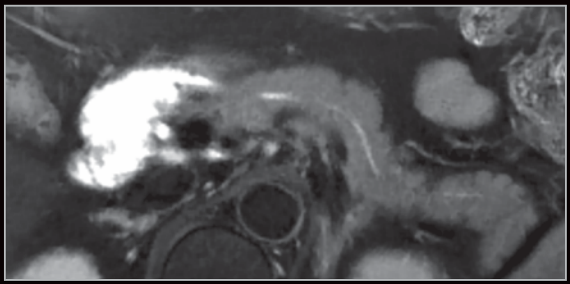


Coronal MPR of an axial LAVA acquisition.

Images courtesy of Osaka University Hospital, Osaka, Japan

SIGNA™ Works AIR™ Edition gallery:
Abdominal imaging (pancreas & MRCP)

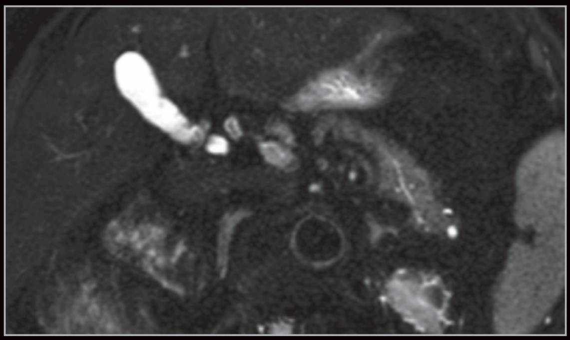


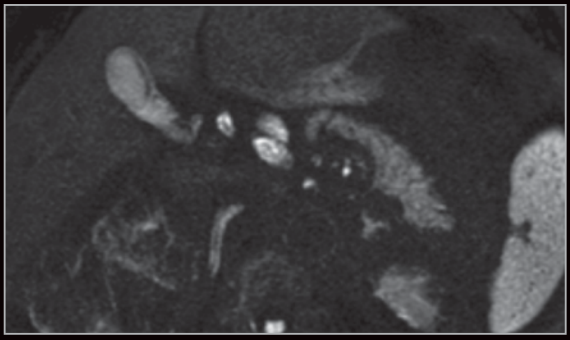


AIR™ Coils are comfortable for the patient and enable higher parallel imaging factors, which reduces patient exam times and drives productivity.

Images courtesy of Osaka University Hospital, Osaka, Japan

Axial T2 FatSat
PROPELLER MB
0.6 x 0.6 x 4 mm
ARC 4.0
4:24 min.

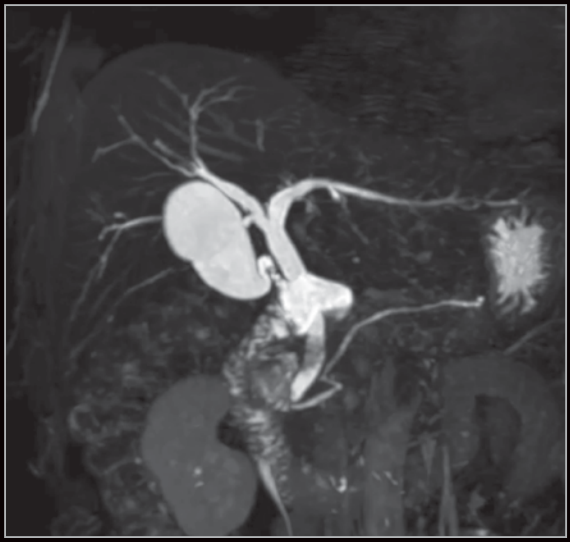


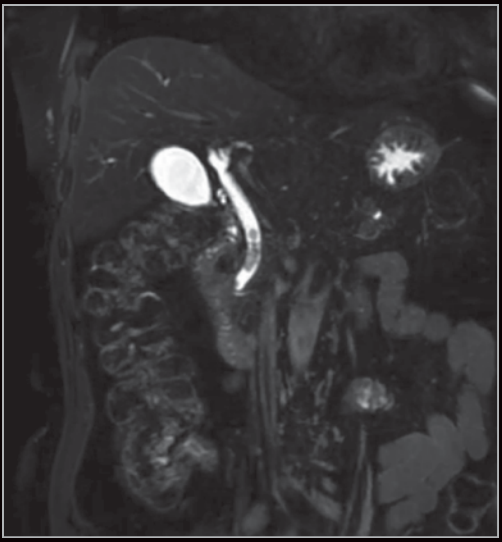


Improved DWI EPI imaging with multi-shot DWI and AIR™ AA Coils.

MUSE allows for reduced susceptibility artifacts, incorporates large matrices for submillimeter resolution and can be combined with distortion correction for additional artifact reduction. Combining MUSE with AIR™ Coils ensures a simply better patient experience and exceptional image quality.

Images courtesy of Emsey Hospital, Istanbul, Turkey

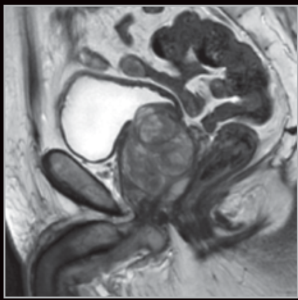




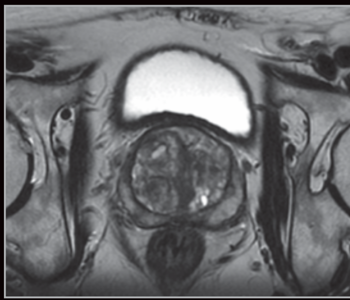
3D MRCP with HyperSense
1.2 x 1.2 x 1.6 mm
3:08 min.

Images courtesy of Haeundae Paik Hospital, Busan, Korea

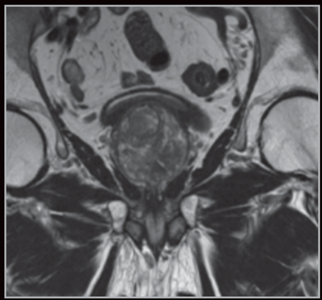
SIGNA™ Works AIR™ Edition gallery:
Pelvis imaging (male & female)



Sagittal T2 PROPELLER
0.7 x 0.7 x 3 mm
3:16 min.

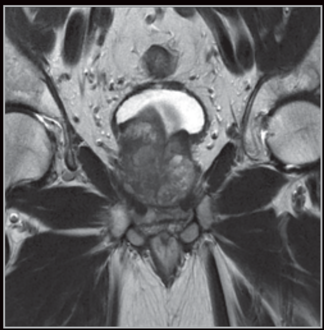


Axial T2 frFSE
0.6 x 0.8 x 3 mm
3:24 min.

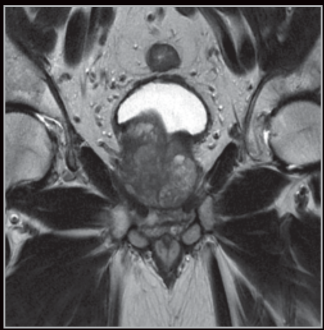


Coronal T2 frFSE
0.7 x 0.7 x 3 mm
3:50 min.

Images courtesy of radiomed, Mainz, Germany

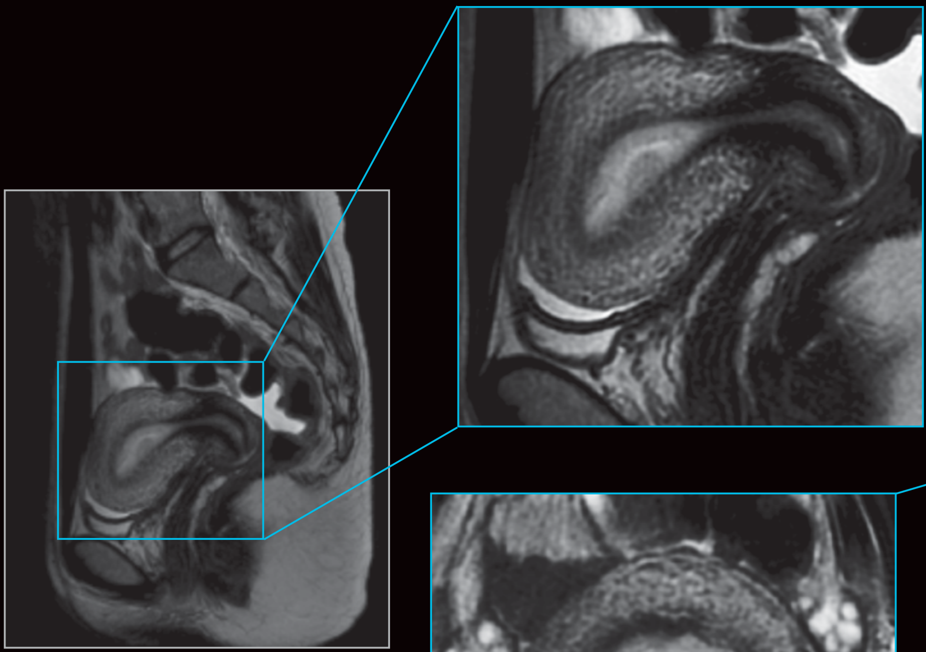


Without AIR™ Recon
4:35 min.

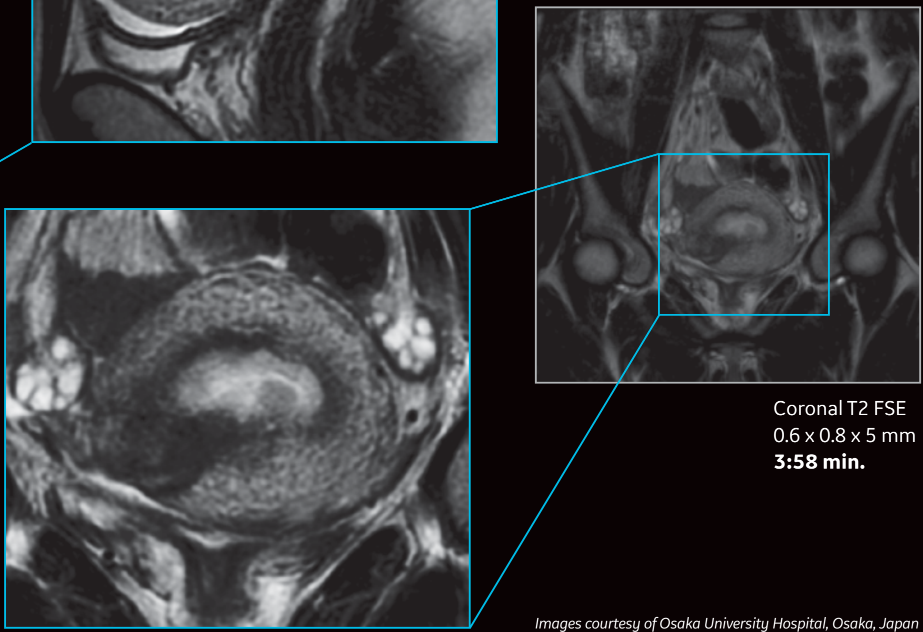


With AIR™ Recon
3:37 min.

AIR™ Recon allows reduction in scan times and can lessen out of field-of-view artifacts to improve image quality and workflow. Both coronal T2 PROPELLER scans were acquired with the same resolution, however, the left image was acquired in 4:35 min. while the image on the right was acquired in only 3:37 min. using AIR™ Recon.



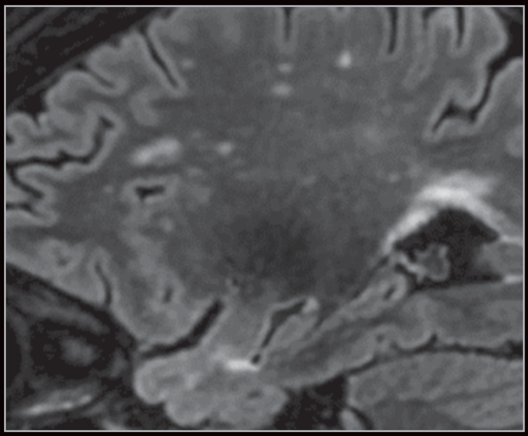
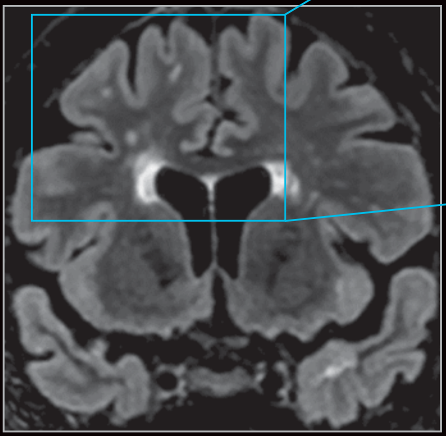
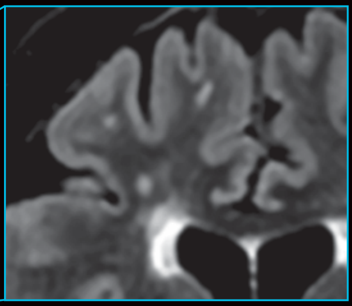
Sagittal T2-weighted
0.6 x 0.8 x 5 mm
3:25 min.



Coronal T2 FSE
0.6 x 0.8 x 5 mm
3:58 min.

Images courtesy of Osaka University Hospital, Osaka, Japan

SIGNA™ Works AIR™ Edition gallery:
Neuroimaging

Sagittal Cube T2 FLAIR and coronal MPR with HyperSense
1 x 1.1 x 1.2 mm
3:30 min.

The AIR™ 48ch Head Coil, available on all 3.0T GE MR scanners, provides excellent SNR and uniformity as demonstrated in a patient with Multiple Sclerosis (above). Cervical spine imaging with FSE Flex and carotid (images on the right).

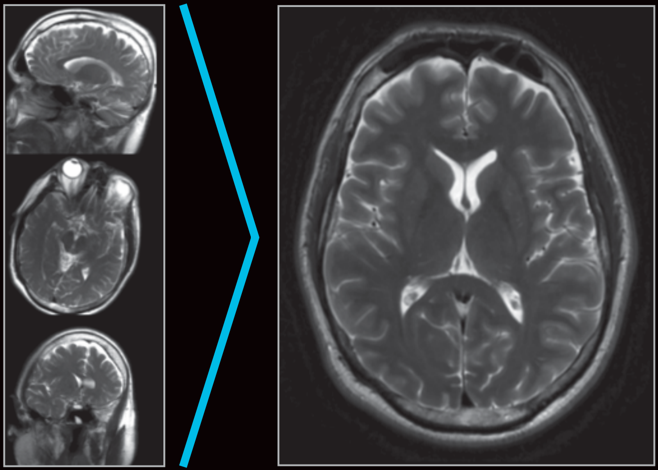


Sagittal T2 FSE (left)
0.7 x 0.8 x 3 mm

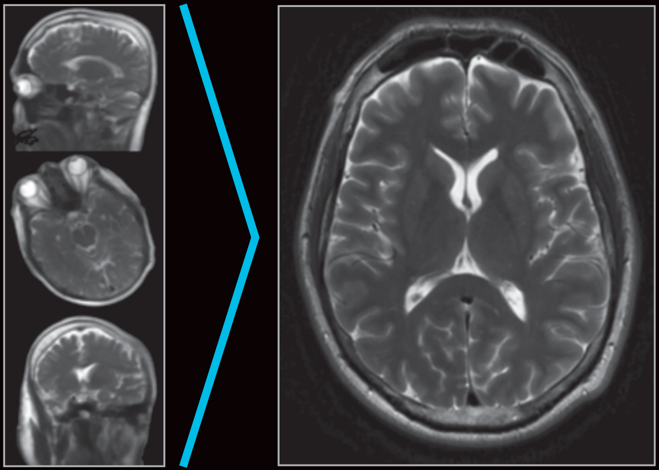
Sagittal T2 FSE Flex (center)
0.9 x 0.9 x 3 mm

ceMRA (right)
0.9 x 0.9 x 1.2 mm

Images courtesy of RNR, Zurich, Switzerland



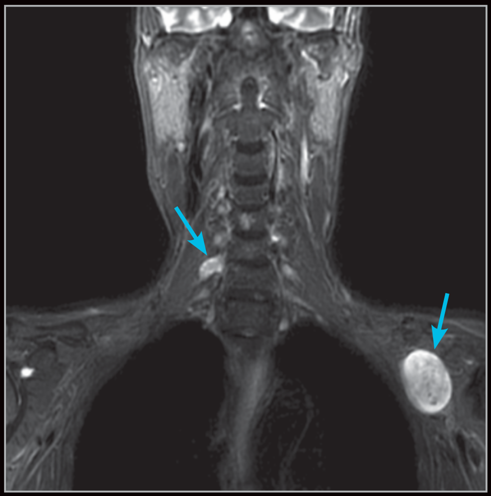
3 plane localizer



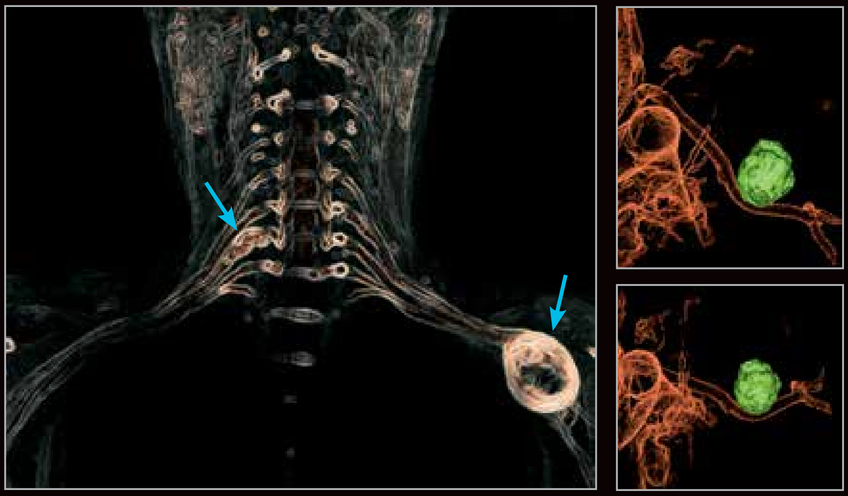
3 plane localizer

Using a deep-learning algorithm trained on tens of thousands of images, AIR x™ revolutionizes the workflow for brain exams. It automatically prescribes slices to help drive consistency and reproducibility regardless of user, patient age, pathology or patient position in the magnet.

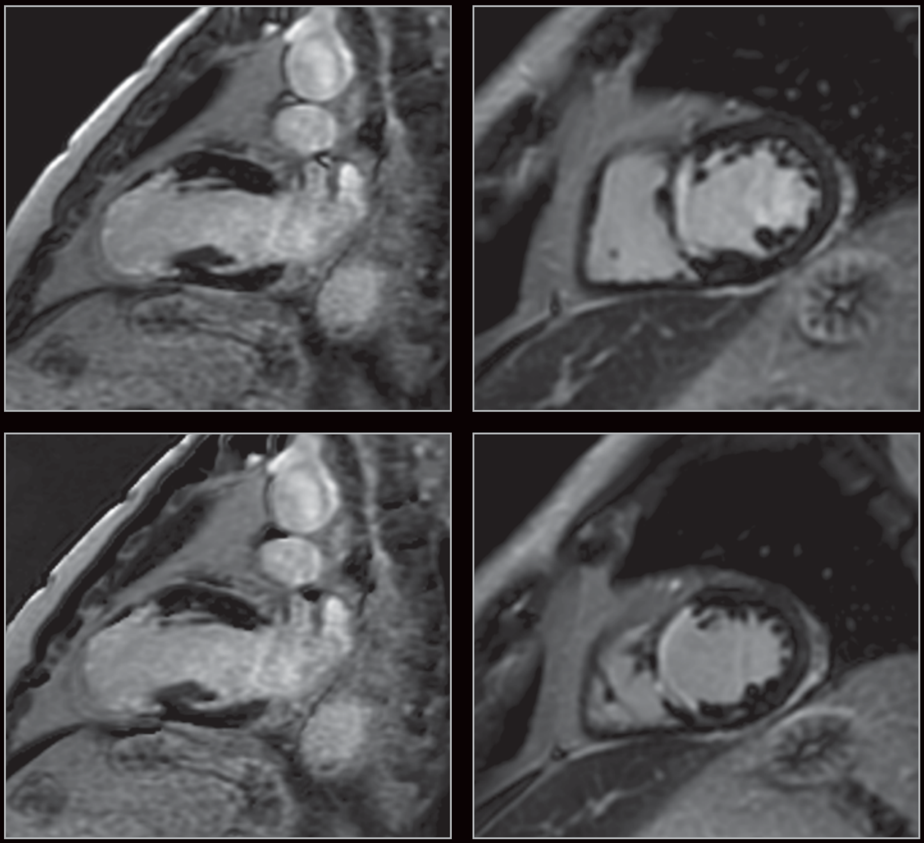
SIGNA™ Works AIR™ Edition gallery:
Chest or thoracic imaging



Coronal T2 STIR PROPELLER
1.1 x 1.1 x 3 mm
4:28 min.



Coronal T2 STIR Cube
1 x 1 x 1.2 mm
4:32 min.



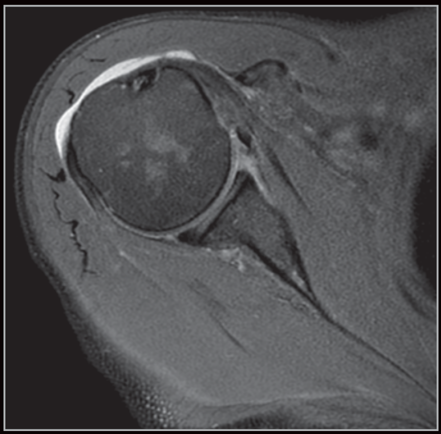
Phase Sensitive MDE
Phase (top) and magnitude (bottom)
1.9 x 2.8 x 8 mm
0:48 min.

Short Axis MDE
1.9 x 2.3 x 8 mm
3:57 min.

Images courtesy of Hospital Universitario Quirón Salud, Madrid, Spain

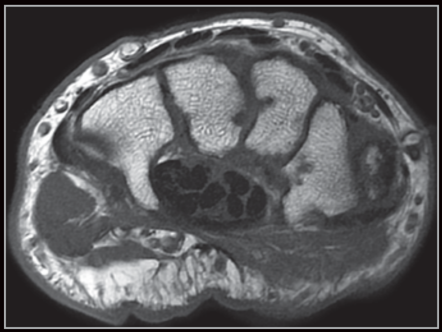
SIGNA™ Works AIR™ Edition gallery:
Musculoskeletal imaging

All images on this page were acquired with AIR™ Multi-Purpose Coils‡.



Axial PD FatSat
0.4 x 0.6 x 3 mm

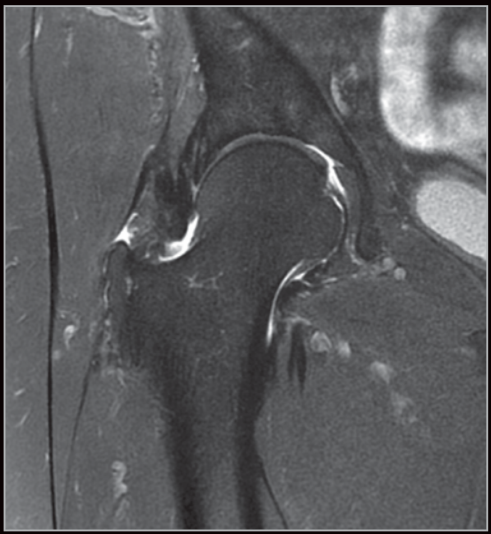
Coronal 3D MERGE
0.3 x 0.3 x 2 mm



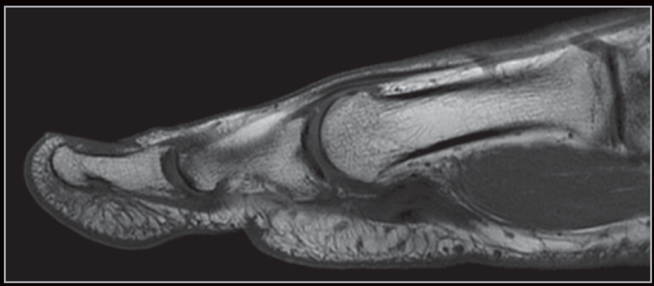
Axial T1 FSE
0.26 x 0.3 x 2.5 mm

Sagittal PD
0.4 x 0.6 x 3 mm

Coronal PD FatSat
0.3 x 0.3 x 3 mm



Coronal PD FatSat
0.4 x 0.4 x 3 mm



Sagittal PD
0.3 x 0.4 x 3 mm

‡ Not yet CE marked. Not available for sale in all regions.

Yang Quanxin MD, PhD
The Second Hospital of Xi'an Jiaotong University
Xi'an, China

Hospital scans 100-plus patients in one 13-hour day on SIGNA Pioneer

At The Second Hospital of Xi'an Jiaotong University, the demand for MR imaging has historically far exceeded capacity. Patient wait times were growing longer, leaving many people to wait one to two weeks to receive an MR examination.

Yang Quanxin, MD, PhD, Director of the Radiology Department, knew that the two existing MR systems — a 3.0T SIGNA™ HDx and a 1.5T from another manufacturer — couldn't keep up with the demand. As he began to explore purchasing a third MR system, he realized that in addition to addressing the clinical need he also wanted a system that could perform scientific research.

GE Healthcare has a strong relationship with the hospital and an excellent reputation for clinical performance across multiple systems and imaging modalities. According to Professor Quanxin, GE 3.0T MR systems are the largest installed base in Shaanxi Province. With GE's assistance, many other sites have performed scientific research that has been published internationally in several peer-reviewed journals.

"My first impression of SIGNA™ Pioneer was the very fast scanning speed," he explains.

> "With the same signal-to-noise-ratio, the scan time for each sequence on SIGNA™ Pioneer was nearly half the time as our sequence on the SIGNA™ HDx 3.0T system when scanning the same body area."
>
> *Professor Yang Quanxin*

Plus, he was intrigued by MAGiC‡ and its unique ability to output multiple image contrasts in a single 5-minute scan. With MAGiC, Professor Quanxin also has the potential to customize DIR for gray and white matter contrasts. Even after the acquisition, MAGiC allows the clinician to change contrast to provide more diagnostic information. Additionally, Professor Quanxin saw more opportunities to shorten scan time with HyperSense, an acceleration technique based on sparse data sampling and iterative reconstruction. For these reasons and the potential for research capabilities, Professor Quanxin chose SIGNA™ Pioneer for the hospital's third MR system.

100-plus scans in a day

The waiting time for MR exams was not only difficult on patients; the radiologists also felt the pressure to read through MR studies as quickly as possible.

"When we first began using SIGNA™ Pioneer, we noticed that it was very fast and also delivered a very high SNR," says Professor Quanxin. "So, we had an idea to see if the system could scan more than 100 anatomic areas in a typical 13-hour day."

The radiology team at The Second Hospital of Xi'an Jiaotong University collaborated with GE to embark on a project to scan as many high-quality MR exams as possible.

In February 2019, the radiology department performed 106 MR examinations from 7:30 am to 8:30 pm on SIGNA™ Pioneer in exams of the

‡It is recommended to acquire conventional T2 FLAIR images in addition to MAGiC.

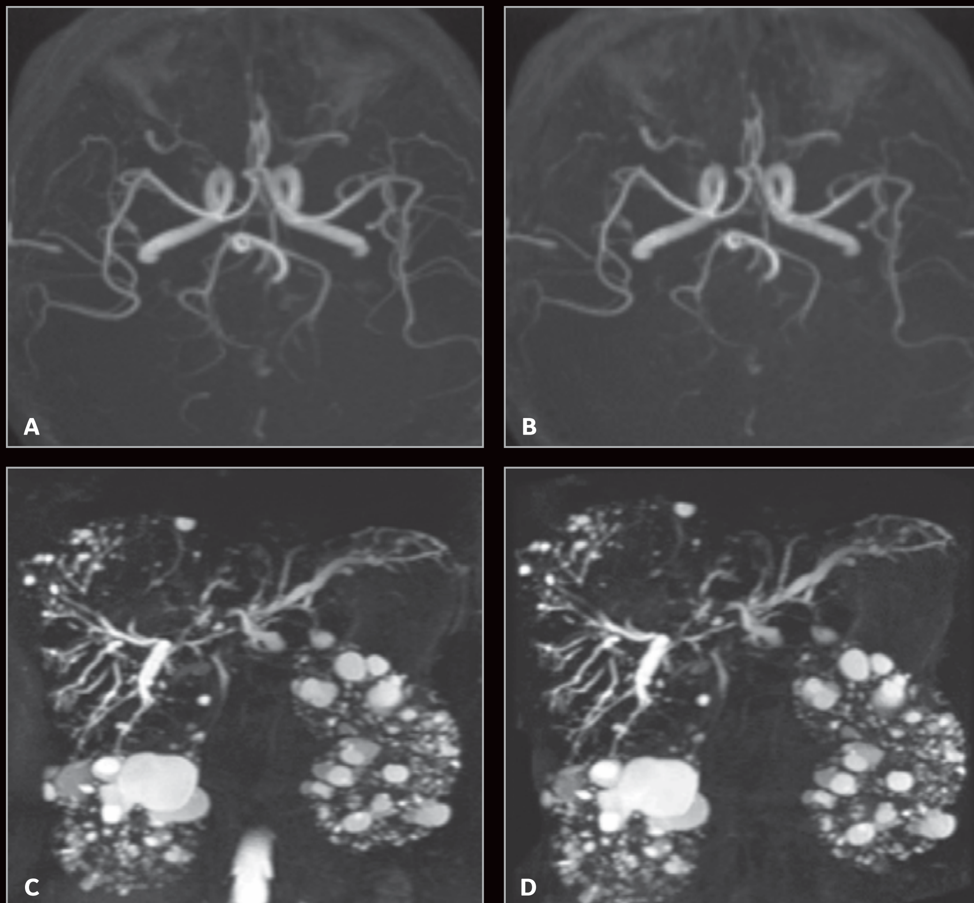


Figure 1. Head MRA and upper abdominal MRCP. (A) Without HyperSense, 0.6 x 0.6 x 0.8 mm, 4:06 min.; (B) HyperSense factor of 2, 0.6 x 0.5 x 0.8 mm, 1:41 min.; (C) MRCP with HyperSense and breath-hold, 0:16 min.; and (D) MRCP with HyperSense and free-breathing, 2:33 min.

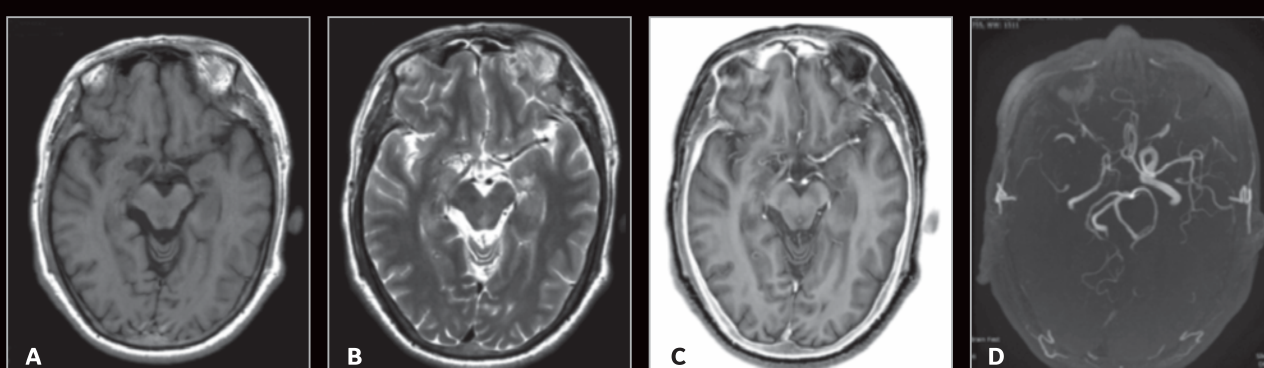


Figure 2. Male, 57 years old, with repeated dizziness for seven years. No clear lesions were detected on the (A) T1 and (B) T2 images. However, the (C) reconstructed PSIR VESSL demonstrated an absent right middle cerebral artery, confirmed by the (D) TOF-MRA.

breast, abdomen, pelvis, various joints and fMRI. The team modified its protocols on SIGNA™ Pioneer, including utilizing HyperSense in MR angiography (MRA) and upper abdominal MRCP studies, and found that the scanning time for head MRA exams could be reduced by 45 percent. In patients who could not hold their breath for an MRCP exam, the speed of HyperSense enabled very short scan times — 16 seconds for breath-hold and 2:33 minutes for free-breathing exams (see Figure 1).

This volume was possible because in China exams are typically reduced to the most important acquisitions, typically three to five sequences. This is a common practice due to the large number of patients referred for an MR exam. At The Second Hospital of Xi'an Jiaotong University, the average study time on the prior system was 10 minutes. With SIGNA™ Pioneer it is now an average of 7 minutes per exam.

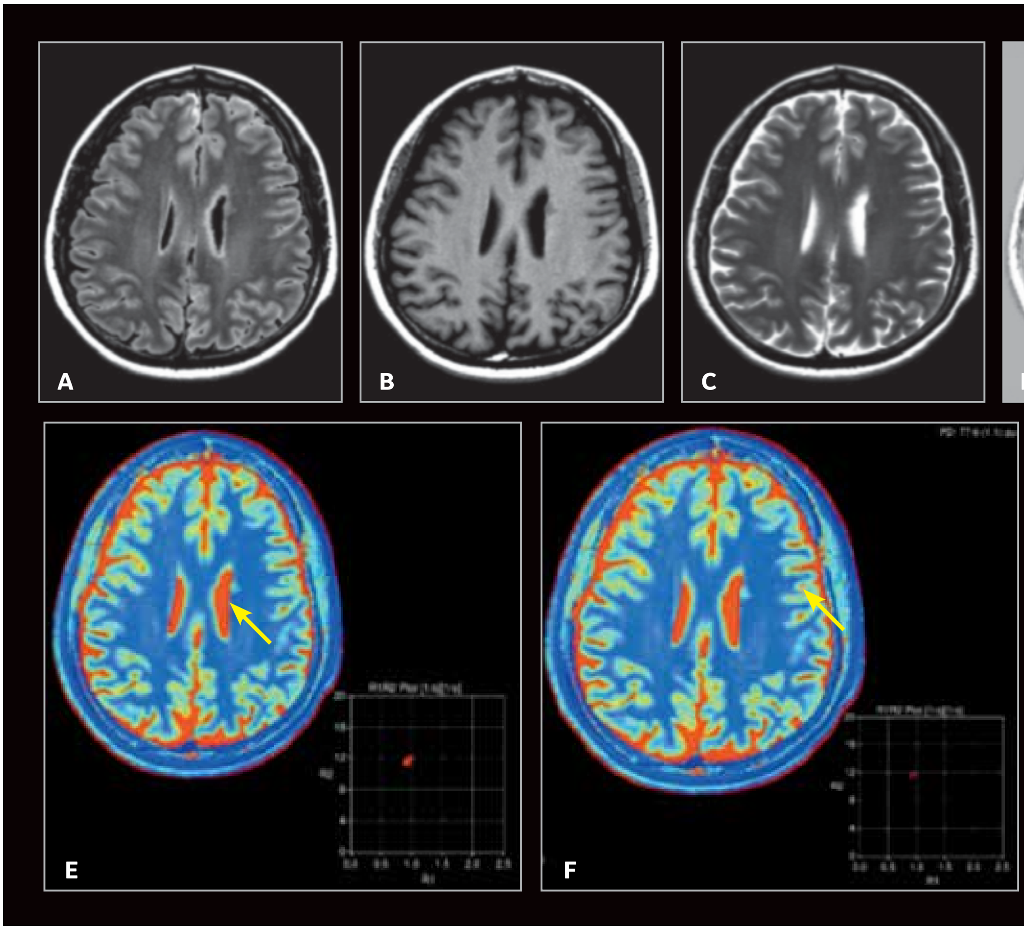


Figure 3. Lesion detected near the left lateral ventricle. Using MAGiC quantitative maps to measure the ROI of the lesion and ectocinerea, the values of T1, T2 and PD in these two tissues were completely consistent, enabling characterization of the lesion as heterotopic gray matter. (A) T2 FLAIR; (B) T1; (C) T2w; (D) PSIR; (E) T2 map, T1 1067 (40) ms, T2 86 (2) ms and PD 78.8 (2.1) pu; and (F) T2 map, T2 1083 (29) ms, T2 86 (2) ms and PD 77.6 (1.1) pu.

"The SNR was nearly unchanged in these shorter exams, so we could still make a confident clinical diagnosis," Professor Quanxin says.

With MAGiC, the department performed one 4-minute scan to obtain the contrast and quantitative maps needed for diagnosis. In one case, a patient with repeated dizziness for seven years was found to have a missing right cerebral artery, detected by the MAGiC reconstructed PSIR and confirmed by time-of-flight MRA (see Figure 2).

"MAGiC quantitative mapping technology can also help us to characterize pathological findings," Professor Quanxin adds (see Figure 3).

DISCO was also utilized to improve the temporal resolution of dynamic contrast-enhanced imaging in the liver, breast and prostate, further enhancing image quality for more efficient and confident reads. In the liver, DISCO was instrumental in capturing the hepatic arterial phase, which can be difficult to clearly obtain with traditional MR sequences.

It's not just the sequences that are helping to shorten and streamline MR scanning on the SIGNA™ Pioneer at The Second Hospital of Xi'an Jiaotong University. The system's Auto Protocol Optimization (APX) simplifies the scanning process, and the touch bar on both sides of the MR table saves time in patient positioning. In just two steps, the technologist/radiographer can complete the positioning, and with APX they simply select between four and five options and then scan.

Today, SIGNA™ Pioneer is regularly utilized for a 15-hour day and often completes over 100 exams during that time frame. The other two MR systems are still used to capacity; however, it is SIGNA™ Pioneer that enables the heaviest workload.

"SIGNA™ Pioneer is a very good 3.0T MR system," says Professor Quanxin. "It has many technologies that increase the scanning speed without losing the SNR of the image. It has definitely helped alleviate the issue of long appointment waiting times for our patients." S

Tiron Pechet, MD
Shields Health Care Group
Boston, Massachusetts

An upgrade that is more like getting a new system

In 1986, Shields Health Care Group opened the first independent regional MR center in New England. Today, the group operates more than 40 imaging locations throughout the region, offering MR, PET/CT, radiation therapy and ambulatory surgical services. More than 30 facilities provide MR imaging services and the organization has more 1.5T wide bore systems than any other provider in Massachusetts. Many of these sites have multiple MR systems; altogether, Shields has nearly 50 MR systems currently in use.

Naturally, as technology advances, older systems may fall behind. That's where GE Healthcare's SIGNA™ Continuum™ program gives customers the ability to combine some of the innovative hardware, electronics and SIGNA™Works applications into an upgrade that best fits their needs.

Shields was faced with this situation on a 10-year-old 1.5T SIGNA™ HDxt running HD16 software at its center in Brockton, MA. According to Assistant Medical Director Tiron Pechet, MD, the system was very limited and compared poorly against other systems in the organization's fleet of MR scanners.

"Many sequences could only be used with particular coils and we couldn't combine coils," Dr. Pechet says. "We had modest SNR, lots of artifacts, limited ARC acceleration, 3D capabilities and phase oversampling, and we used a lot of time on pre-scanning and calibration scans, increasing overall exam length without adding clinical information."

Additionally, the older system was limited in the type of exams it could offer and Dr. Pechet wanted to expand MR imaging services in the prostate, MR-Conditional implants, hand/finger, MRCP and enterography.

Initially, Shields considered a forklift upgrade and decommission of the old magnet. They also considered replacing the system with a 3.0T MR. However, the more Dr. Pechet learned about SIGNA™ Continuum™, the more he was intrigued by the potential to extend the life of the magnet. With several magnets across the organization nearing end-of-life, he was very cognizant of the costs, including construction, and downtime that a new installation would incur.

"GE has distinguished themselves by supporting and continuing to upgrade their own product," Dr. Pechet says. "We have other vendors' MR systems that have no path to extend the life of the magnet."

After careful consideration weighing both advantages and disadvantages, Dr. Pechet and the Shields administration determined the SIGNA™ HDxt SIGNA™Works Edition upgrade was the way to go.

"The difference in cost and value is pretty impressive with the upgrade," he adds. "It is a fraction of the price of a new magnet with less than one week of downtime."

On Tuesday, May 7 at 6:30 pm, the SIGNA™ HDxt at Shields' Brockton imaging center scanned its last patient. After three days for GE engineers to assess the existing system and

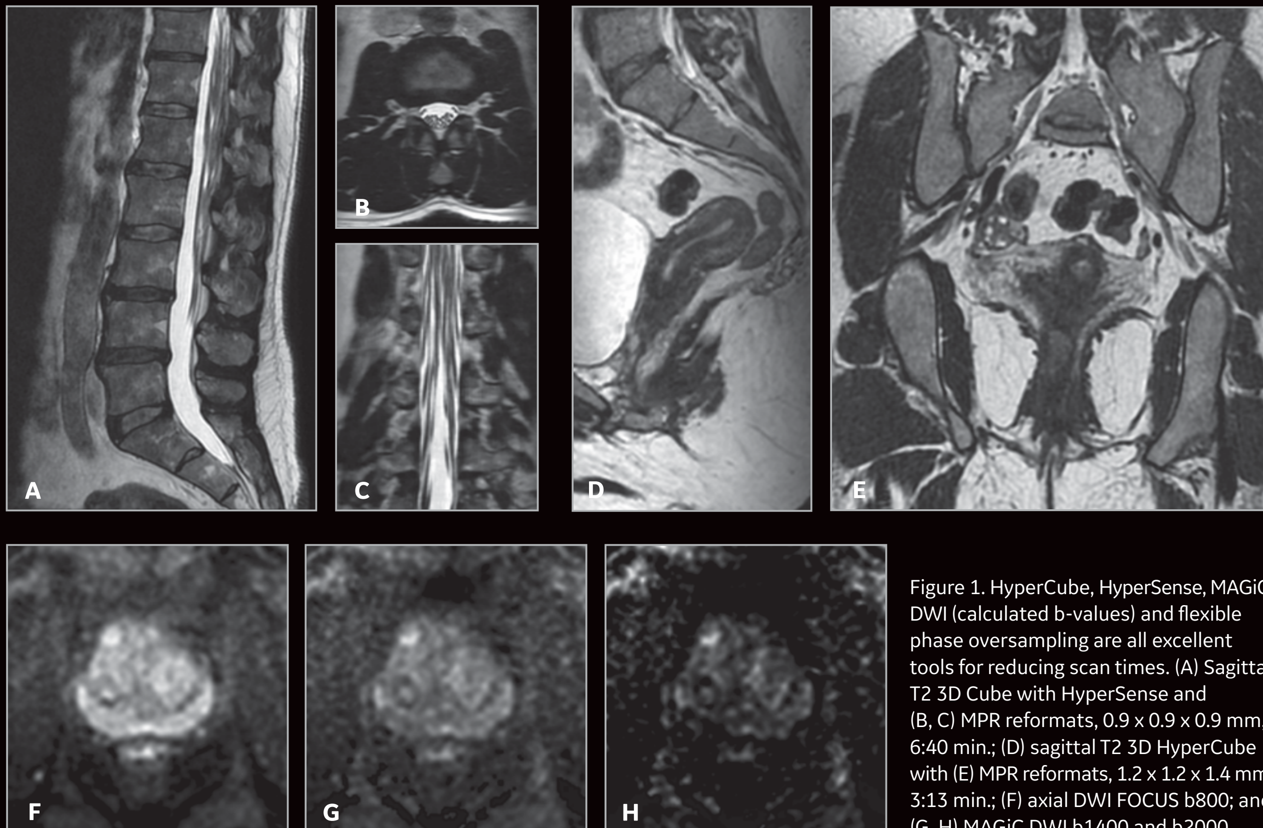


Figure 1. HyperCube, HyperSense, MAGiC DWI (calculated b-values) and flexible phase oversampling are all excellent tools for reducing scan times. (A) Sagittal T2 3D Cube with HyperSense and (B, C) MPR reformats, 0.9 x 0.9 x 0.9 mm, 6:40 min.; (D) sagittal T2 3D HyperCube with (E) MPR reformats, 1.2 x 1.2 x 1.4 mm, 3:13 min.; (F) axial DWI FOCUS b800; and (G, H) MAGiC DWI b1400 and b2000.

complete the upgrade, the system was ready by midday on Saturday, May 11; however, the team decided to conduct staff training on Monday, May 13. By Tuesday, May 14, the first patients were scanned on the newly upgraded system.

> "This is more like getting a new machine than an upgrade, and at a fraction of the cost and downtime. It is the most significant upgrade we have ever performed, and we have nearly 50 MR systems. This upgrade elevates our magnet to the equivalent capabilities of a new GE 1.5T system."
>
> *Dr. Tiron Pechet*

The impact

Most notable is the substantial improvement in image quality and shorter scan times. With the prior system, the technologists often chose to optimize scan time because even if they increased scan time to enhance image quality, the benefit in SNR was minimal. Also, it was important for department scheduling to maintain consistent exam times across all MR systems.

"MR is all about signal and you need to decide how you are going to use it — for better image quality, faster scan times or a combination of both," Dr. Pechet explains. With the new hardware, he estimates a better than 20% improvement in SNR, but the new pulse sequences and software are also much better.

This package of new hardware and software — new digital receive chain, coils, sequences and reconstruction technology — is absolutely key in Dr. Pechet's opinion. This required protocol development, particularly since there were many capabilities and several new sequences that Shields had not previously used.

The team started with longer scan times and patient slot times, initially at one hour. As the protocols were improved, the scan times decreased and they compressed the schedule. Dr. Pechet worked with GE applications specialist Jorge Forero to refine protocols, and in many cases develop new protocols for sequences they had not previously used, so that each was 80% optimized. Then they moved to the next one.

As a pilot site, Shields Brockton had on-site GE support, which Dr. Pechet acknowledges won't be available to every site. However, the sequence development work that he and Forero completed will be available to subsequent sites and users.

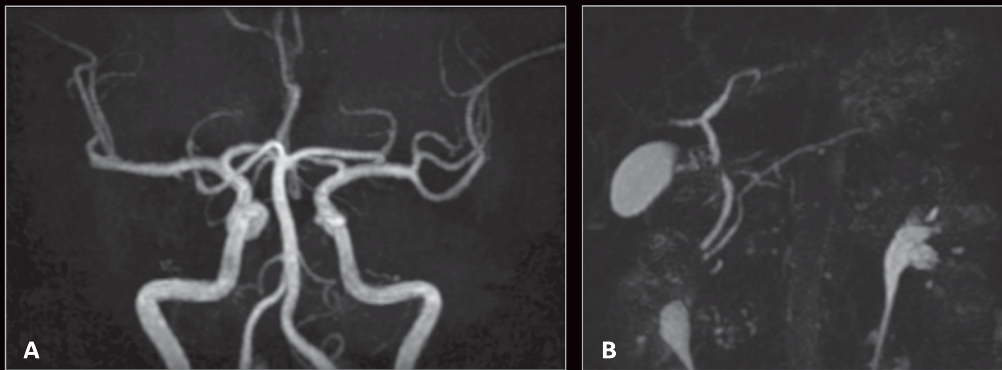


Figure 2. With HyperSense, 3D TOF angiography exam times have been reduced by nearly 50 percent. (A) Axial 3D TOF with HyperSense, 0.7 x 0.9 x 1 mm, 3:04 min. and (B) coronal 3D MRCP with HyperSense, 1.2 x 1.2 x 1.4 mm, 3:01 min.

Figure 3. PROPELLER and FOCUS improve image quality in prostate exams. (A) Axial T2 PROPELLER, 0.8 x 0.8 x 3 mm, 3:57 min.; (B) axial diffusion FOCUS b800, 2 x 2 x 5 mm, 5:53 min.; and (C) axial T2 PROPELLER fused with axial DWI FOCUS b800.

In the first month, Shields Brockton had a 16 percent reduction in scan times despite extending imaging slots and the ongoing sequence development. Equally important, there was no system downtime, no increase in system reboots and no hardware failure — and that was much better than expected. Overall reduction in scan time was 19 percent during the second month while simultaneously increasing the complexity of the exams performed and shifting those complex exams from other magnets to the upgraded SIGNA™ HDxt SIGNA™Works Edition.

Training was comprehensive, with the technologists learning "10 years of MR in a short period of time," Dr. Pechet says. They had to learn everything from the user interface for 3D imaging to new sequences such as HyperSense, HyperCube, Cube and FSE Flex, ASL and much more.

He also advises other sites to train radiologists on the new sequences: if the clinicians don't have experience with the new MR techniques, they may not indicate to the technologist to use them. This applies to reading and interpretation, as well. For example, the technologist may know how to acquire an IDEAL IQ scan, but does the radiologist know how to interpret the data? It is a reasonable challenge that once addressed can result in tremendous improvements.

"If the technologists and radiologists don't know about the new capabilities, then you will be running a Porsche as though it were a Plymouth Duster," Dr. Pechet says. "If the site is working with up-to-date GE equipment, then it's a relatively easy upgrade and training. If not, then I would advise that they treat the upgrade like a brand new magnet."

Clinical excellence and efficiency

Before the upgrade, many exams were scheduled on other systems due to poorer image quality and slower scan times on the SIGNA™ HDxt. Now, the opposite is happening at Shields Brockton: cases are being moved from the other machine to the SIGNA™ HDxt SIGNA™Works Edition because of its speed and image quality.

HyperCube, HyperSense, MAGiC DWI (synthetic DWI) and flexible phase oversampling are all excellent tools for reducing scan times, Dr. Pechet adds. With the added SNR, he can now utilize these fast-scanning techniques and increased acceleration factors that have in many instances shortened scan times by an average of 25 percent.

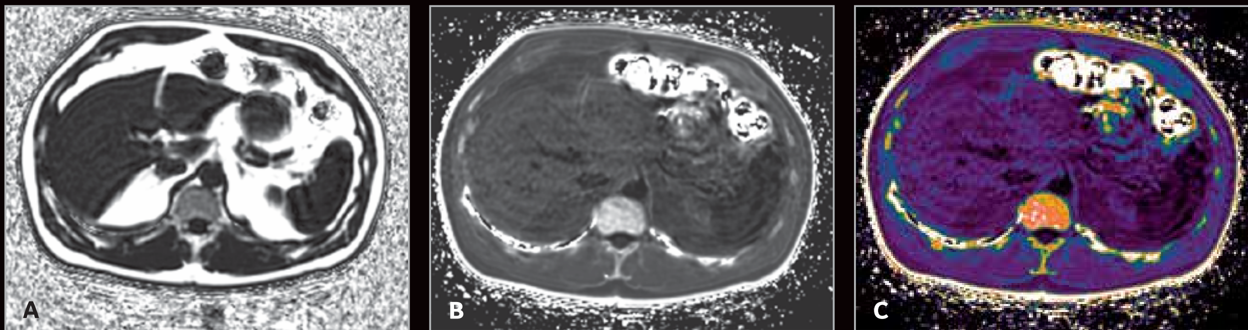


Figure 4. Every liver exam at Shields now includes IDEAL IQ for quantitative fat fraction and iron assessment of the liver. (A) Axial 3D IDEAL IQ, 20 sec. breath-hold fat fraction map; (B) axial 3D IDEAL IQ, 20 sec. breath-hold R2* map (Hz); and (C) axial 3D IDEAL IQ, 20 sec. breath-hold R2* map (Hz — colored).

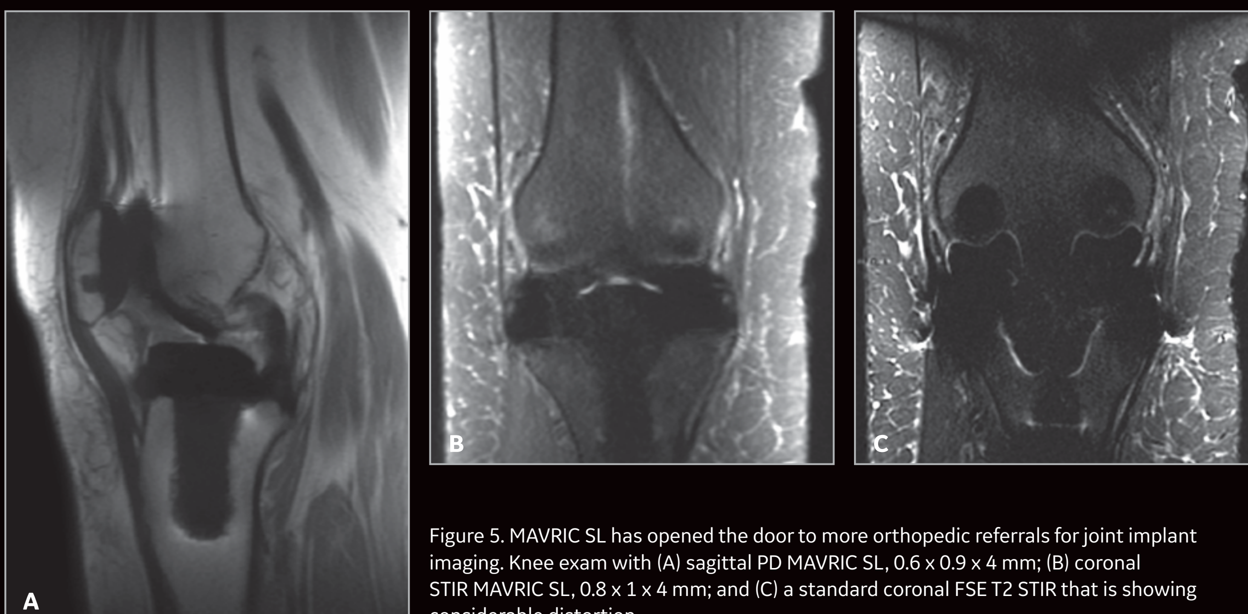


Figure 5. MAVRIC SL has opened the door to more orthopedic referrals for joint implant imaging. Knee exam with (A) sagittal PD MAVRIC SL, 0.6 x 0.9 x 4 mm; (B) coronal STIR MAVRIC SL, 0.8 x 1 x 4 mm; and (C) a standard coronal FSE T2 STIR that is showing considerable distortion.

"We get great results from HyperSense in angiography cases. At 1.5T, we find the overall acceleration is best at 1.2, or 20 percent compared to 1.3 or 1.4 on a 3.0T system," Dr. Pechet explains. He believes that HyperSense provides the best results in "high-contrast" exams (rough equivalent to sparse data) such as angiography and T2 sequences. With the SIGNA™ HDxt SIGNA™Works Edition, these angiography exam times have been reduced by nearly 50 percent, from almost 8 minutes to 4 minutes.

All prostate MR exams are now on the upgraded SIGNA™ HDxt with improved quality, especially the T2 sequences that all now use PROPELLER. Previously, these were scheduled on a different MR system because prior to the upgrade, the SIGNA™ HDxt could not provide the proper diffusion b-values to meet ACR criteria. And, of course, FOCUS is a critical diffusion sequence for all prostate exams. According to Dr. Pechet, only the exams performed at 3.0T are better than the ones the upgraded system now delivers.

Diffusion is much less prone to gas artifact and is faster with the addition of FOCUS and MAGiC DWI: Dr. Pechet and his team will acquire two b-values and then calculate, or synthesize, two more b-values. Every liver exam now includes IDEAL IQ. Soon, Dr. Pechet will explore the value of DISCO; he just hasn't had time yet to evaluate all the new tools available in the SIGNA™ HDxt SIGNA™Works Edition.

MAVRIC SL‡ has opened the door to improved options for orthopedic referrers in joint implant imaging and is often used to supplement spine exams. However, Dr. Pechet shares that work still needs to be done on the low SAR feature for MR-Conditional implant imaging.

"We use Cube with HyperCube and HyperSense as frequently as possible on all spines, which typically comprise

‡MAVRIC SL should only be used with MR-Conditional implants and within the MR conditions specified for those implants.

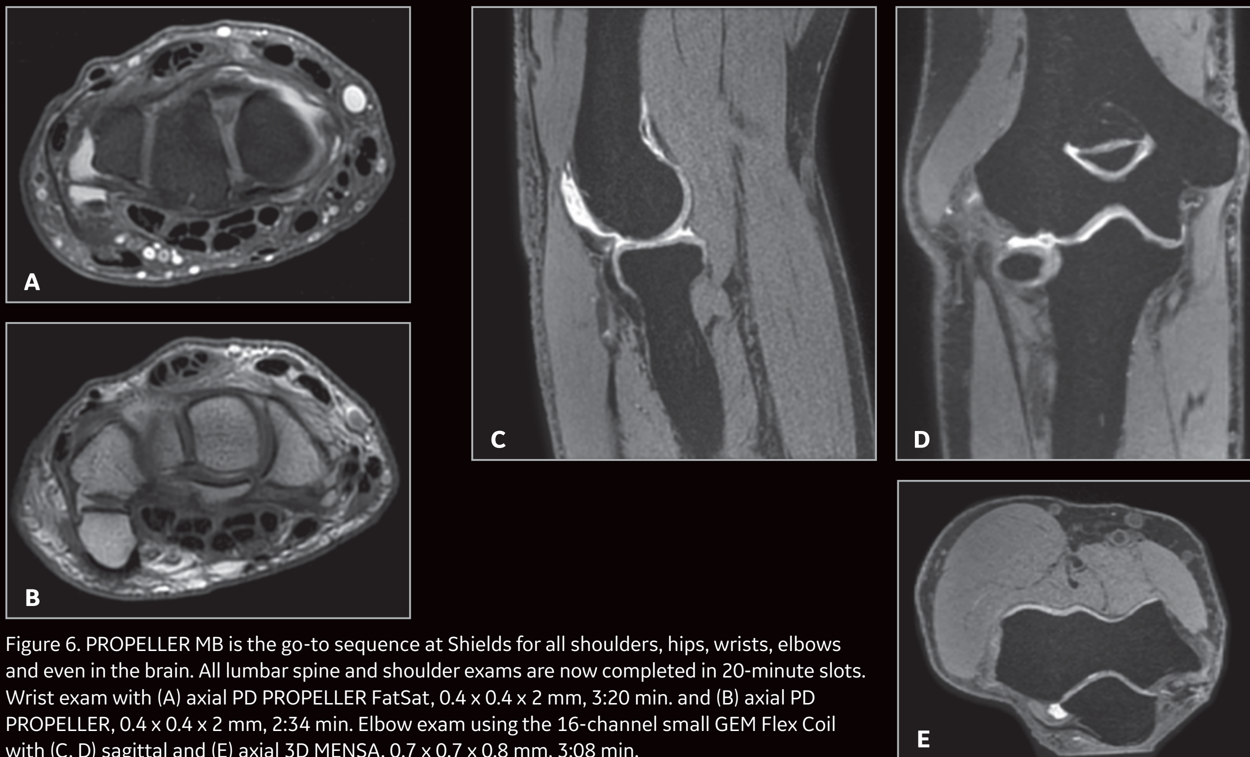


Figure 6. PROPELLER MB is the go-to sequence at Shields for all shoulders, hips, wrists, elbows and even in the brain. All lumbar spine and shoulder exams are now completed in 20-minute slots. Wrist exam with (A) axial PD PROPELLER FatSat, 0.4 x 0.4 x 2 mm, 3:20 min. and (B) axial PD PROPELLER, 0.4 x 0.4 x 2 mm, 2:34 min. Elbow exam using the 16-channel small GEM Flex Coil with (C, D) sagittal and (E) axial 3D MENSA, 0.7 x 0.7 x 0.8 mm, 3:08 min.

of sagittal T1, STIR and T2 Cube, which is then reformatted in the oblique axial plane through the disc spaces," Dr. Pechet says. "There is some limitation in parallel imaging acceleration and HyperSense because of our coil configuration compared to SIGNA™ Pioneer, but it is still very good."

PROPELLER MB is the "go-to sequence" for all shoulders, hips, wrists, elbows and even in the brain. All lumbar spine and shoulder exams are now completed in 20-minute slots. Many hip exams now include multi-echo in the steady-state acquisition (MENSA), which is a technique that combines two echoes acquired within the same repetition time (TR) for increased fluid signal. SPECIAL (ASPIR) is available for extremity imaging, yet they often use Flex, which provides excellent fat suppression even when the anatomy is not isocenter. For example, they can scan hands and wrists with the patient's arms by their side and avoid the "swimmer's" or "superman" position, which is uncomfortable for the patient and can lead to problems with motion — even in patients who don't have trouble lying still.

While the improved SNR is also enabling better control of artifacts, Dr. Pechet attributes this result to better coils, such as the GEM Flex Coils and the 16-channel cardiac coil. The GEM Flex Coils are more comfortable for the patient in foot/ankle, wrist, elbow and knee exams. In fact, one person told him how much more comfortable a foot exam was with the 16-channel small GEM Flex Coil.

"The patient experience is considerably improved overall with the combination of coils, improved SNR from the optical receive chain and enhanced PSDs."

Dr. Tiron Pechet

He looks forward to continued improvements as more data is collected internally and more time is spent optimizing the protocols.

Improved image quality has also increased clinical confidence and provided an avenue to expand the practice. In addition to adding more prostate exams, Shields Brockton also offers enterography, liver fat quantification with IDEAL IQ and is currently considering adding elastography of the liver with MR Touch.

"Our exam times are now equal to or faster than the other MR system at this site with often better image quality," he says. "The SIGNA™ HDxt went from being the least preferred to the primary machine. Overall, the significant improvements in image quality have translated to happier radiologists and the shorter scan times has led to happier patients. The upgraded SIGNA™ HDxt SIGNA™Works Edition is now a tool that we can use to grow the practice." S

Kenji Ogawa MD, PhD
Nippon Koukan Hospital
Tokyo, Japan

A two 1.5T MR department meets the clinical needs at Nippon Koukan Hospital

Nippon Koukan Hospital (Tokyo) installed a SIGNA™ Voyager and upgraded a 12-year-old 1.5T MR to SIGNA™ Explorer in May 2018. While many hospitals may opt to implement one 3.0T MR and one 1.5T MR, Kenji Ogawa MD, PhD, Director, Department of Radiology, believed a two 1.5T MR department would best meet the hospital and patient needs.

MR exams account for 7 percent of all radiology imaging studies at Nippon Koukan Hospital. Since the hospital is focused on sports medicine, the most common applications are spine (30 percent) and orthopedics (21 percent), with the majority of the latter being knee exams. Gastrointestinal MR exams are also commonly employed.

A key factor in Dr. Ogawa's decision to select SIGNA™ Voyager was SIGNA™Works, including key sequences such as PROPELLER MB, the HyperWorks suite, VIBRANT Flex, IDEAL IQ and MR Touch.

Dr. Ogawa believes the applications on SIGNA™ Voyager are of such high quality that he didn't need to move to 3.0T MR. Plus, with the SIGNA™ Explorer upgrade, he was able to further extend advanced MR imaging capabilities in the department in a fiscally responsible way.

Advanced apps

On SIGNA™ Voyager, Dr. Ogawa is very impressed by PROPELLER MB, HyperSense and HyperCube. The high scanning speed of HyperSense and HyperCube, coupled with high-resolution matrix imaging, were important for the department to maximize scanning efficiency. HyperSense is an advanced, iterative reconstruction technique for accelerating the acquisition. By utilizing HyperSense, Dr. Ogawa found that he can image the posterior fossa and surrounding areas with high resolution and he can shorten the MR angiography (MRA) scan time in the brain. He has the added advantage of using 3D Cube to reconstruct sagittal and coronal images from an axial acquisition as well as shorten acquisition times with HyperSense.

"The reconstructed coronal and sagittal images are clear and such good quality that they don't look like they were reformatted from the axial plane," he adds.

"Having two 1.5T MR systems is easier to manage within the department, particularly in terms of protocol standardization. In terms of functionality, SIGNA™ Voyager offers equivalent applications to those found on a 3.0T system with the added benefit that there is a lower susceptibility to MR-Conditional metal implants or devices, therefore less noticeable metal artifacts, in 1.5T compared to 3.0T."

Dr. Kenji Ogawa

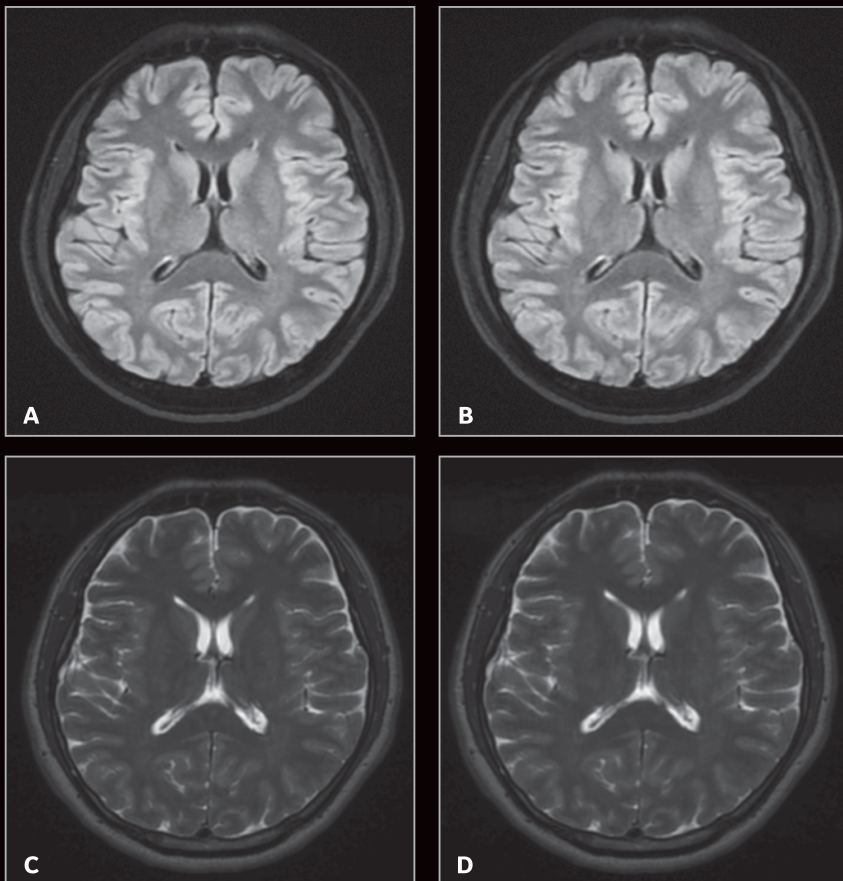


Figure 1. Using HyperSense with a factor of 1.5 and ARC with a factor of 2 have decreased T2 Cube and T2 FLAIR exam times by approximately 30 percent at Nippon Koukan Hospital. (A) Axial T2 Cube FLAIR, 0.9 x 1.2 x 2.6 mm, 2 NEX, 5:04 min. and (B) axial T2 Cube FLAIR with HyperSense, same acquisition in 3:28 min. (C) Axial T2w Cube, 0.9 x 0.9 x 2.6 mm, 2 NEX, 5:26 min. and (D) axial T2w Cube with HyperSense, same acquisition in 3:31 min.

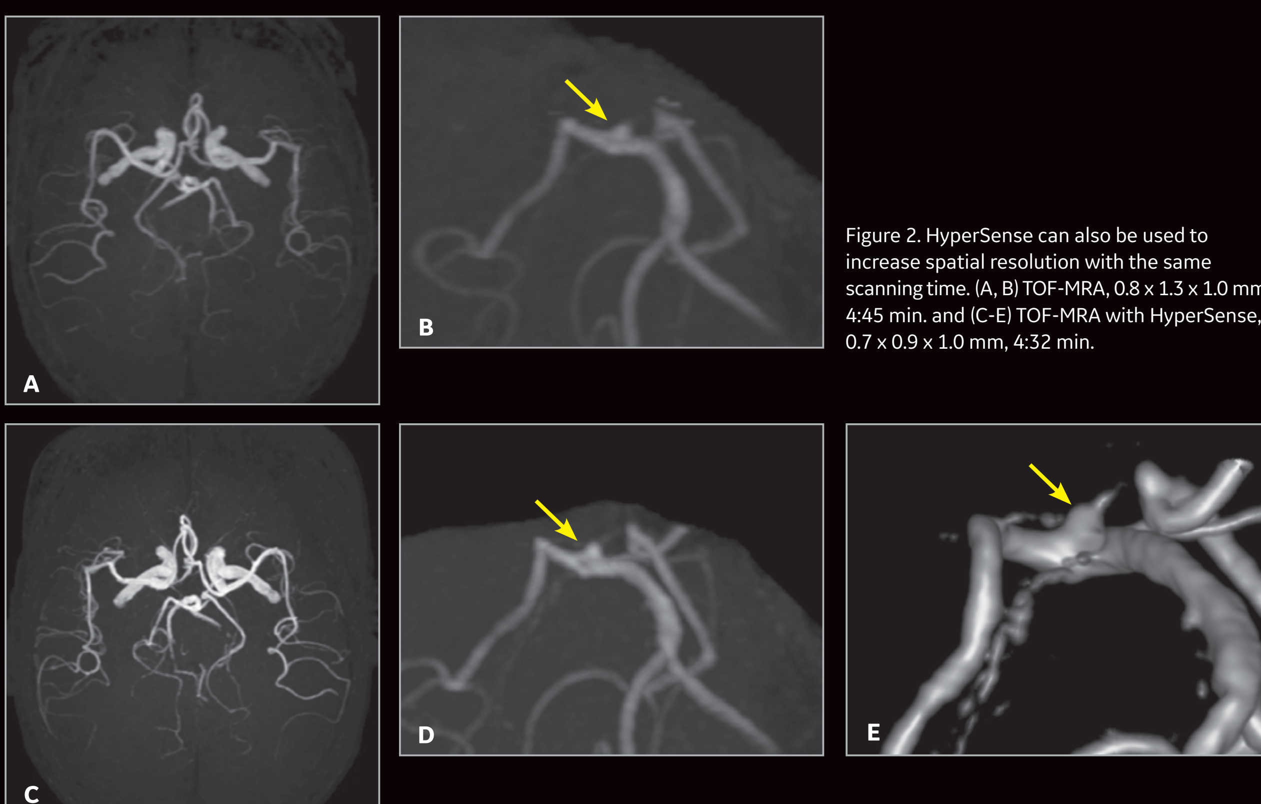


Figure 2. HyperSense can also be used to increase spatial resolution with the same scanning time. (A, B) TOF-MRA, 0.8 x 1.3 x 1.0 mm, 4:45 min. and (C-E) TOF-MRA with HyperSense, 0.7 x 0.9 x 1.0 mm, 4:32 min.

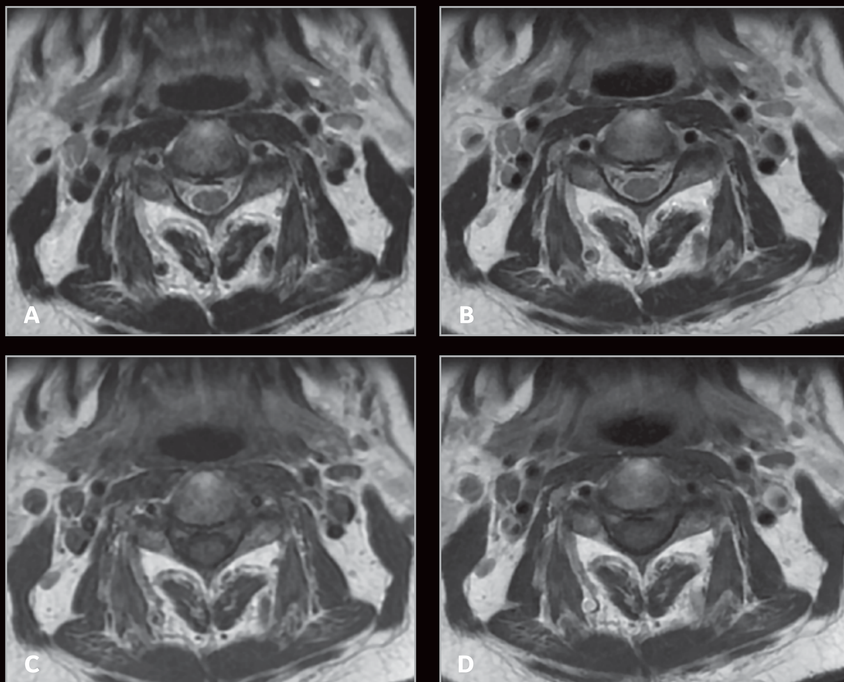


Figure 3. PROPELLER MB helps preserve tissue contrast regardless of weighting while also reducing motion artifacts and providing a more signal rich image. C-spine images: (A) axial T2w FSE, 0.7 x 0.7 x 5 mm, 2:03 min.; (B) axial T2w PROPELLER MB, 0.6 x 0.6 x 5 mm, 2:21 min.; (C) axial T1w FSE, 0.7 x 0.8 x 5 mm, 2:05 min.; and (D) axial T1w PROPELLER MB, 0.6 x 0.6 x 5 mm, 3:01 min.

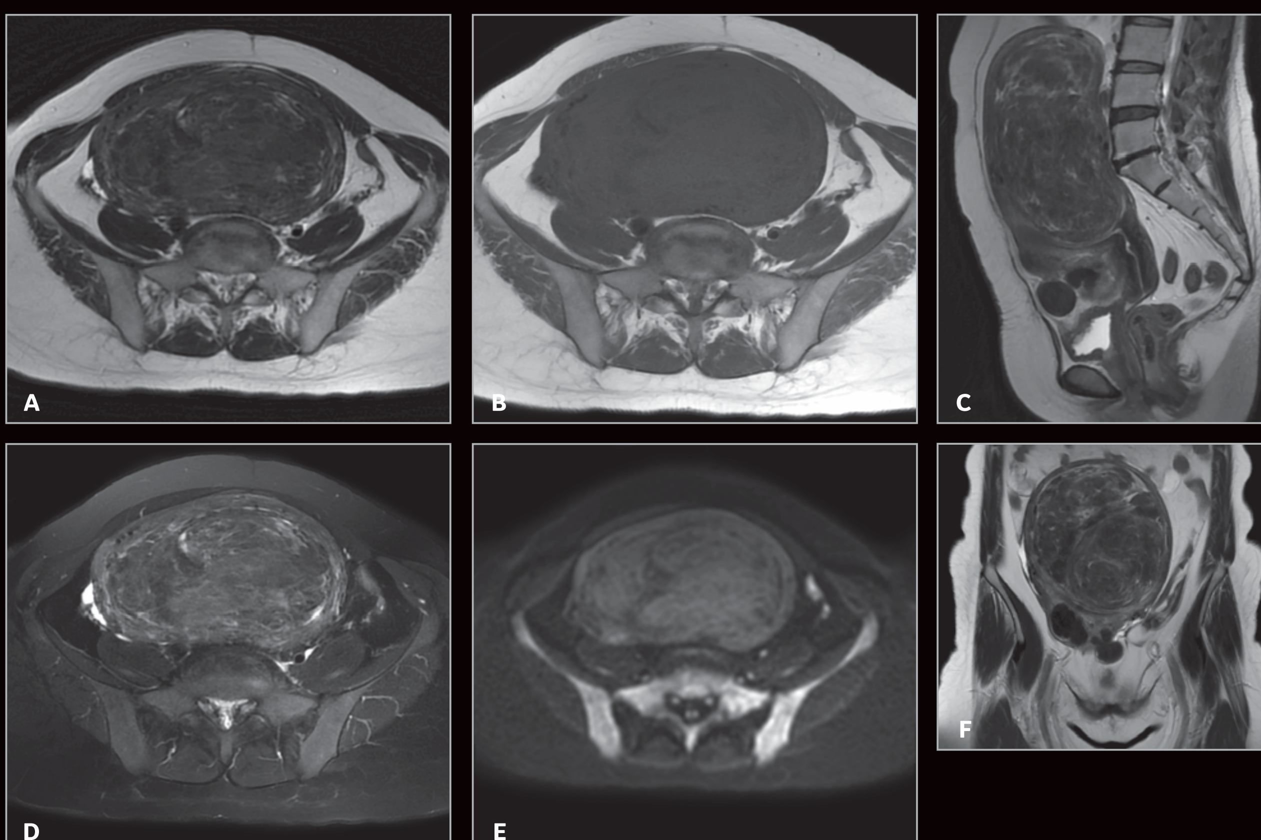


Figure 4. PROPELLER MB in the female pelvis. (A) Axial T2w PROPELLER, 1:13 min.; (B) coronal T1w PROPELLER, 2:53 min.; (C) sagittal T2w PROPELLER, 3:01 min.; (D) axial T2w FatSat PROPELLER, 2:48 min.; (E) axial DW-EPI, b1000, 2:44 min.; and (F) coronal T2w PROPELLER, 3:01 min.

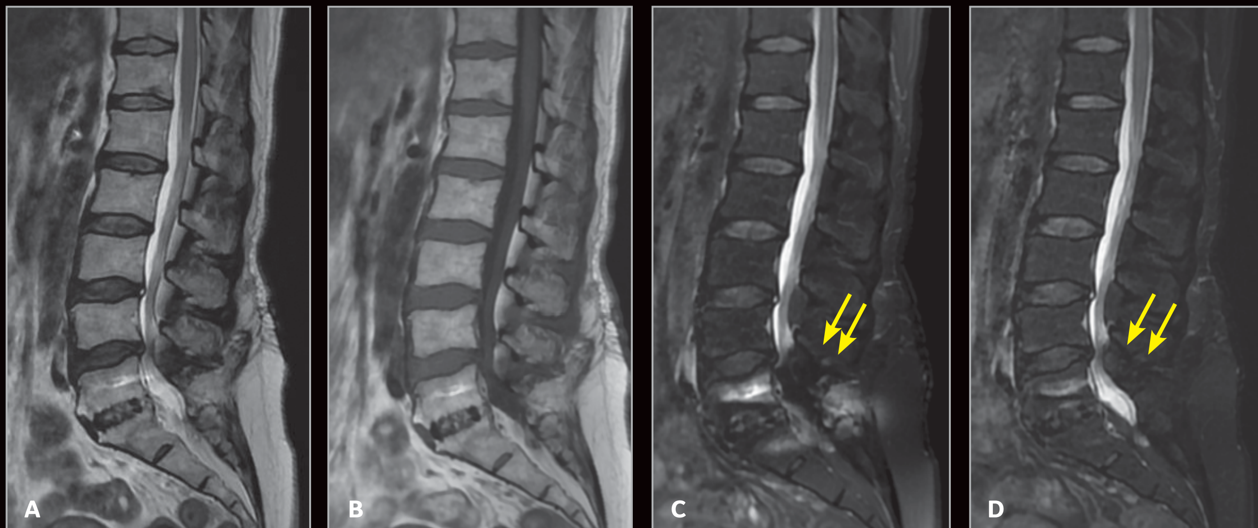


Figure 5. FSE Flex delivers homogenous FatSat images in a single scan, even in the presence of MR-Conditional implants such as fixation hardware. These images are post-surgery in a patient who had fixation hardware affixed in the L4/5 vertebrae in the lumbar spine. (A) Sagittal T2w, 0.9 x 1.1 x 5 mm, 2:13 min.; (B) sagittal T1w, 0.9 x 1.1 x 5 mm, 2:50 min.; (C) sagittal T2w FatSat, 1.1 x 1.1 x 5 mm, 1:59 min.; and (D) sagittal T2w FSE Flex, 1.1 x 1.1 x 5 mm, 3:11 min.

PROPELLER MB (Multi-shot Blade) combines multiple blades together to achieve shorter TEs and improved motion correction for true T1 and proton density (PD) contrast imaging. It is compatible with Auto Navigator, shim volumes, sat bands and ASPIR.

"The impact of PROPELLER MB is especially noticeable in pelvic and cervical spine examinations. I believe the PROPELLER MB image is the best in the pelvis, where I can clearly see the edges of a lesion. When I first saw the image quality, I noticed it was completely different and improved from before. The cervical spine image with PROPELLER MB is by far the best I've seen, and I believe the female pelvis has benefited the most from this sequence."

Dr. Kenji Ogawa

Another key area of improvement is the 2-point DIXON FSE Flex for excellent fat suppression. Dr. Ogawa says it has helped address the issue of fat remaining on the edge of the image, making it more difficult and stressful for the radiologists to read through the image for a confident diagnosis. This was particularly an issue in orthopedic patients with certain MR-Conditional metal implants.

"Until now, the effect of fat suppression was sometimes poor due to metal artifacts from implants," Dr. Ogawa explains. "In addition, uniform fat suppression can also be a challenge in breast imaging. Now, fat suppression has become particularly uniform, especially in the rim of the breast, such as the chest wall."

The dynamic breast protocol at Nippon Koukan Hospital now includes VIBRANT Flex. However, one disadvantage is that fat suppression in a normal shoulder without any physical findings sometimes appears black, "because the fat suppression is too effective," says Dr. Ogawa. "Even with this, the images of the shoulder and elbow have clearly improved with SIGNA™ Voyager."

Dr. Ogawa attributes some of the improvement in FatSat on SIGNA™ Voyager to the 70 cm bore. He can position the patient in the center of the bore and patients seem to be more comfortable.

Since SIGNA™ Explorer and SIGNA™ Voyager have a similar suite of SIGNA™Works applications, Dr. Ogawa doesn't see much difference in the images. All MR elastography (MRE) exams are performed on SIGNA™ Voyager, so he knows which scanner was used in that case. In most other instances, he cannot easily recognize on which scanner an MR exam was conducted.

Addressing liver disease with MR Touch and IDEAL IQ

Even though the incidence of viral hepatitis and overall liver disease and liver cancer in Japan has dropped in the last decade,[1] it remains a health issue. The incidence of hepatic cirrhosis, both alcoholic and non-alcoholic steatohepatitis, continue to increase in Japan.[2] Ultrasound elastography is commonly used in Japan, however, the technique is highly operator dependent and may not be reproducible.

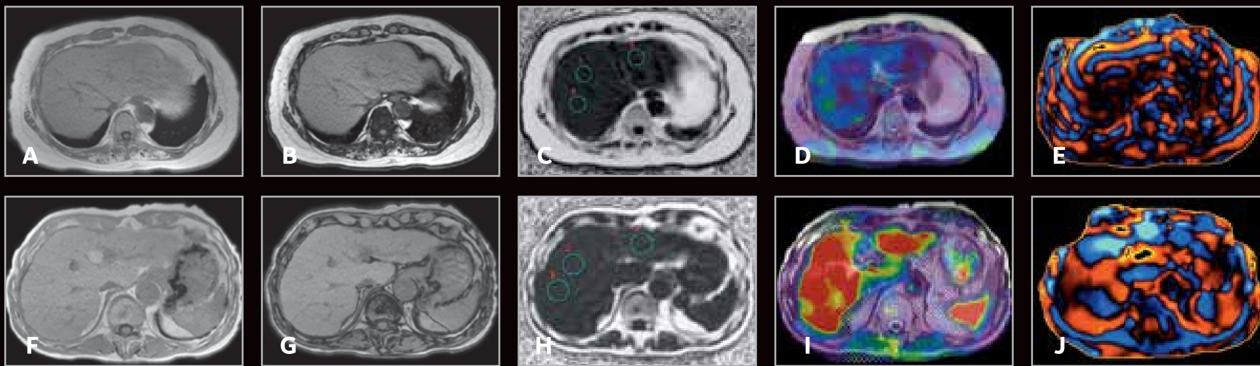


Figure 6. Liver imaging with MRE (MR Touch) and IDEAL IQ. (A, F) In-phase; (B, G) out-of-phase; (C, H) IDEAL IQ, (C) fat fraction 9%, (H) fat fraction 0.6-2.6%; (D,I) MRE and T2w SSFSE fused images; and (E, J) MRE wave images.

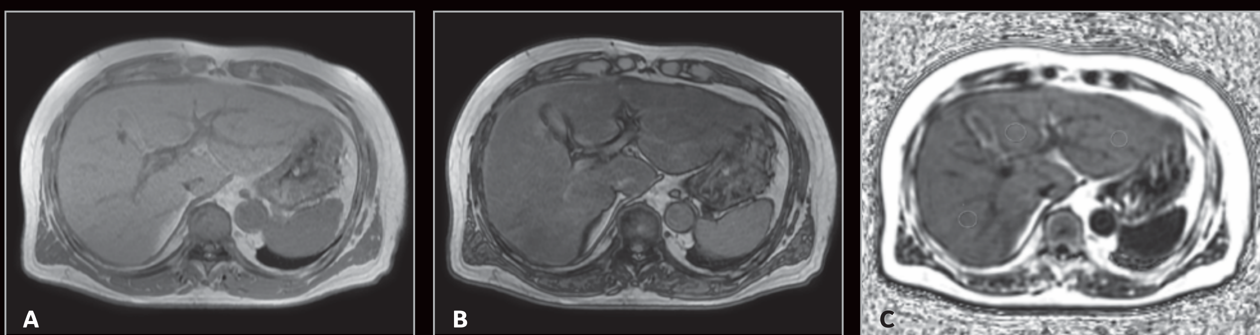


Figure 7. IDEAL IQ delivers quantitative measurements of iron and fat content. (A) Axial in-phase and (B) axial out-of-phase at 1.25 x 2.5 x 7 mm, 14 sec.; and (C) fat fraction with IDEAL IQ, 2.75 x 2.75 x 8 mm, 19 sec.

MR Touch is reproducible across exams and provides relative stiffness data of the liver, which may help with the assessment of liver fibrosis. IDEAL IQ is included in patients with fatty liver disease to obtain quantitative measurements of iron and fat content.

The department has been collecting MRE data since the implementation of SIGNA™ Voyager and Dr. Ogawa believes the technique will become a point of distinction and strength for the hospital.

With two specialists in liver medicine at the hospital, Dr. Ogawa sees liver imaging as an area of potential growth in terms of patient volume and attracting specialists. He is hopeful for the possibility of conducting joint research with other academic hospitals in the near future.

> "The unique quantification provided by IDEAL IQ and the relative stiffness data of MR Touch are very good. Quantitative analysis will be important to the future of MR imaging."
>
> *Dr. Kenji Ogawa*

Dr. Ogawa is hopeful that continued improvements in tissue characterization, including deposition of metals, as well as time resolution, will further extend diagnostic capabilities. While it can be difficult for radiologists to read through some artifacts, he believes that completely removing artifacts with image processing is not as important as correcting movement with tools such as PROPELLER MB. Some artifacts, such as respiratory-induced artifacts in the lower abdomen, are to be expected when reading these types of images.

He adds, "I think that MR will benefit us and our patients more with improvements in quantitation and temporal resolution of images."

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Amaresh Ranchod, MB BCh
Netcare Waterfall City Hospital
Midrand, South Africa

Samantha Palliam, MB ChB
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Upgrade delivers imaging excellence

What began as a single practice in Springs, South Africa, has grown into a multi-site radiology group serving the residents in and around the Johannesburg-Pretoria area. National Radiology Services, Inc., (NRS) has invested in a full spectrum of state-of-the-art imaging technology. Recently NRS upgraded its Optima™ MR360 1.5T MR system to a SIGNA™ Explorer at Netcare Waterfall City Hospital in Midrand.

Netcare Waterfall City Hospital, a multi-disciplinary hospital with a Level III 24-hour ER, provides a range of services — from a bariatric center to epilepsy monitoring and robotic-assisted surgery for localized prostate, bladder and kidney cancer. Yet, it is the pediatric services that often set this hospital apart, with a pediatric and neonatal ICU, and a pediatric high care ward.

In 2012, the hospital installed an Optima™ MR360 for advanced MR imaging. However, as technology advanced, the hospital found its MR system lagged behind the competition. Although the hospital had a very good reputation, it was losing referrals to a nearby hospital with a new MR system.

Amaresh Ranchod, MB BCh, a diagnostic radiologist, explains that the hospital and radiology group looked at several options, including buying new or upgrading the existing scanner. He knew replacing the MR system would incur more cost and downtime.

"The upgrade was the middle option that we hoped would give us more value," Dr. Ranchod says.

"We also felt the upgrade would be the best option to shorten exam times and improve image quality," adds Samantha Palliam, MB ChB, a diagnostic radiologist at Netcare Waterfall City Hospital who often handles oncology and pediatric cases.

Excellence in pediatric imaging

Many children are under general anesthesia for an MR exam, and the clinicians want the duration of both the scan and the anesthesia to be as short as possible.

"Imaging a patient in the shortest amount of time with all the sequences needed is ideal for these children," Dr. Palliam adds. "There are many advantages for pediatric MR with the new upgrade."

For example, MAGnetic resonance imaging Compilation (MAGiC) allows her to scan up to eight contrasts in one 5½ minute scan and then change TE, TR and T1 after the exam. Dr. Palliam also has access to parametric maps, including T1, T2, R1, R2 and PD.

Kumeshnie Kollapen, MB ChB
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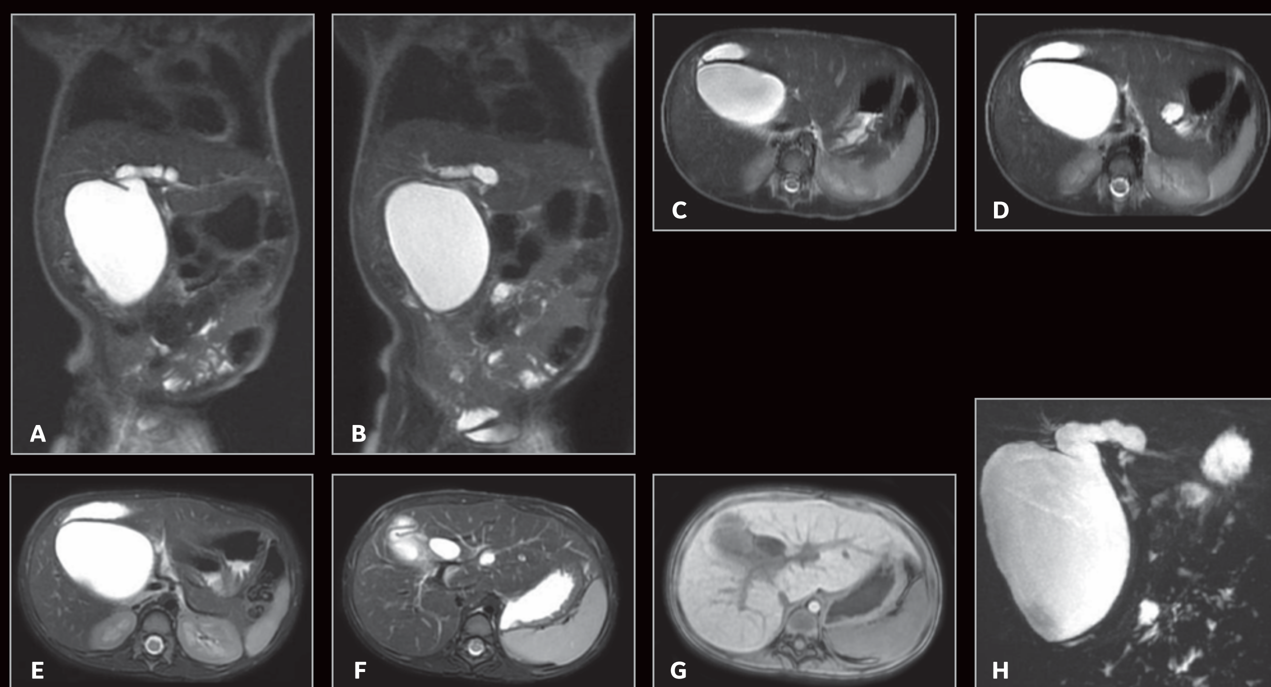

Figure 1. A 33-month-old child with a cystic lesion in the gallbladder fossa. An MRCP exam was scheduled, however, there were issues with breathing and respiration. Auto Navigator for free-breathing was utilized to obtain diagnostic-quality images of a lesion that is highly suggestive of a choledochal cyst with a Todani type II classification. (A-D) SSFSE with breath hold. (E-H) Free-breathing exam using Auto Navigator; (E, F) axial T2 FrFSE; (G) 3D axial FSPGR Dual Echo; and (H) 3D MRCP.

"It is really important to be as quick as possible without compromising image quality," Dr. Palliam says. "We are still adjusting our protocols. The system and sequences are not yet as fast as they can be, but we plan to improve them over the next year. Overall, there has definitely been an improvement in image quality."

Dr. Palliam recalls a recent case of a 33-month-old child with a cystic lesion in the gallbladder fossa (see Figure 1). Initially, there was concern that the lesion involved another organ, such as the liver or pancreas. Ultrasound was indeterminate, so an MRCP exam was scheduled.

"During the exam, we tried to do an MRCP sequence, however, we were still having issues with respiration and breathing artifacts," she explains. Fortunately, the SIGNA™ Explorer with SIGNA™Works includes Auto Navigator, a free-breathing approach to combat respiratory motion in the body that uses a navigator pulse to track the motion of the diaphragm. By automatically placing the navigator tracker pulse over the right hemidiaphragm, the acquisition is synchronized to the patient's breathing pattern and thus minimizes respiratory ghosting artifacts. Real-time adjustment allows threshold levels to be modified during the acquisition — eliminating failures due to changes in respiratory patterns of the patient.

As a result of using Auto Navigator in the MRCP exam, Dr. Palliam was able to determine the lesion was highly suggestive of a choledochal cyst with a Todani type II classification.

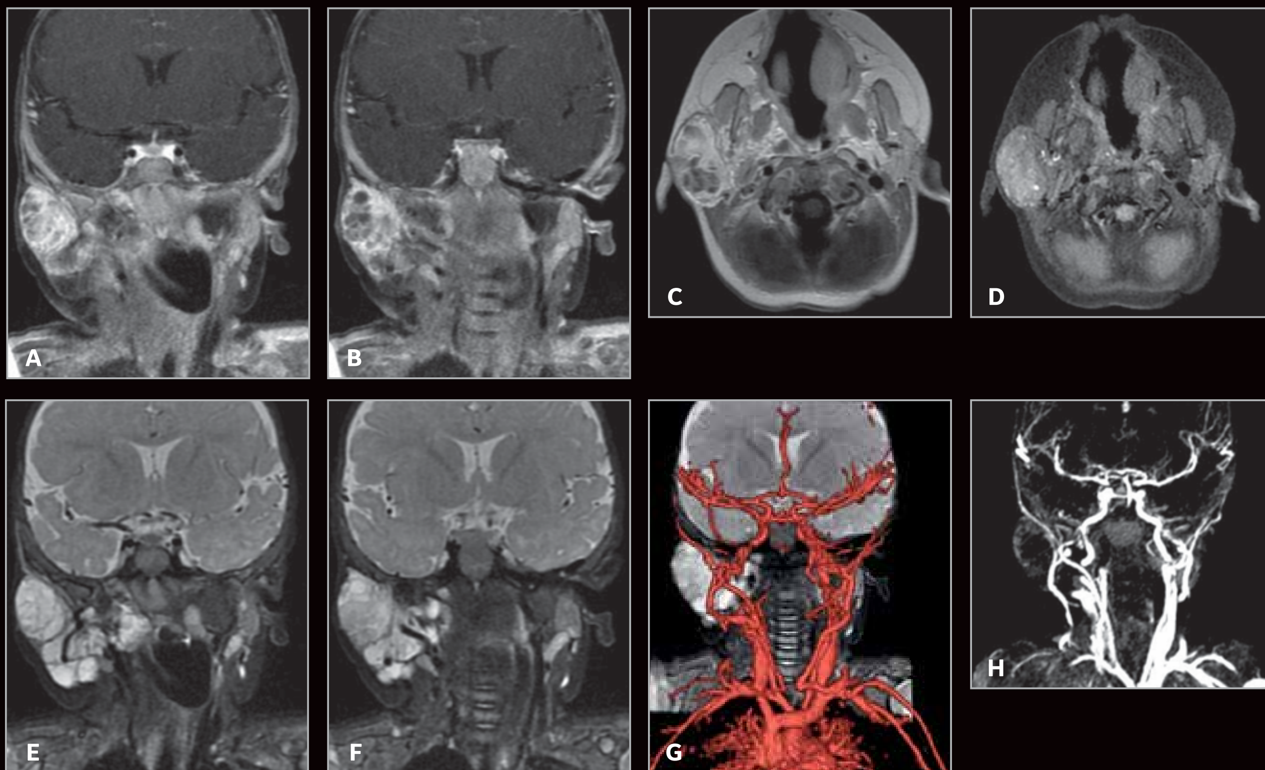

Figure 2. A six-month-old boy with swelling on the right side of the face. (A-D) The lesion was predominantly hypointense on T1 FatSat images, including (D) IDEAL, with scattered areas of hyperintense signal. (E, F) Coronal T2 STIR showed the lesion was encased by the branches of the external carotid artery and there were multiple fluid levels. (G, H) TRICKS helped depict the different phases of enhancement in a large, complex lobulated soft tissue mass lesion seen arising from the right parotid gland.

In Dr. Palliam's opinion, this case demonstrates the advantage of the SIGNA™ Explorer with sequences that can more easily augment breathing patterns, minimize artifacts and deliver the image quality needed for diagnosis.

Kumeshnie Kollapen, MB ChB, has an interest in pediatric radiology and says the services they provide are quite different from other hospitals because of the underlying high quality of imaging devices and clinical expertise. She recently joined the practice serving Netcare Waterfall City Hospital.

> "Ideally, we want to always optimize image quality in children and with the new hardware, software and sequences we are able to do that. With optimal quality, we can avoid repeating sequences and that's important because we don't want the pediatric patients under anesthesia for too long."
>
> *Dr. Kumeshnie Kollapen*

The T1 PROPELLER sequence delivers excellent resolution and addresses patient motion to provide her with the information she needs to assess the normal midline pediatric CNS structures. While 3D Cube may be a longer scan than T2 FLAIR, it is important to get the information needed in cases where there are subtle changes in brain white matter, such as hypoxic injuries.

"We have the tools to tailor each case to the individual pediatric patient," Dr. Kollapen adds.

In one case, a six-month-old boy presented with swelling on the right side of the face (see Figure 2). An initial ultrasound helped her diagnose a complex cystic lesion demonstrating multi-compartmental involvement of the right side of the neck, predominantly involving the preauricular and submandibular regions. However, an MR exam was ordered to further determine the type of lesion.

Using TRICKS on SIGNA™ Explorer, Dr. Kollapen was able to appreciate the different phases of enhancement that provided additional information to help her diagnose a vero-lymphatic malformation. The mass demonstrated persistent delayed enhancement.

"The lesion was predominantly hypointense on T1 with scattered areas of hyperintense signal, which may represent a proteinaceous or hemorrhagic component," she explains. "The lesion encased part of the branches of the external carotid artery and there were multiple fluid levels that were best appreciated with the T2 acquisition."

Prostate imaging

With the upgrade to SIGNA™ Explorer, Dr. Ranchod got the value he hoped for in body and prostate imaging. In MSK imaging, he routinely uses FSE Flex for consistent and reliable FatSat. With one scan, he can obtain a fluid-sensitive sequence that is useful in MSK cases. In prostate imaging, he has discovered multiple benefits since the upgrade.

The LAVA sequence has improved, particularly in the post-contrast phase. And, since diffusion imaging with ADC is an important sequence for all prostate cancer MR exams, Dr. Ranchod now has access to MAGiC DWI.

> "MAGiC DWI allows us to get the high diffusion value we need without scanning, so that reduces exam times to some extent. But, the overall quality is better and that makes a difference."
>
> *Dr. Amaresh Ranchod*

In one case, a patient had a rising PSA that spiked. The prior random systematic biopsy was negative. Dr. Ranchod detected a lesion suspicious for cancer (PI-RADS® v2.1) in the left anterior peripheral zone at the apex. The lesion was missed on the initial non-directed biopsy; guided biopsy post-MR confirmed prostate carcinoma.

"Now, we can direct the urologist to the target lesion by fusing MR with ultrasound for precise image guidance," he says.

Improvement across the board

The SIGNA™ Explorer has improved nearly all exams, adds Michael Maila, RT(R), Head Radiographer at Netcare Waterfall City Hospital. He is impressed by many of the new sequences, although it is the selection of coils that really impacts his daily routine.

> "It is very easy to position the patient with the 16-channel Flex Coils compared to the hard shell fixed coils. The new system is impressive. We have the same user-friendly interface, but with more options and more sequences. That gives us an advantage, especially when combined with the new coils."
>
> *Michael Maila*

By upgrading to the SIGNA™ Explorer, technologists can now more successfully perform challenging cases. It has expanded the clinical capabilities of the site considerably and, along with the increase in image quality, will enable Netcare Waterfall City Hospital to deliver excellence in MR imaging.

Sandip Biswal, MD
SiteOne Therapeutics, Inc., and PainSeek
Bozeman, Montana

Understanding the underlying molecular underpinnings and pathology of pain using PET/MR

The numbers are staggering. In the US alone, nearly one-third of adults report suffering from at least one type of chronic pain (e.g., neck, back, leg, knee or other kind of pain).[1] Estimates for the global incidence rate of chronic pain sufferers are currently one in five people, and one in 10 adults are newly diagnosed with chronic pain each year.[2] Moreover, the Institute of Medicine estimates that pain costs society between $560 and $635 billion per year while federal and state costs add another $100 billion annually, making the total burden nearly $800 billion each year.[1] These facts highlight that chronic pain is a significant public health issue.

Sandip Biswal, MD, a co-founder of SiteOne Therapeutics, Inc., and PainSeek, has spent the last 20 years pioneering a better way to accurately identify pain generators in patients with chronic pain.

"The ugly truth is that current methods to diagnose pain are not always accurate or based on objective methods," he explains. "Instead, it's based on empirical testing, often without getting to the root of the problem. In a large number of patients, we are prescribing treatments that merely mask pain without understanding its etiology. It's no wonder current pain treatments are estimated to be only 30 percent effective. It is also no surprise we have an opioid epidemic since physicians resort to alleviating the symptoms of pain without understanding the cause of one's pain since physicians do not have any good tools to pinpoint the site of pain generation."

Although MR is widely utilized for diagnosing the source of pain, the findings from an MR exam may not be related to the patient's pain. One of the most famous examples of this is what is known as the Framingham knee study, which used MR imaging of the knee in patients with an unclear cause of knee pain. The study found that 61 percent of subjects had meniscal tears in their knee yet did not have pain, aching or stiffness during the previous month. Further, only 63 percent of subjects experiencing pain, aching or stiffness in their knee actually had a meniscus tear.[3]

"We have found that conventional MR techniques either have limited sensitivity or find a number of abnormalities that may or may not be diagnosed as the pain generator," Dr. Biswal explains. This leads Dr. Biswal to question whether the pathology visualized is related to the patient's pain.

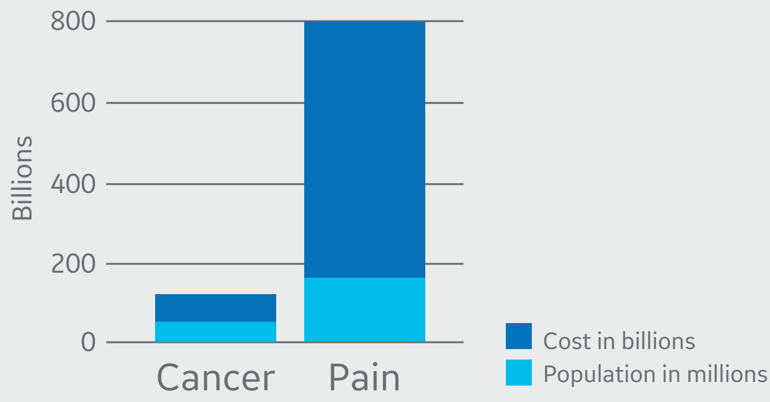

Figure 1. In the US alone, the total cost to society and government for chronic pain is nearly $800 billion.

This is where the combination of simultaneous PET/MR can help. With PET/MR, Dr. Biswal can acquire both MR and PET image data at the same time — both cameras are on — and then register them together as one unified image. He interprets the PET images in real-time to identify abnormal FDG uptake throughout the body, using PET imaging findings as a guide to perform high-resolution multiparametric MR imaging to evaluate tissues and structures for the identification of pain generators and a specific diagnosis.

"The simultaneous acquisition in PET/MR gives me more confidence because fusing two studies acquired at different times, such as those acquired with PET/CT, may not be precise," he says.

He references a paper that showed fusing a separate PET and CT in the head led to a difference in spatial registration of 7 mm between the two data sets using a standard PET head holder.[4] That difference can introduce uncertainties that may result in different diagnoses and therapies when evaluating small structures such as nerve roots, joints and surrounding tissue.

The simultaneously acquired PET and MR image data led to much higher fidelity of co-registered data sets, which is critical for Dr. Biswal when making treatment management decisions based on small structures in complex anatomic areas. Additionally, the time-of-flight PET and Q.Clear image reconstruction algorithm available on the SIGNA™ PET/MR system allows him to accurately detect small abnormalities with very high sensitivity and low noise.

Whole-body PET/MR imaging provides further insight into the manifestation of pain in its evaluation of both central and peripheral pain generators. This whole-body view ensures that all potential causes of pain will be captured since pain can be referred from locations remote to the site of symptoms. This is in contrast to current conventional methods to pain diagnosis where the standard of care is limited to the examination of only the site of pain (e.g., when someone presents with knee pain, only the knee is scanned). With this new approach, the entire body is studied, including the brain and spine, thereby significantly increasing the likelihood the pain generator will be identified.

By using PET/MR, Dr. Biswal can see more than just the anatomic abnormalities that may give rise to pain. He can also visualize the cellular and molecular makeup of the injury or inflammation and understand the underlying biology and pathology of pain. He is also examining nociception and neuronal inflammation as a means of improving objective, image-guided diagnosis and treatment of chronic pain disorders.

Using a novel tracer, ^{18}F-S1R‡, Dr. Biswal has imaged sigma-1 receptors that are overexpressed in injured or inflamed tissues and are thought to be more specific than FDG. In a published case report, the tracer was used to identify the source of refractory left knee pain of unknown origin. The patient was thought to have peroneal neuropathy, however, the PET showed uptake in an intercondylar notch that corresponded to an intra articular synovial lipoma detected in the simultaneously acquired MR exam.[5]

Another study that Dr. Biswal co-authored examined the use of whole-body FDG PET/MR as a diagnostic tool to visualize pathology and hypermetabolism in patients with chronic sciatica, a pain that starts in the lower back. Identifying the cause of sciatica can be difficult — it

‡^{18}F-S1R is not cleared or approved by the US FDA or any other global regulator.

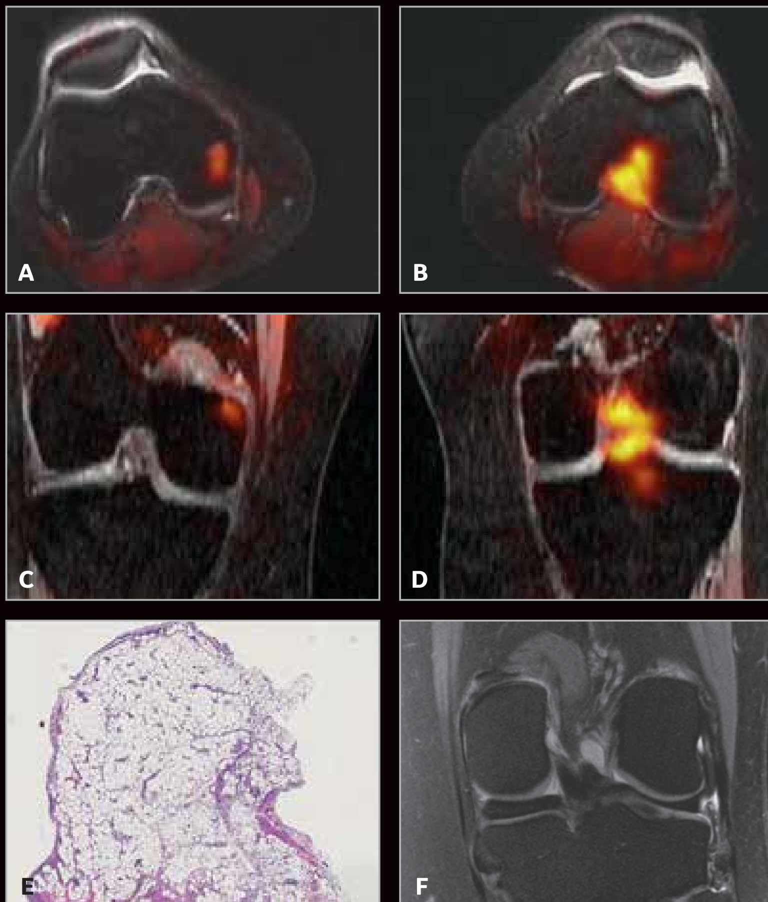

Figure 2. Simultaneous PET/MR with novel sigma-1 receptor-specific radiotracer identifies source of pain (an intraarticular inflamed synovial lipoma) in patient with chronic knee pain of previously unclear origin. Patient reported 8-10/10 left knee pain for years. Presented for S1R PET/MR which showed a "hotspot" in the center of knee, which was subsequently removed arthroscopically and completely resolved the patient's pain. (A-D) Fused PET/MR images; (E) pathology; and (F) MR image depicting lesion.

can result from disc herniations or other degenerative changes in the lower spine and it is not uncommon for the findings of an MR exam to be inconsistent with the patient symptoms.[6] With FDG PET/MR, Dr. Biswal and co-authors were able to locate the source of sciatica in nine patients. In five patients, the source of pain was a herniated disc. However, in four patients different lesions were detected in the peripheral nerve, leg muscles, pars and facet joints where the FDG uptake was abnormally high on PET, yet the MR demonstrated mild or no abnormalities in these areas.[7]

Addressing this need to identify pain generators is why Dr. Biswal co-founded PainSeek along with Michelle James, PhD, and others. According to Dr. Biswal, the company will be dedicated to developing pain diagnostics as well as new therapies for pain, including the development of PET tracers to identify certain molecules and cells specific to pain. They hope to develop objective molecular measurements of pain that highlight changes visualized in pain-sensing nerves.

> "Even referring physicians are amazed at the initial results of imaging pain patients with PET/MR. It's one thing to provide high-quality imaging, but another to help improve patient outcomes by figuring out what is really wrong."
>
> *Dr. Sandip Biswal*

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Gazi University Faculty of Medicine,
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Ankara, Turkey

Advancing clinical neuroimaging with PET/MR

At Gazi University Faculty of Medicine, Application and Research Hospital (Ankara, Turkey), Professor Lütfiye Özlem Atay, MD, Head of the Nuclear Medicine Department, is providing the latest advancements in multimodal imaging with SIGNA™ PET/MR. From oncology to neurodegenerative diseases to epilepsy, Professor Atay's vision for bringing the technology of the future to her department is changing the way patients are diagnosed and managed with the expectation of better outcomes.

Ten years after Gazi University Hospital opened in 1979, the Department of Nuclear Medicine was formed. In addition to being one of the country's leading reference centers for nuclear medicine, the department is also an important education and research center. To date, the department has trained 24 nuclear medicine specialists and was accredited by the UEMS (European Association of Medical Specialists) in the field of nuclear medicine education.

Gazi University Faculty of Medicine's Department of Nuclear Medicine implemented Turkey's first PET/CT system in 2004, added a dual-head gamma camera in 2008 and acquired their first SIGNA™ PET/MR system in December 2015. This was the first SIGNA™ PET/MR system in the region and beyond — Turkey, Central Asia, Russia, the Middle East and Africa.

"PET/MR is a technology of the future," says Professor Atay. "In cases where we cannot distinguish soft tissue on PET/CT images, we can distinguish these structures easily when we perform PET/MR on the same patient. The superior soft tissues contrast of PET/MR provides a significant advantage."

With the importance of PET in patient diagnosis and follow-up, and academic studies in oncology and neurology demonstrated in the literature, Professor Atay was excited to explore both research and clinical use of this hybrid technology. It provides the latest technology in multimodal imaging by combining molecular information and simultaneous multiparametric MR information.

She saw an opportunity to build upon the experience of scanning 40,000 PET/CT patients performed since 2004 at Gazi University Hospital and explore the value of PET/MR in following patients with chronic health disorders and diseases. In addition, the technology could help her further position the hospital as a leading brain research and reference center in the region.

Gazi University Hospital is also a center of excellence in pediatric oncology imaging. The value of the SIGNA™ PET/MR is especially relevant for this patient cohort, as it can reduce total patient ionizing radiation dose.

"Currently, PET/MR is the most important diagnostic imaging method for us in pediatric oncology patients, especially in patients requiring long-term follow-up, such as lymphoma," Professor Atay adds.

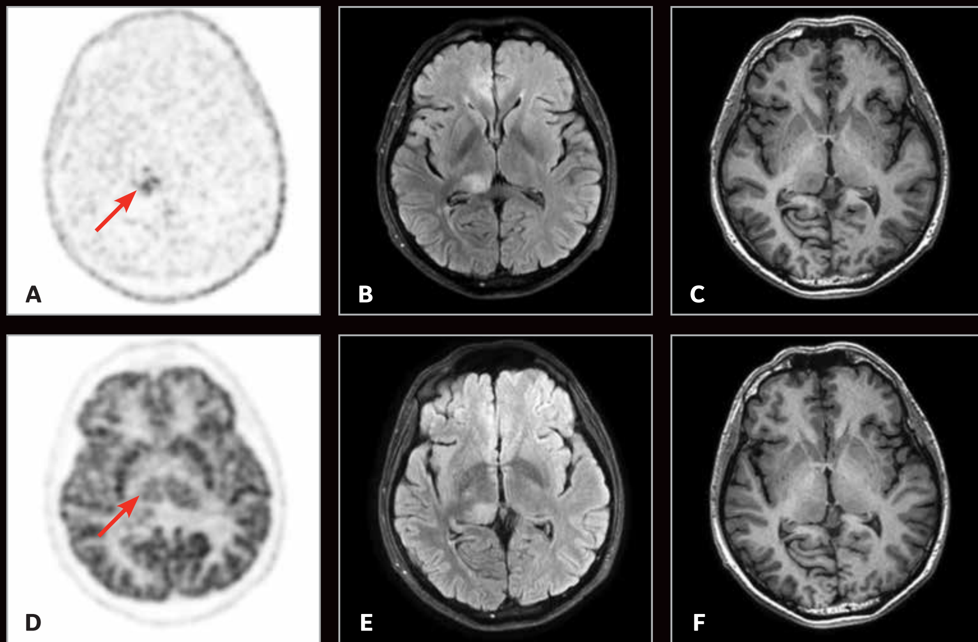

Figure 1. A 35-year-old male patient with glioblastoma in the right frontal and parietal lobes. On follow-up exam post-surgery, a suspected lesion was observed posterior to right thalamus. The PET exam shown here is positive for recurrence. (A) ^{18}F-FLT PET‡; (B) T2 FLAIR: (C) T1 3D BRAVO; (D) ^{18}F-FDG PET; (E) T2 FLAIR; (F) T1 3D BRAVO.

In a recently published study, Professor Atay and co-authors retrospectively evaluated the data of 34 pediatric patients with various oncologic diagnoses and demonstrated that PET/MR exhibits better performance than PET/CT in terms of anatomic correlation of FDG-avid lesions.[1]

"In most of the pediatric oncology cases in our center, pediatricians prefer PET/MR imaging to PET/CT for whole-body FDG PET examinations. This is due to the decrease in radiation dose and the detection of lesions with high soft tissue contrast," Professor Atay says.

Implementing PET/MR

As the first center in Turkey to perform FDG PET/CT imaging, Gazi University Hospital's nuclear medicine physicians had extensive experience in reading these studies. Prior to installing PET/MR, the team participated in PET/MR-related courses and visited sites that already had a system installed for training.

According to Professor Atay, GE Healthcare's clinical applications team provided support and protocol development guidance. She is impressed by the level of expertise provided by the GE support teams and finds added value in the continued development of GE PET and MR technology.

In the first year, the department performed PET/CT and PET/MR sequentially on most patients. The nuclear medicine physicians participated in multi-disciplinary councils and international workshops, and support staff received additional training on the use and safety of PET/MR. Having technologists experienced in MR imaging was critical to the department's successful launch of the PET/MR service.

"PET/MR technology is more complex compared to PET/CT. Therefore, its use requires additional training and experience," Professor Atay says.

Currently, the department performs approximately eight PET/MR exams each nine-hour day, with a total of more than 4,450 PET/MR studies completed since the installation.

Neuro-oncology

At Gazi University Hospital, PET/MR is used to differentiate recurrence from radiation necrosis in primary brain tumor patients, as well as for diagnosis and staging in patients with primary central nervous system lymphoma or brain metastasis. Metastatic patients also receive a whole-body PET/MR in the same scanning session.

Radiation oncology and neurosurgery physicians use PET/MR images similarly to PET/CT for the purpose of treatment planning. Although conventional MR is used for routine follow-up of neuro-oncology patients, any patient with suspicious findings is referred to PET/MR (Figure 1).

"With PET/MR, brain PET findings can be more easily correlated with suspicious lesions on MR compared to PET/CT," Professor Atay explains. "Therefore, PET/MR images directly affect the patient's follow-up decision and treatment planning in patients with recurrence. PET/MR data is used to determine surgical margins and to plan radiotherapy."

‡ ^{18}F-FLT PET is not cleared or approved by the US FDA or any other global regulator.

Neurodegenerative diseases

Since installing the SIGNA™ PET/MR, Gazi University Hospital has been performing FDG PET/MR exams for the differential diagnosis of neurodegenerative diseases such as Alzheimer's disease, frontotemporal dementia, idiopathic Parkinson's disease and atypical parkinsonism syndromes. In Parkinson's patients, the department also performs dopamine transporter (DAT) imaging with SPECT.

With the incidence of dementia increasing across populations, Professor Atay believes that early diagnosis and treatment of neurodegenerative diseases will be among the most important issues facing modern medicine. It is also critical to differentiate the type of neurodegenerative disease in a patient as new treatments emerge that are specific to the different dementia-related diseases (Figure 2).

> "In terms of neuroimaging, PET/MR technology will be the most important imaging modality of the future, especially with the introduction of new radiopharmaceuticals targeting pathological proteins, such as amyloid and tau."
>
> *Professor Lütfiye Özlem Atay*

Gazi University Hospital Department of Nuclear Medicine is involved in a prospective, multi-center study involving early Alzheimer's patients that will involve amyloid PET imaging for the first time in Turkey. The study aims to evaluate the association of vascular pathologies with amyloid deposition and clinical progression. With the integrated PET/MR system, Professor Atay believes that spatial normalization and quantification of PET data will be performed accurately and the MR imaging will add morphological information about the brain, which will contribute to the investigation of vascular pathologies.

Using brain FDG PET imaging, clinicians at Gazi University Hospital can accurately detect changes in cortical metabolism using an institutional normal brain FDG PET database and quantitative analysis methods. Brain FDG PET/MR provides additional diagnostic information, especially in the identification of disease-specific metabolic patterns, which contribute significantly to the clinician's ability to make a differential diagnosis. The department is also planning to perform quantitative analysis in more detail by correcting the partial volume effects. In this respect, the use of the PET/MR system is an advantage, says Professor Atay (Figure 3).

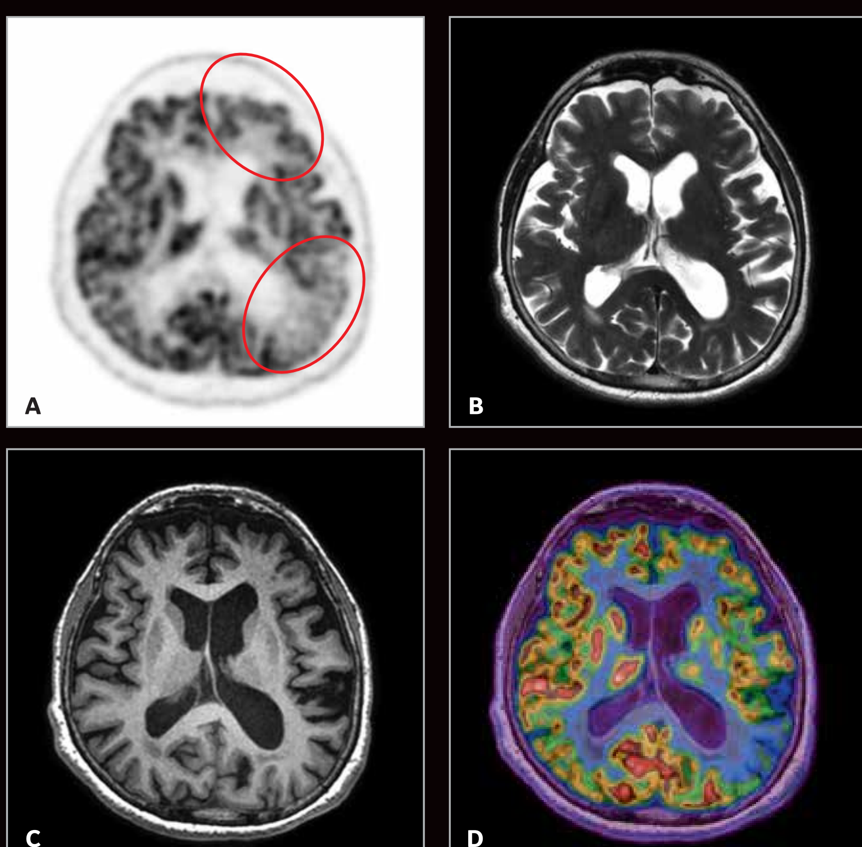

Figure 2. A 70-year-old female patient with complaints of progressive speech difficulty (naming, repetition). Patient was not suffering memory problems. Neurological physical examination was normal. The clinical diagnosis was frontotemporal dementia. FDG PET exam showed left prominent bilateral frontal and left temporal hypometabolism. Accompanying MR showed cortical atrophy in these regions. PET/MR confirmed neurological exam findings that were compatible with frontotemporal dementia. (A) ^{18}F-FDG PET; (B) T2 PROPELLER; (C) T1 3D BRAVO; (D) Fused PET/T1 3D BRAVO.

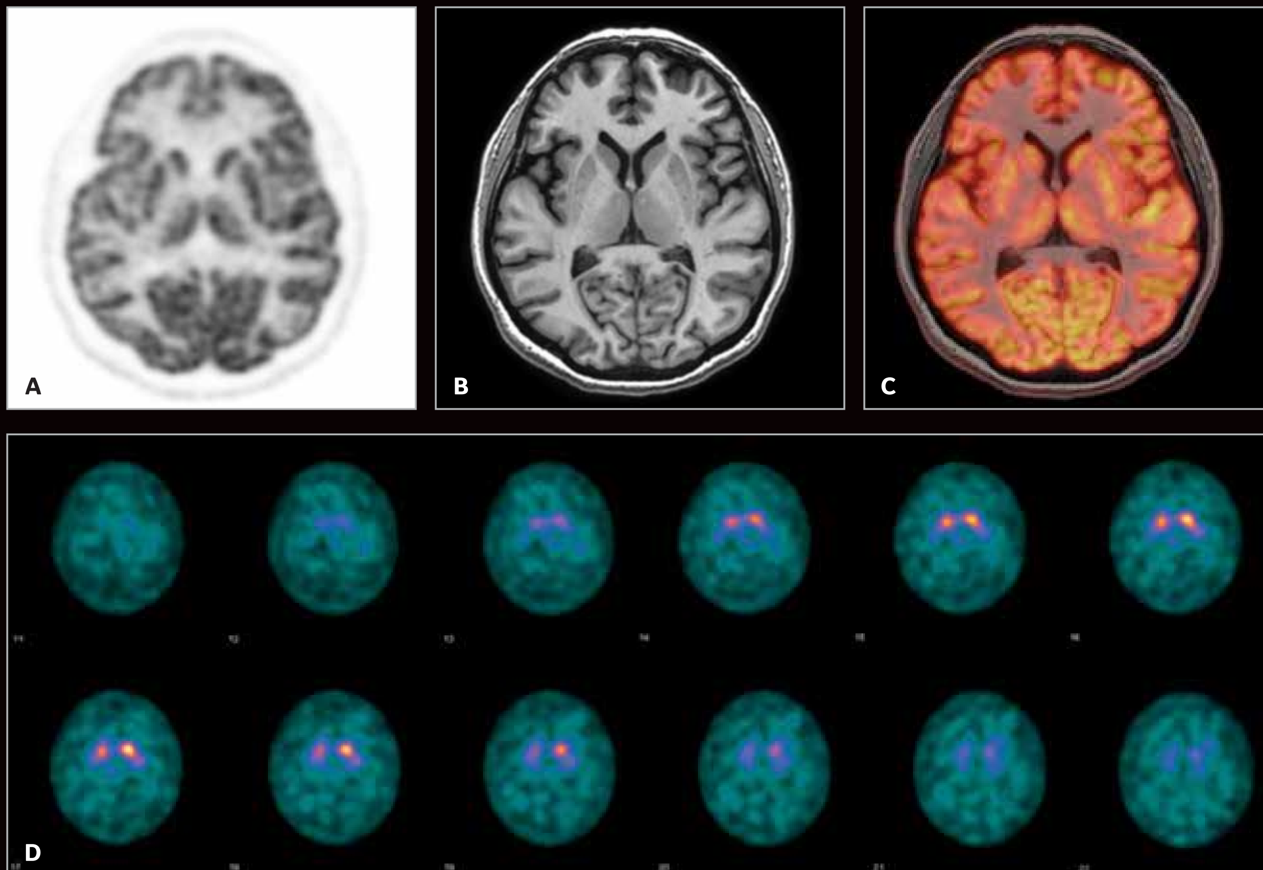

Figure 3. A 57-year-old female patient with parkinsonism. The suspected clinical diagnosis was multi-system atrophy or corticobasal ganglionic degeneration. The DATSCAN SPECT of the patient showed right dominant bilateral decrease, or uptake, in basal ganglia, indicating the presence of a neurodegenerative parkinsonism syndrome. FDG PET image showed right insular and perisylvian cortical, right basal ganglion and thalamic nucleus hypometabolism, which is compatible with corticobasal ganglionic degeneration. (A) ^{18}F-FDG PET; (B) T1 3D BRAVO; (C) Fused PET/T1 3D BRAVO; (D) DATSCAN SPECT.

Over 1,000 brain FDG PET/MR studies have been performed at Gazi University Hospital. Approximately 200 patients with neurodegenerative diseases have been evaluated.

Epilepsy

As a reference center for epilepsy surgery, the Department of Nuclear Medicine has evaluated more than 2,000 epileptic patients.[2,3] According to Professor Atay, clinicians in the epilepsy surgery council prefer PET/MR to PET/CT for brain FDG PET studies. Interictal brain FDG PET/MR is performed for each epileptic patient who requires surgery or other invasive intervention (Figure 4). The institution's normal brain FDG PET database and quantitative analysis are used to evaluate the images.

"We've obtained imaging results consistent with the clinical follow-up data of the patients and the high success of the post-surgical follow-up results has led clinicians to rely on the brain FDG PET/MR imaging," says Professor Atay. "In one of our ongoing studies we showed that using quantitative analysis and data mining methods increased the diagnostic accuracy above 90 percent in lateralization of brain FDG PET examinations in temporal lobe epilepsy. This is especially true in the evaluation of cortical dysplasia, where brain FDG PET examinations significantly contribute to the detection of pathological findings in MR evaluations and, in some cases, it can offer complementary results. In other words, when PET findings are considered negative, MR findings may contribute to the detection of abnormal PET findings."

Beyond neuroimaging

Professor Atay believes that PET/MR can have an important role in other areas beyond the brain, particularly in the liver, prostate and breast. In cases of indeterminate PET findings in the liver, the addition of MR benefits the clinician in assessing the presence of lesions.

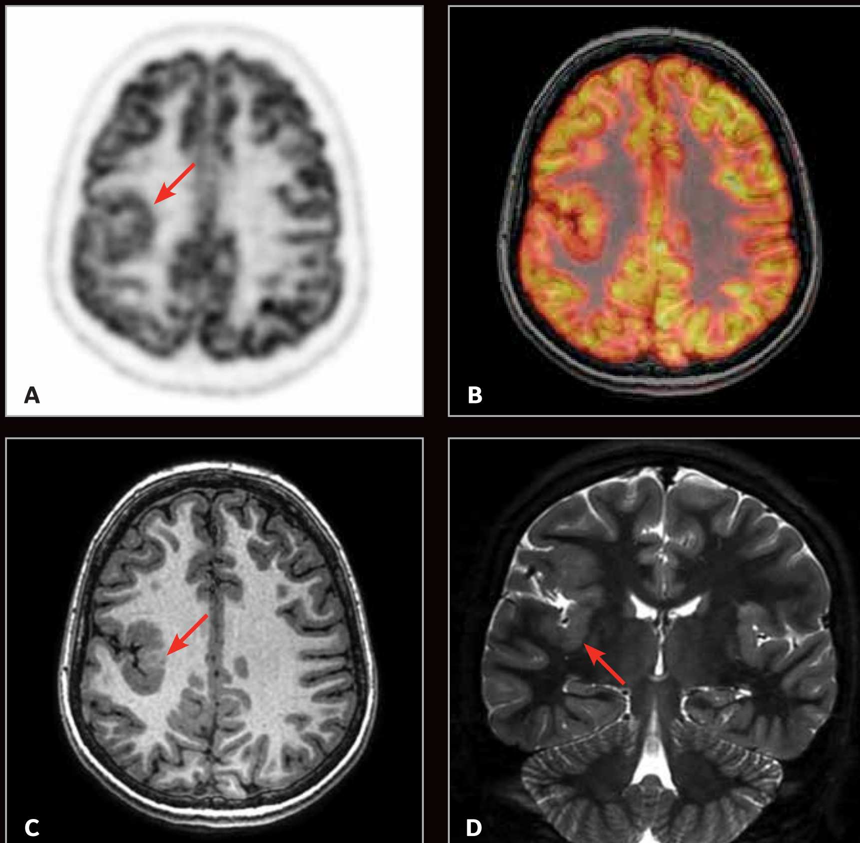

Figure 4. A 16-year-old female patient with partial seizures. The epileptogenic region was on the right hemisphere according to EGG findings. The MR exam showed a lesion in the right perisylvian region compatible with cortical dysplasia. The lesion was mildly hypometabolic on FDG PET images. The addition of PET/MR has helped with pre-surgical planning and post-surgical success at the hospital. (A) ^{18}F-FDG PET; (B) Fused PET/T1 3D BRAVO; (C) T1 3D BRAVO; (D) T2 FSE-IR.

Professor Atay says, "With an experience of more than 300 ^{68}Ga PSMA‡‡ PET/MR primary staging studies of prostate cancer, we have detected the primary intraprostatic lesions and metastatic lesions more precisely in combined PET/MR imaging with superior soft tissue contrast compared with PET/CT." This observation is consistent with the results of previous studies.[4,5]

Currently, the department is performing whole-body and high-resolution regional PET/MR imaging using ^{68}Ga-labeled PSMA‡‡ in prostate cancers and ^{68}Ga-labeled DOTATATE‡‡ in neuroendocrine tumors. In the near future, the department will explore the use of novel radiopharmaceuticals beyond FDG in primary rectal and head and neck cancers.

"We are at the beginning of the road for exploring the value of PET/MR imaging and its impact in clinical practice," Professor Atay says. Ⓢ

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‡‡ ^{68}Ga PSMA, ^{68}Ga-labeled PSMA and ^{68}Ga-labeled DOTATATE are not cleared or approved by the US FDA and may not be available for clinical use in all markets.

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Advanced MR imaging in spine lesions

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> Spine imaging can be challenging due to the small size of the anatomy and the potential for respiratory- and cardiac-induced motion. Applying the same techniques used in neuroimaging with high-field MR can provide the information needed for a confident diagnosis and assist with surgical planning.

With 3.0T MR, we can now perform advanced imaging of the spine and spinal cord lesions. In our daily clinical practice, we are utilizing advanced high-field MR imaging techniques to aid in our diagnosis and provide more precise details to help guide the neurosurgeon and orthopedic surgeon in their pre-surgical planning, as well as during the procedure. These advanced techniques include: diffusion tensor imaging (DTI) with fractional anisotropy (FA), mean diffusivity (MD) and tractography, dynamic contrast enhanced (DCE) MR perfusion with permeability study.

Diffusion-weighted imaging and diffusion tensor imaging

DWI and DTI are challenging techniques in spinal imaging for several reasons, including the small size of the spinal cord relative to the brain and respiratory and cardiac motion artifacts. Therefore, spine diffusion imaging requires high spatial resolution that should be combined with distortion reduction techniques and homogeneous fat saturation. However, these goals are difficult to achieve with the single-shot fast spin echo (SSFSE) EPI diffusion sequence, especially when image acquisition is in the sagittal plane, which is preferred for evaluating the spine. Specific aspects of these techniques include fat saturation, image distortion and b-values and directions.

DTI is a newer technique that can assess water movement, called Brownian motion, and water diffusion in three dimensions based on the spatial location. DTI can help the clinician detect microstructures of the central nervous system and abnormalities that may not be visible using conventional MR sequences such as SSFSE.

DTI shows the magnitude, degree of anisotropy and orientation of diffusion anisotropy. In estimating the connectivity patterns of white matter in the brain, white matter tractography can be used to assess diffusion anisotropy and diffusion direction. In the central nervous system, diffusion of water is more anisotropic in white matter and more isotropic in gray matter and cerebrospinal fluid.

Diffusion from water in biological tissues occur inside, outside, around and through cellular structures. Diffusion is a picture of directional dependent anisotropy of the white matter where the myelin sheath and axonal membrane become barriers to the movement of water molecules in a random direction. The maximum MD value describes the direction of nerve fibers.

Broadly speaking, tensors are abstract mathematical entities that can help describe complex physical phenomena. The latest terminology states that tensors are simple matrix values obtained from diffusion measurements in different directions. The diffusivity value can be estimated in each

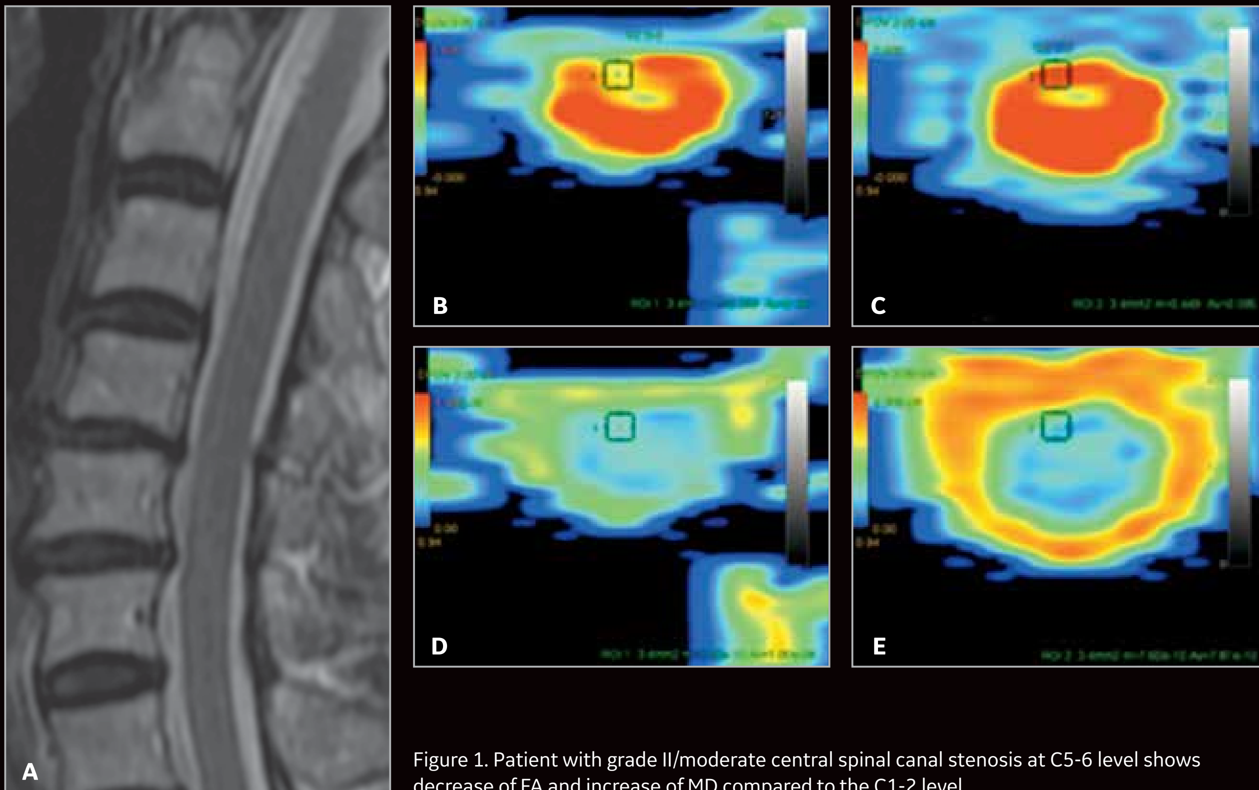

Figure 1. Patient with grade II/moderate central spinal canal stenosis at C5-6 level shows decrease of FA and increase of MD compared to the C1-2 level.

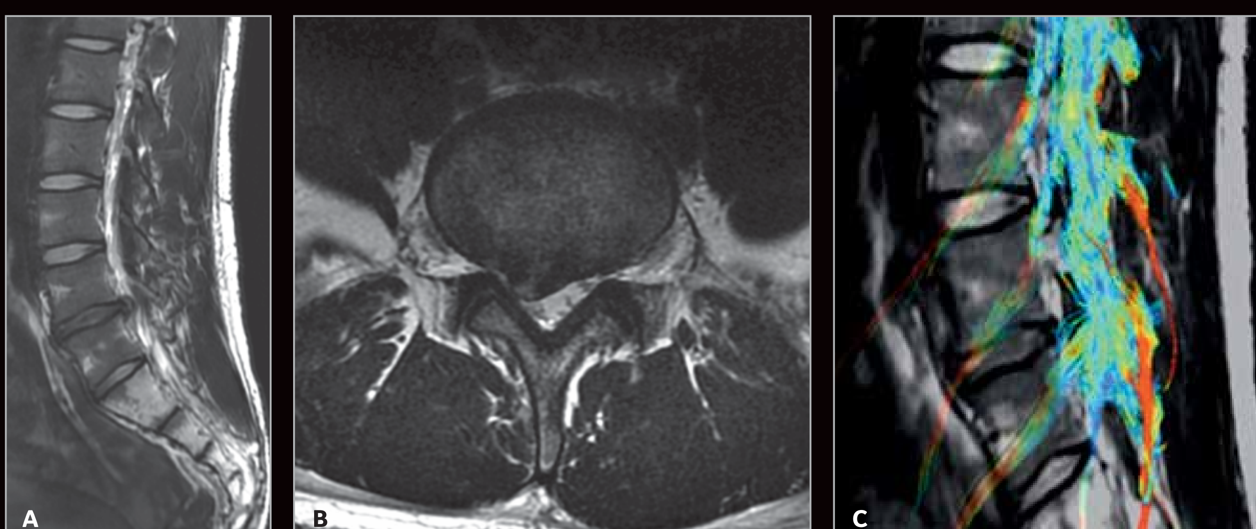

Figure 2. Patient with right radicular pain. (A, B) Sagittal and axial T2 images demonstrate disk extrusion to the right paracentral with indentation of L5 right traversing the nerve root. (C) DTI with tractography shows the indentation of the right L5 traversing the nerve root.

direction or used to determine the direction of the maximum diffusivity. Tensor matrix is easier to describe in the form of an ellipsoid where the diameter in each direction predicts diffusivity in that direction and has a major axis that describes the direction of the maximum diffusivity. This concept is the basis for diffusion tensor, which is a mathematical model of diffusion in the three-dimensional space. By using DTI, both anisotropy degree and direction of fibers in the white matter can be assessed in each voxel.

The same principle of DTI that is performed in the brain can also be used in the spinal cord, including measuring FA and MD. Measurements can be obtained by marking the region of interest (ROI) on sagittal and axial images; however, it is possible to be more precise when marking an ROI on an axial image, potentially making these measurements more reliable.

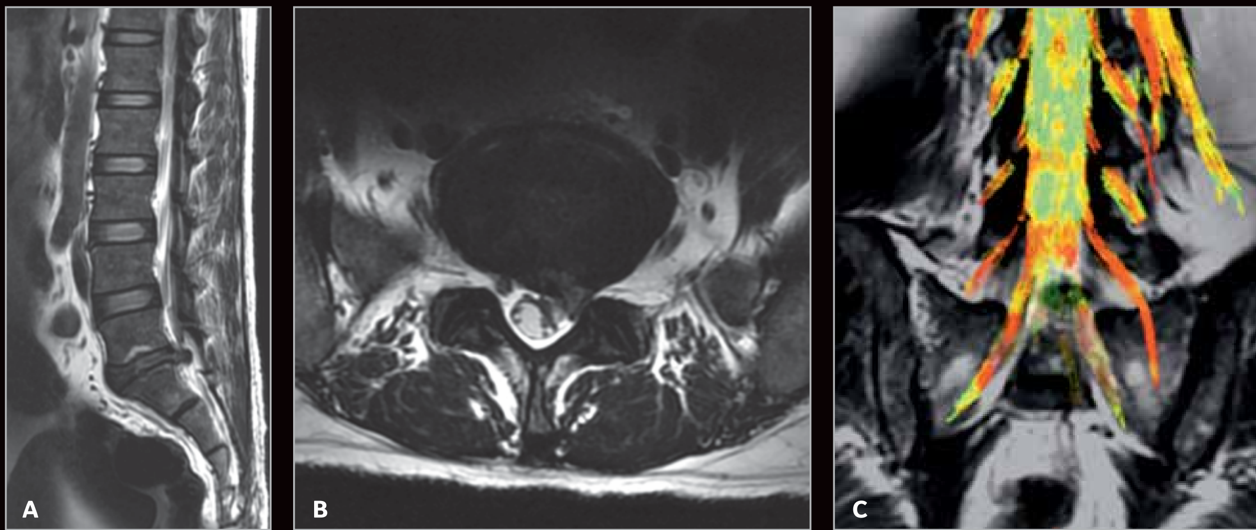

Figure 3. Patient with left radicular pain. (A, B) Sagittal and axial T2 shows L5-S1 left paracentral disk extrusion. (C) DTI with tractography shows an indentation of the left S1 traversing the nerve root.

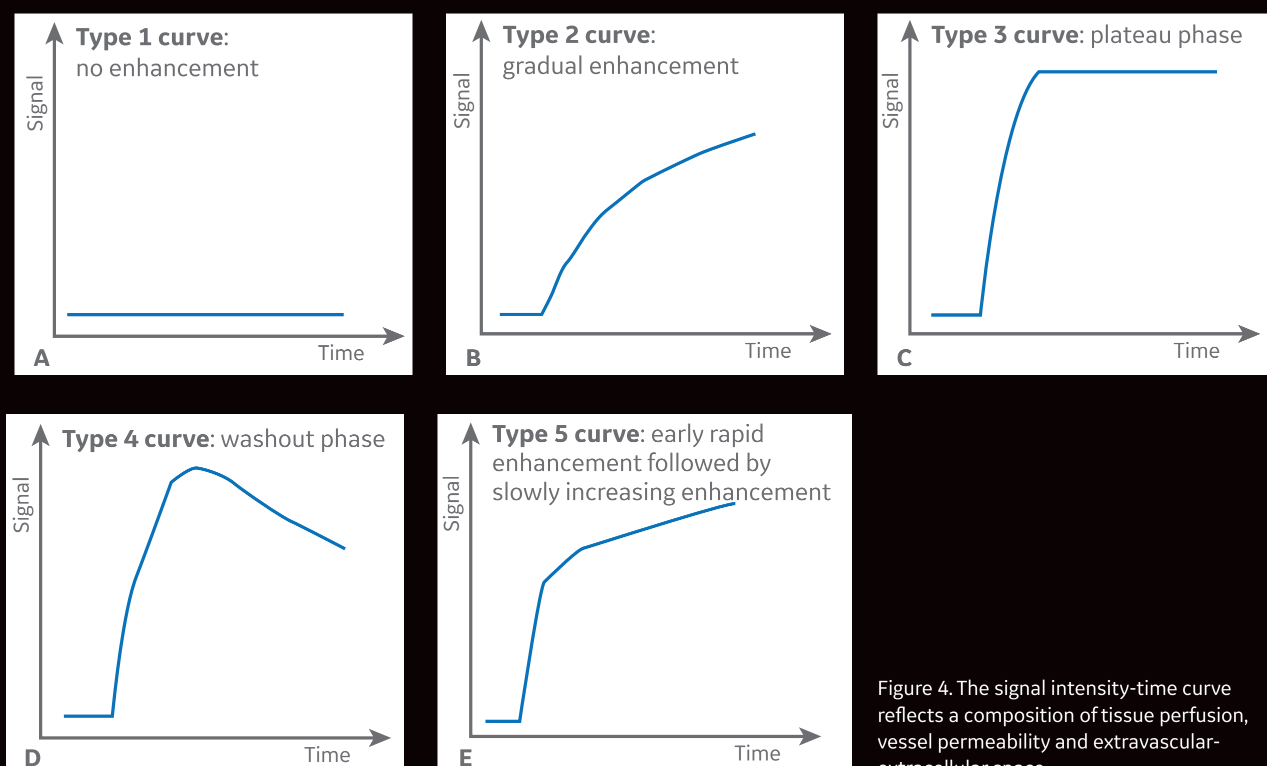

Figure 4. The signal intensity-time curve reflects a composition of tissue perfusion, vessel permeability and extravascular-extracellular space.

Dynamic contrast-enhanced (DCE) MR perfusion

DCE MR perfusion, also widely referred to as permeability MR, is based on the acquisition of serial T1-weighted images before, during and after administration of extracellular low-molecular-weight MR contrast media, such as a gadolinium-based contrast agent. The resulting signal intensity-time curve reflects a composite of tissue perfusion, vessel permeability and extravascular-extracellular space.

In contrast to conventional static contrast-enhanced, T1-weighted MR imaging, which displays contrast enhancement at a single point in time, DCE MR perfusion imaging depicts the wash-in, plateau and washout contrast kinetics of the tissue, thereby providing insight into the nature of the bulk tissue properties at the microvascular level.

Most often, DCE MR perfusion imaging is based on a two-compartmental (plasma space and extravascular-extracellular space) pharmacokinetics model. The general process, in order, is:

1. Perform baseline T1 mapping
2. Acquire DCE MR perfusion images
3. Convert signal intensity data to gadolinium concentration
4. Determine the vascular input function, and
5. Perform pharmacokinetics modeling.

With pharmacokinetics modeling of DCE MR perfusion data, several metrics are commonly derived: the transfer constant (k^{trans}), the fractional volume of the extravascular-extracellular space (v_e), the rate constant (k_{ep}, where $k_{ep} = k^{trans} / v_e$), and the fractional volume of the plasma space (v_p).

The most frequently used metric in DCE MR perfusion is k^{trans}. It can have different interpretations depending on blood flow and permeability. When there is very high permeability, the flux of a gadolinium-based contrast agent is limited only by flow, and thus k^{trans} mainly reflects blood flow. In situations in which there is very low permeability, the gadolinium-based contrast agent cannot leak easily into the extravascular-extracellular space, and thus k^{trans} mainly reflects permeability.

Advanced MR techniques such as DCE MR perfusion with permeability, DWI and DTI with FA, MD and tractography are very useful when evaluating whether a lesion is benign or malignant and in cases where injection can mimic a tumor. Metrics derived from DCE perfusion can help depict the different behavior in a mass to identify metastases and are used to assist with pre-surgical planning, including guidance for the incision site. DWI assists with differentiating an abscess formation and granulation tissue or tumor and is a useful tool in patients with chronic kidney failure who cannot tolerate the use of contrast.

Armed with these techniques, we can more clearly and confidently diagnose spinal abnormalities using DTI and DWI to positively impact patient management.

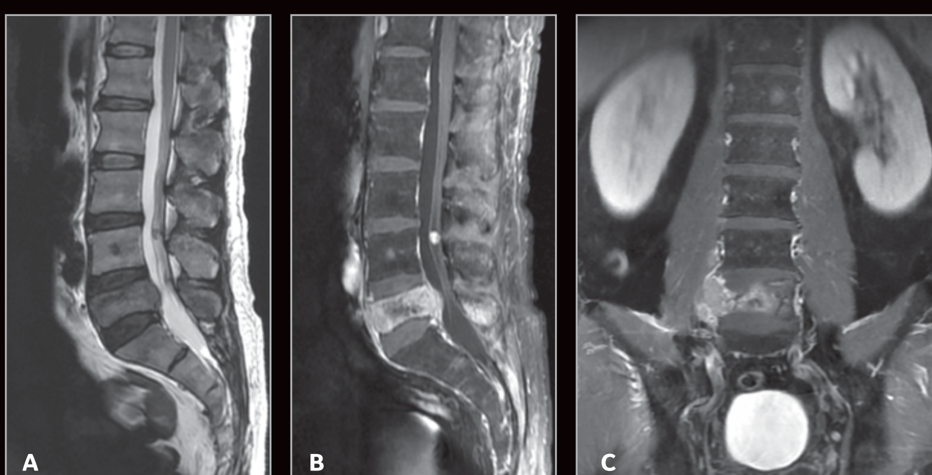

Figure 5. Patient with low back pain. (A) Sagittal T2, (B) CE T1 FatSat sagittal and (C) coronal show damage to the L4 and L5 vertebrae resulting from compression, posterior bulging of L5 consistent with a malignancy that is highly suspicious of metastasis and contrast-enhancing nodule at cauda quine, indicating a metastasis or neurinoma.

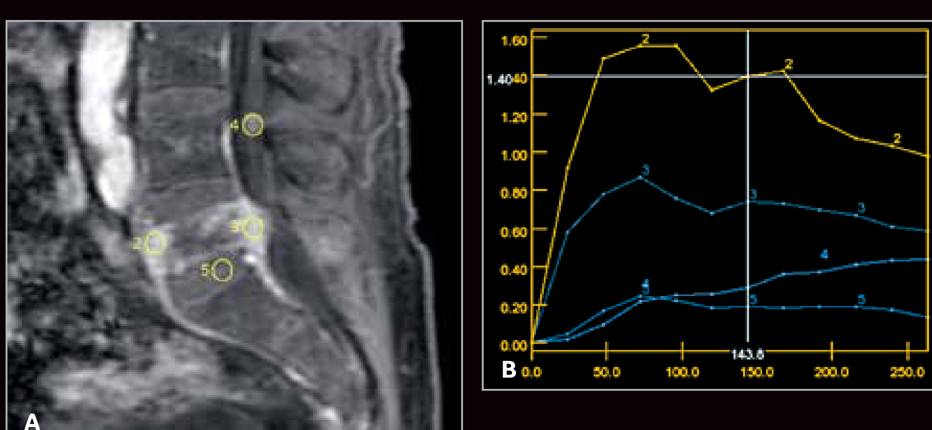

Figure 6. DCE MR perfusion demonstrates a Type 3 curve with early wash-in and a continued plateau at L5 level consistent with malignancy and a Type 2 curve with gradual enhancement at cauda equina nodule that is consistent with a benign lesion.

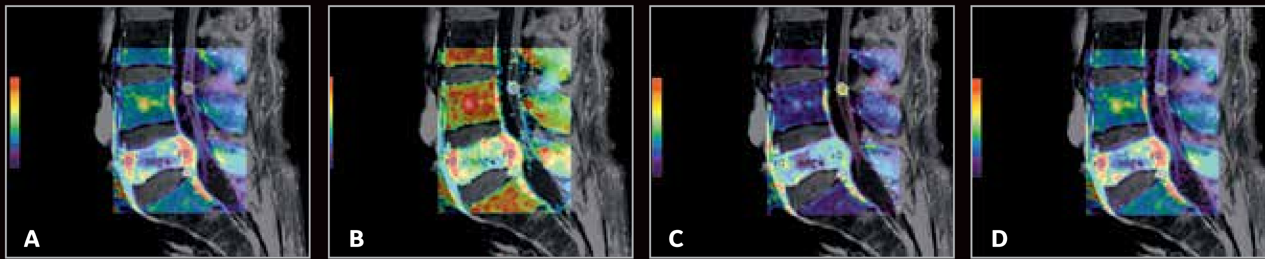

Figure 7. Permeability study demonstrates an increase in (A) k^{trans}, (B) K_{ep} and (C) V_e at L5 level that is consistent with malignancy and no increase in k^{trans}, K_{ep}, (D) IAUGC and V_e at cauda equina nodule that is consistent with a benign lesion, most likely a neurinoma.

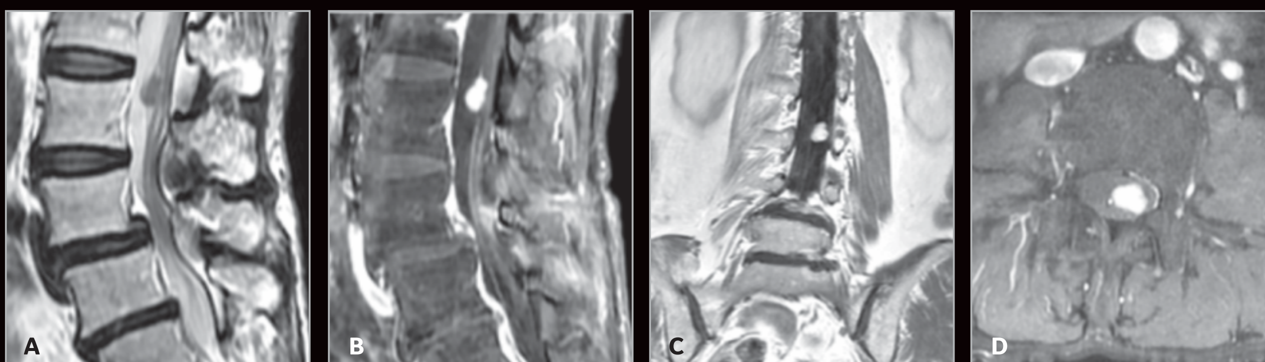

Figure 8. Patient with low back pain. Sagittal (A) T2 and (B) contrast-enhanced T1 FatSat images demonstrate a homogenous contrast-enhancing nodule at cauda equine L3 level that is next to the degenerative disk with central disk extrusion and grade I anterolisthesis L4-5 level. (C) Coronal T2 and (D) axial contrast-enhanced T1 FatSat.

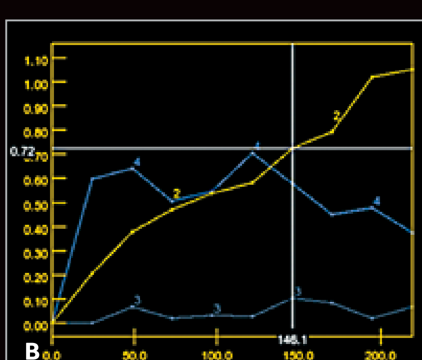

Figure 9. MR perfusion depicts a Type 2 curve with gradual contrast enhancement that is consistent with a benign lesion, likely a neurinoma.

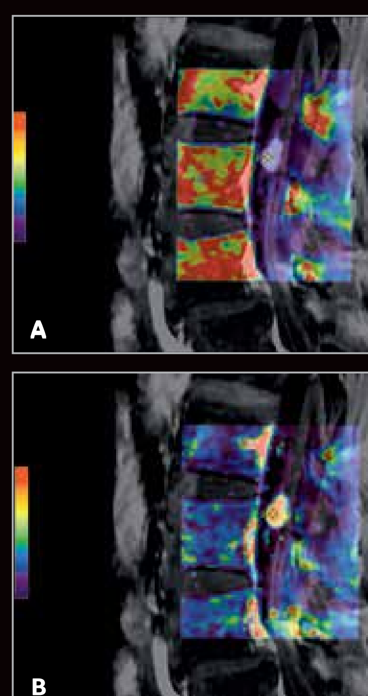

Figure 10. Permeability study shows no increase of (A) k^{trans} although there is an increase of (B) V_e. The adjacent normal soft tissue also shows an increase in V_e, which is consistent with a benign lesion that is most likely a neurinoma.

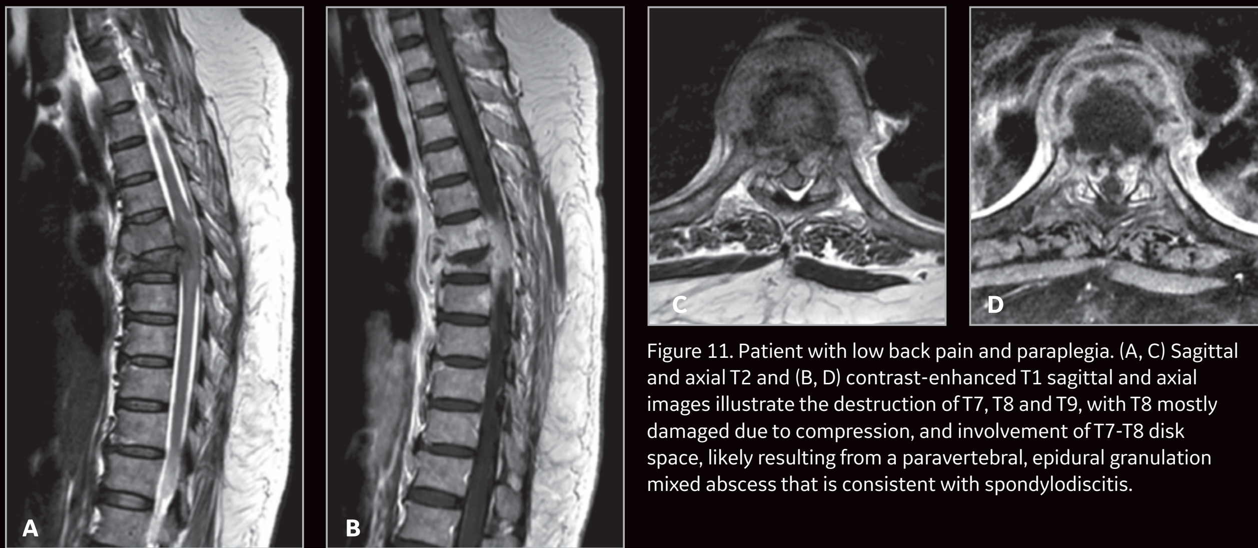

Figure 11. Patient with low back pain and paraplegia. (A, C) Sagittal and axial T2 and (B, D) contrast-enhanced T1 sagittal and axial images illustrate the destruction of T7, T8 and T9, with T8 mostly damaged due to compression, and involvement of T7-T8 disk space, likely resulting from a paravertebral, epidural granulation mixed abscess that is consistent with spondylodiscitis.

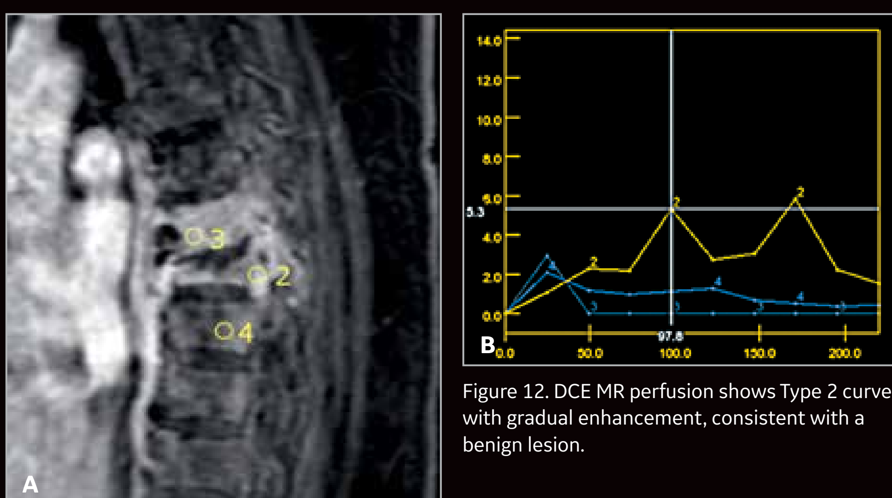

Figure 12. DCE MR perfusion shows Type 2 curve with gradual enhancement, consistent with a benign lesion.

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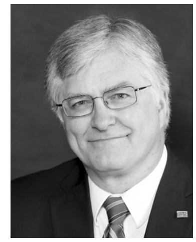

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The growing need for a comprehensive, non-invasive liver health assessment

By Michael J. Kalutkiewicz and Richard L. Ehman, MD, President and CEO, Resoundant, Inc., Rochester, MN

There exists great need for a non-invasive diagnostic test that can help identify early stage liver disease, both fibrosis and steatosis, in a patient population that is prone to obesity and underlying metabolic disease (type 2 diabetes mellitus, obesity, hypertension, etc.). Recent innovations in rapid, low-cost MR imaging may be that answer.

Liver disease has rapidly emerged as a complex global health challenge, impacting advanced and developing countries alike. Worldwide, nearly one in four people are now known to have abnormal levels of lipid in their liver tissue, a condition known as non-alcoholic fatty liver disease (NAFLD).[1] NAFLD is defined as liver fat of greater than 5 percent with no history of excess alcohol consumption and is the precursor of a more advanced form of the disease called non-alcoholic steatohepatitis (NASH), which can lead to liver failure and death. In addition to NAFLD there are many other conditions that can eventually lead to end-stage liver disease such as chronic hepatitis B and C infections, which affect millions of people worldwide.

A recent study reports a five-fold increase in the incidence of NAFLD diagnosis from 1997 to 2014, based on data from the Rochester Epidemiology Project database.[2] This explosion in NAFLD and NASH has paralleled the rise in metabolic syndrome worldwide (e.g., type 2 diabetes) and is strongly linked to overnutrition and a sedentary lifestyle.

Part of the challenge is diagnosing NAFLD early, as patients often progress asymptomatically. Researchers are also seeking to better define observed differences in progression rates and directionality of disease advancement. All of this uncertainty makes it difficult to stage NAFLD, stratifying patients based on who might progress from the relatively benign and manageable NAFLD to the more worrisome NASH.

This matters not only in terms of healthier outcomes, but also systemic costs. The transition to NASH hallmarks the point at which modest lifestyle changes are less likely to be effective. There is hope that combination therapies will be able to halt or even reverse NASH progression, but the cost of such strategies is expected to be significant. Moreover, NASH patients remain at heightened risk of cirrhosis, liver decompensation and/or liver cancer — all of which are strongly linked to higher rates of mortality. Because of this, NAFLD and NASH are projected to be the leading cause of end-stage liver disease requiring liver transplantation as early as 2025.[3]

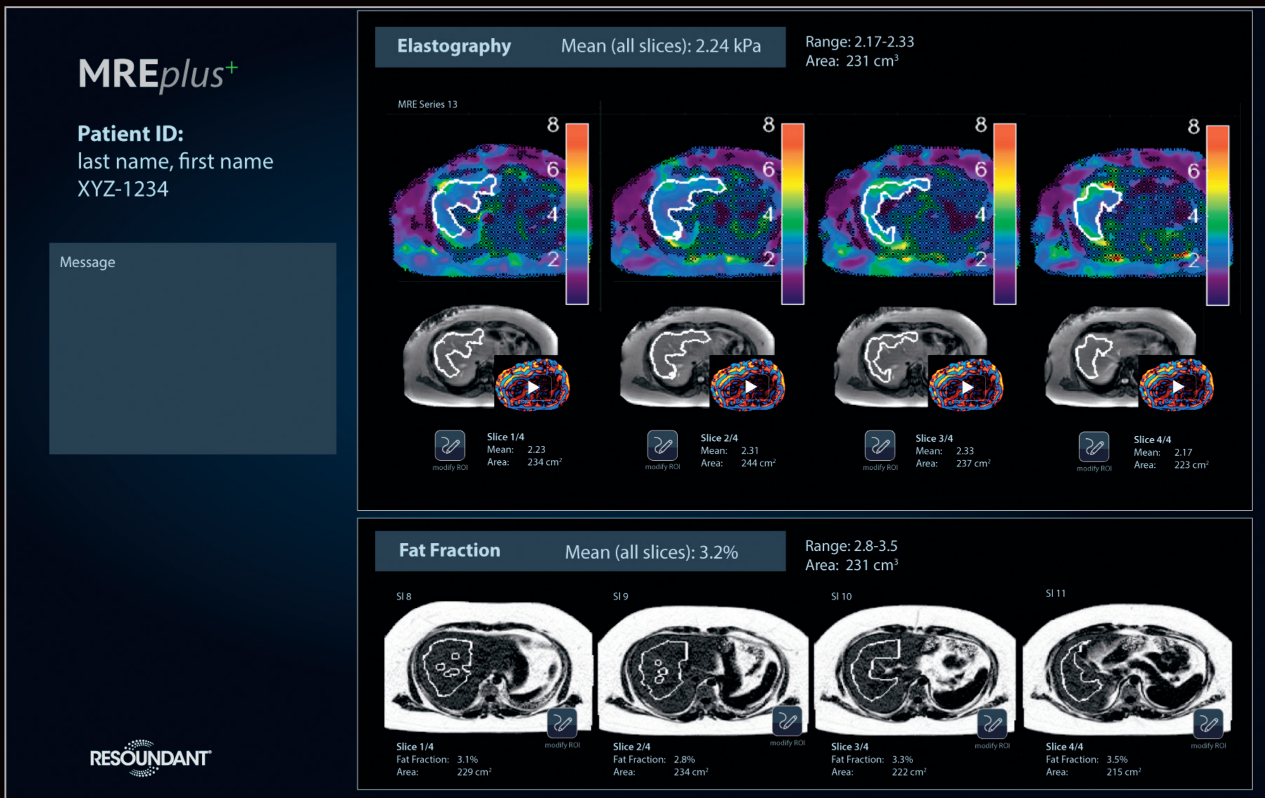


Figure 1. MRE*plus*+ is an automated liver analysis tool that creates ROIs for each liver metric (MRE and PDFF) based on the optimal data for each acquisition.

With the hopes of curtailing this trajectory, the European Union and the US have launched ambitious projects (e.g., LITMUS and NIMBLE) to identify reliable diagnostic approaches for evaluating suspected NAFLD and NASH patients. For decades, liver biopsy has been regarded as the only reliable diagnostic tool, providing a direct histologic assessment of steatosis and fibrosis. However, liver biopsy is invasive, costly and is affected by sampling error and subjectivity in histologic review, making this test a very imperfect gold standard.

Advances in imaging technology have offered alternatives to biopsy in assessing liver fat and fibrosis. Ultrasound-based elastography and attenuation measurements can be used to assess fibrosis and steatosis, respectively, but may be unreliable in NAFLD due to obesity, which is prevalent in over two-thirds of NAFLD patients.[4]

MR-based solution

MR is stepping up to fill this gap. Two advances in particular have gained consensus in the scientific and clinical community as new gold standards for liver assessment. MR elastography (MRE, MR Touch) for fibrosis staging and proton density fat fraction (PDFF, IDEAL IQ) for steatosis assessment are not only highly accurate, but also perform well in obese patients where ultrasound techniques are often difficult. These MR-based techniques can be combined in a short, efficient exam that has been called a “Hepatogram.”[5]

Both techniques are individually validated, widely available and recognized in leading gastroenterology and hepatology practice guidelines.[6,7] In the past, concerns about cost have hampered the adoption of powerful diagnostics based on MR imaging. But radiology as a medical specialty is embracing the public health challenge of NAFLD and NASH. Thanks to a new CPT code (76391), MRE and PDFF can be done as a rapid, low-cost standalone exam, perhaps marking an exciting trend toward adoption of a pragmatic MR exam that can be used in routine clinical practice for targeted applications.

To assist workflow, researchers have developed a comprehensive analysis tool for MRE and PDFF data that automatically quantifies these critical biomarkers. This tool, which will be made widely available from Resoundant as MRE*plus*+, instantly generates appropriate ROIs and measurements for MRE, PDFF and R2* images based on the optimal data from these acquisitions. The tool outputs these metrics and images in a format that can be used by the interpreting radiologist and provided to the referring physician and patient. The tool provides consistent and repeatable measurements, well-suited for longitudinal assessments of patients with NAFLD and for clinical trial support.

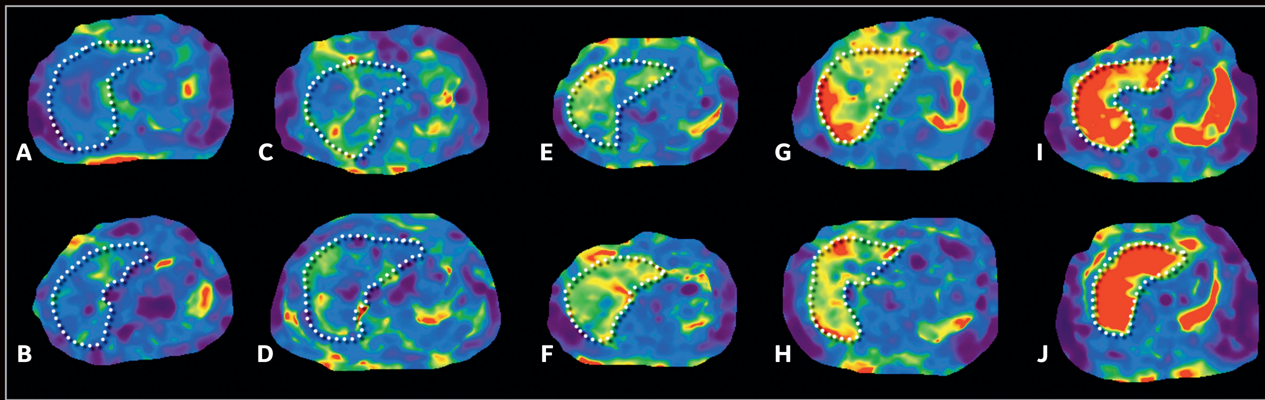
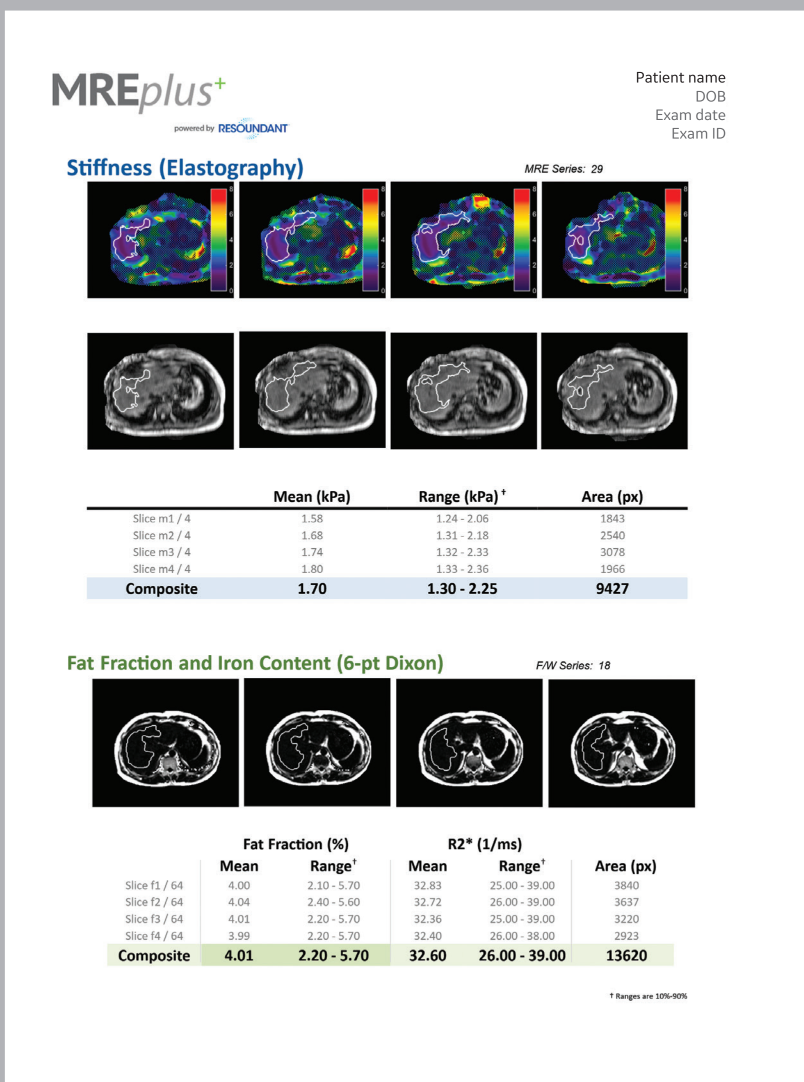


Figure 2. MR Touch helps the clinician identify variations in liver tissue stiffness. (A, B) Fibrosis 0 (F0); (C, D) F1; (E, F) F2; (G, H) F3; and (I, J) F4.



	Mean (kPa)	Range (kPa)†	Area (px)
Slice m1 / 4	1.58	1.24 - 2.06	1843
Slice m2 / 4	1.68	1.31 - 2.18	2540
Slice m3 / 4	1.74	1.32 - 2.33	3078
Slice m4 / 4	1.80	1.33 - 2.36	1966
Composite	**1.70**	**1.30 - 2.25**	**9427**

	Fat Fraction (%)		R2* (1/ms)		
	Mean	Range†	Mean	Range†	Area (px)
Slice f1 / 64	4.00	2.10 - 5.70	32.83	25.00 - 39.00	3840
Slice f2 / 64	4.04	2.40 - 5.60	32.72	26.00 - 39.00	3637
Slice f3 / 64	4.01	2.20 - 5.70	32.36	25.00 - 39.00	3220
Slice f4 / 64	3.99	2.20 - 5.70	32.40	26.00 - 38.00	2923
Composite	**4.01**	**2.20 - 5.70**	**32.60**	**26.00 - 39.00**	**13620**

† Ranges are 10%-90%

Figure 3. MRE*plus*+ provides an intuitive summary of the automated analysis with images showing ROIs and tabulated values for any combination of liver stiffness, proton density fat fraction and R2* data.

A new paradigm for MR

While the challenges presented by NAFLD and NASH are enormous, the addition of a rapid, low-cost MR exam is an example of how it is possible to democratize one of medicine's most powerful technologies — making it more accessible to the millions at risk for these conditions and transforming the way that clinicians and health systems approach the global problem of liver disease. S

Disclosure: Dr. Ehman serves as President and CEO of Resoundant, Inc. The Mayo Clinic and Dr. Ehman have intellectual property rights and a financial interest in MRE technology.

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Fast MR prostate protocol in less than 15 minutes

By Nicola Schieda, MD, FRCPC, Associate Professor of Radiology and Director of Abdominal and Pelvic MRI and Prostate Imaging, The Ottawa Hospital, Ottawa, Canada

The introduction of the Prostate Imaging Reporting and Data System (PI-RADS®) for prostate MR in 2012 has led to more standardized acquisition, interpretation and reporting of prostate MR. The revised PI-RADS® Version 2 and Version 2.1 have improved upon the original PI-RADS® and, based on multiparametric (mp) MR imaging findings, enable assessment of the level of suspicion that an MR abnormality represents a clinically significant cancer.[1]

After starting our MR prostate program in 2012 where we performed approximately 85 studies per year, our volume has grown exponentially to over 2,000 exams per year. Our initial protocol was approximately 40 minutes and was abbreviated to our main protocol which was approximately 30 minutes and included: localizers, coronal T2-weighted SSFSE, three planes of T2-weighted FRFSE, axial T1-weighted in-plane (IP) and out-of-plane (OP), conventional DWI including acquired high b-value (NEX 10), DCE (5 minutes) and large field-of-view (FOV) T1-weighted LAVA Flex post-contrast sequences.

Discovery™ MR750w

PARAMETERS	Coronal T2w	Axial T2w	MAGiC DWI	DCE
TR (ms):	7100	5200	3000	min
TE (ms):	128	128	74	min
FOV (cm):	20	20	22	35
Slice thickness (mm):	3	3	4	2
Frequency:	320	320	80	128
Phase:	256	256	128	128
NEX:	2	2	1, 2, 4	1
Scan time (min):	2:20	2:20	2:12	0:09 / phase
Options/other (b-value, no-phase wrap, etc.)	N/A	N/A	b-values: 0, 500, 1000	
BW (kHz):	41	41	250	62
ETL:	20	20	N/A	N/A

In autumn of 2018, we switched to a pseudo-fast protocol using conventional DWI by eliminating sequences (namely multiplanar T2-weighted FRFSE and elimination of large FOV imaging). This reduced scan time to under 20 minutes.

To further improve scan times, in March 2019 we introduced MAGiC DWI, which included calculated (rather than acquired) high b-value DWI. For approximately one month, patients were evaluated with both conventional and synthetic DWI, and our observations were similar image quality and artifacts on ADC map images, but with improved contrast on the synthetic high b-value DWI compared to the conventional acquisition with tumor-to-background contrast improvements.

In April 2019, we fully converted patients who were undergoing prostate MR for pre-biopsy assessment, active surveillance or with previous negative biopsy but persistent concern for possible cancer to a fast mpMR protocol using MAGiC DWI. We have performed over 250 fast mpMR exams so far.

The fast MR reduced scan time from the conventional sequence by more than half. We can scan patients door-to-door in under 15 minutes. We book four patients per hour. The doubling

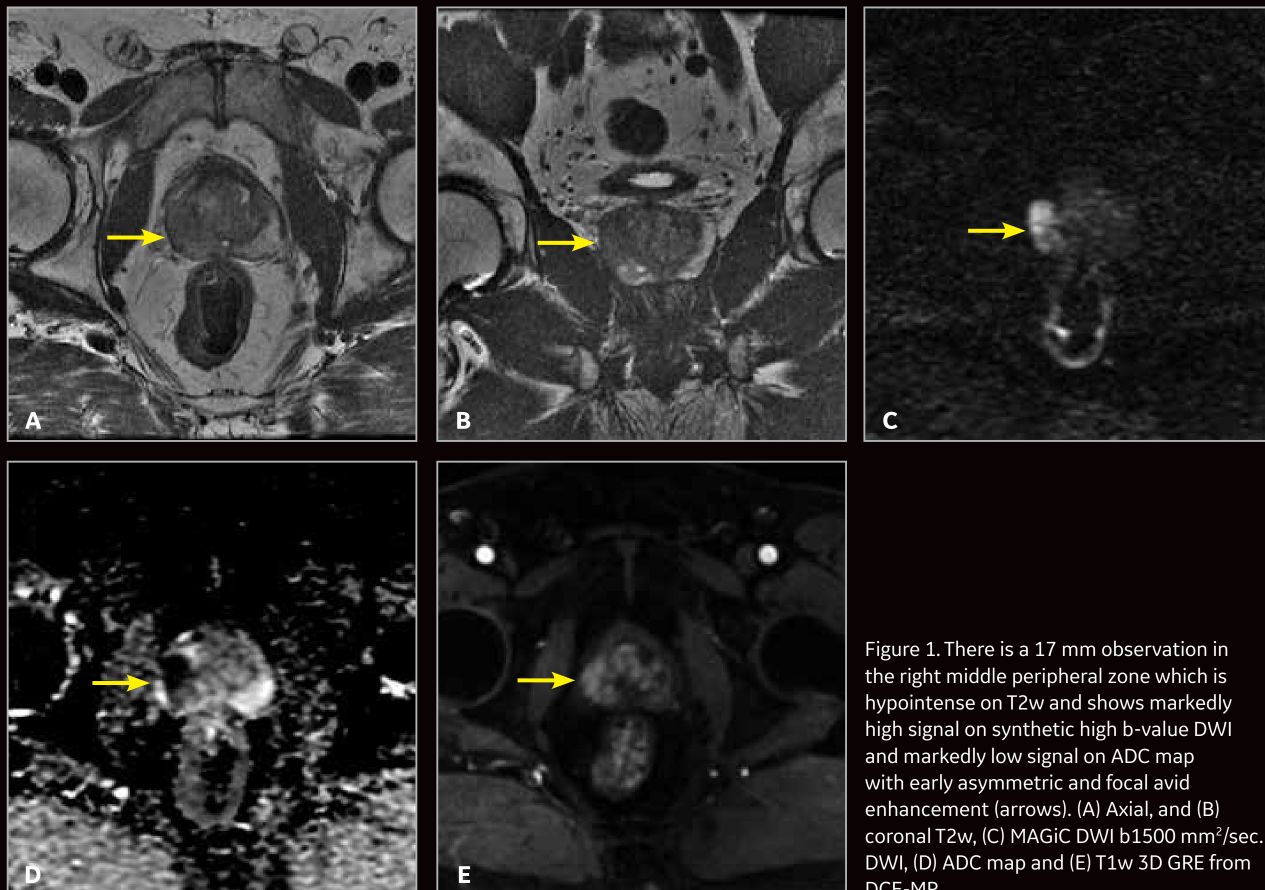

Figure 1. There is a 17 mm observation in the right middle peripheral zone which is hypointense on T2w and shows markedly high signal on synthetic high b-value DWI and markedly low signal on ADC map with early asymmetric and focal avid enhancement (arrows). (A) Axial, and (B) coronal T2w, (C) MAGiC DWI b1500 mm^2/sec. DWI, (D) ADC map and (E) T1w 3D GRE from DCE-MR.

of efficiency enabled us to manage precious resource allocation, which is limited in Canada, and provide access for increased utilization of prostate MR (volume doubled from 2016 to 2019) without an increase in operational hours or blocking access to MR for other patients.

Further reductions in scan time could be achieved if using an abbreviated biparametric (bp) MR rather than an mpMR exam. The main difference between bpMR and mpMR is the use of gadolinium-based contrast agents (GBCA) and dynamic contrast-enhanced (DCE) imaging in the later protocol.

The use of GBCA for DCE in prostate MR is a controversial topic due to concerns of gadolinium retention, higher associated costs and longer scan times. In general, there has been increased scrutiny regarding the liberal use of GBCA for many MR exams, leading to interest in bpMR.

A meta-analysis of 33 studies found that the pooled specificity between mpMR and bpMR were not significantly different.[2] However, bpMR had a statistically significant lower sensitivity (80 percent compared to 85 percent) that the authors suggest may be attributed to the ability to detect subtle lesions with DCE-MR, even though DCE has a limited role in the diagnosis of prostate cancer.[2]

A recent study comparing mpMR, bpMR and a "fast" (monoplanar) bpMR in 626 biopsy-naïve men reported the same sensitivity (95 percent) for all protocols and a specificity of 65 percent for the "fast" bpMR and 69 percent for both the bpMR and mpMR.[3] Inter-reader agreement was 90 percent for the fast bpMR and 93 percent for the bpMR.[3] The authors reported that both bpMR protocols had an equal detection rate of high-grade prostate cancer equivalent to mpMR, and the "fast" bpMR had a high negative predictive value of 97 percent. However, there are added benefits of the "fast" bpMR, such as the ability to increase prostate MR capacity at a lower cost and the avoidance of potential risks associated with GBCA administration.[3]

We presently do not perform bpMR at our institution and all patients undergo a comprehensive mpMR exam that is fully compliant with PI-RADS® v2.1 guidelines, including two planes of T2-weighted imaging, axial DWI and axial DCE. In our own experience, we estimate DCE is required in the following situations: approximately 10 percent of cases where DWI may be compromised by artifact (e.g., from rectal gas, hip prosthesis); in PI-RADS® v2.1 assessment category 3 lesions in the peripheral zone; and in patients who have undergone therapy (e.g., radical prostatectomy, radiotherapy) and there is concern for local recurrence. We are actively considering the use of bpMR with the strategy of calling patients back when DCE-MR is required; however, we continue to perform mpMR in all patients. For patients referred for local staging of a known significant prostate cancer, we perform a comprehensive staging mpMR, which is acquired in under 30 minutes but includes all three planes of T2-weighted imaging and large FOV sequences of the whole pelvis to assess for lymphadenopathy and the pelvic marrow.

Patient history

A 64-year-old male with Prostate Serum Antigen (PSA) 12.3 ng/mL undergoing fast prostate MR for targeting pre-biopsy.

Results

A low T2-weighted lesion in the peripheral zone with marked restricted diffusion and avid early asymmetric enhancement was noted. The observation was characterized as a PI-RADS® v2.1 category 5 (clinically significant cancer is very likely to be present). Subsequent transrectal ultrasound-MR fusion biopsy confirmed Gleason 4+3=7 prostate cancer.

Technique

Our first attempt at fast MR included one plane of T2-weighted imaging (the axial plane). Our experience, which is in line with PI-RADS® v2.1 recommendations, is that a proportion of transition zone nodules may appear partially or incompletely circumscribed, partially or incompletely encapsulated, or show blurred or indistinct margins due to volume averaging effects when using only axial T2-weighted images. PI-RADS® v2.1 suggests at least one additional plane of T2-weighted imaging in addition to the axial plane, and we have found that this strategy improves our characterization of transition zone nodules. The use of a T2-weighted 3D sequence (i.e., Cube) is another strategy and, when used with a novel time saving technique that combines parallel imaging and compressed sensing (i.e., HyperSense), could be a real alternative to a conventional T2-weighted 2D sequence with expected marked reduction in scan time and artifact.

Discussion

In our experience using the fast mpMR technique, we found no difference in the detection of cancers overall but subjectively improved contrast-to-noise on synthetic high b-value DWI, improving reader confidence for detection of prostate cancers. There was also no change in biopsy rates or accuracy; however, we did experience improved reader confidence when evaluating potential tumor to background on the synthetic high b-value images.

More importantly, we doubled our capacity to accommodate a significant increase in requests for prostate MR with no change in operational hours or funding, or an increase in wait times. Patients are very satisfied with the shorter exams.

The accuracy of the fast mpMR protocol is not better than the standard mpMR protocol; however, it is not inferior in terms of cancer detection rates, and that is important. Based on the results from the PRECISION trial[4], we could infer that in the 30 percent of men who have a negative mpMR and are undergoing imaging for elevated PSA or abnormal DRE, biopsy could be avoided in the future if further validation of this practice becomes available, thus saving costs and potential morbidity for the patient.

At The Ottawa Hospital, we are evaluating switching to a bpMR protocol for most patients and recalling the subset of patients who require DCE-MR if we believe that may help to improve the exam quality (e.g., artifact compromising DWI, PI-RADS® 3 peripheral zone observation). More vigilant protocolling of cases, i.e., identifying patients with metallic implants in the pelvis and those with suspected local recurrence of tumor after therapy, would further delineate which patients would require GBCA at the time of their first exam.

Based on our experience in prostate MR, we are considering implementing MAGiC DWI into all of our pelvic MR protocols, especially those for rectal and cervical cancer assessment.

Other institutions that evaluate synthetic DWI sequences such as MAGiC DWI may also discover what I have found: more is not better. Patient tolerance for MR exams decreases over time and the shorter the exam, the better success in reducing patient-induced motion artifacts. The results from our adoption of the synthetic DWI, combined with our own reductions in sequences, incorporate engineering advances with practical experience to improve exam quality, shorten exam times, increase patient tolerance and enhance access/capacity while maintaining diagnostic accuracy. S

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Non-contrast prostate and vascular imaging

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Concerns regarding the use of gadolinium-based contrast agents in MR imaging, particularly in patients with renal or kidney disease, have led to an increase in the use of non-contrast MR sequences in Japan. There is also growing awareness that many procedures involving needles such as biopsy and sedation can have potentially dangerous side effects to patients, add additional costs to procedures and extend patient recovery times. At The Second Kawasaki Saiwai Clinic, we have embraced the use of GE Healthcare's Needle-Free Suite of sequences for many common MR imaging exams. We believe that avoiding the use of contrast can improve patient comfort, simplify workflow and reduce cost.

Although contrast-enhanced MR has been the current standard for non-invasive detection of prostate tumors, several studies suggest that non-contrast biparametric MR with T2-weighted and diffusion-weighted imaging (DWI) may be sufficient for diagnosis and also satisfy the requirements of PI-RADS® v2.1.[1] For non-contrast prostate exams at The Second Kawasaki Saiwai Clinic (Kanagawa, Japan), the use of PROPELLER and DWI are important for the detection of cancerous tumors (see Cases 1-3).

PROPELLER reduces effects of patient voluntary and physiologic motion without sedation, and reduces susceptibility artifacts. Since The Second Kawasaki Saiwai Clinic uses PROPELLER MB to minimize motion artifacts they do not need to use glucagon or a paralytic drug to suppress bowel motion. DWI provides high SNR diffusion images with short acquisition times and multiple b-values to provide measurement of apparent diffusion coefficient (ADC) map with reduced effect of perfusion.

In addition to prostate imaging, we also find that non-contrast MR is very useful for the follow-up of stent grafts to detect endoleak (see Case 4). Historically, CT imaging is used to follow-up patients after performing a stent graft treatment. However, because stent grafts are composed of artificial blood vessels (grafts) and metal frameworks (stainless steel, nitinol), the quality of the CT exam is often affected by metal artifacts. MR imaging is typically less impacted by metal artifacts and is therefore often utilized for these cases.

Case 1

Patient history

A 79-year-old patient referred for MR exam for suspected prostate cancer.

MR findings

PI-RADS® score 4 with a lesion slightly smaller than 7 mm in the transition zone detected on DWI with ADC map.

SIGNA™ Creator — Cases 1-3

PARAMETERS

	Axial T2w PROPELLER	*Sagittal T2w PROPELLER*	*Axial T1w PROPELLER*	*Coronal T1w PROPELLER*	*Coronal T2w FatSat PROPELLER*	*Coronal STIR PROPELLER*	*DWI*
TR (ms):	4440	4000	400	600	4500	3500	5000
TE (ms):	120	120	15.4	15	129	81.5	86
FOV (cm):	20 x 20	22 x 22	20 x 20	24 x 24	24 x 24	24 x 24	35 x 28
Slice thickness (mm):	4	5	4	5	5	5	4
Frequency:	352	352	288	288	352	192	96
Phase:	352	352	288	288	352	192	128
NEX:	3	3	2.5	2.5	3	5	16
Scan time (min.):	3:38	3:16	2:58	2:09	3:25	3:44	4:10
b-value:							b1400

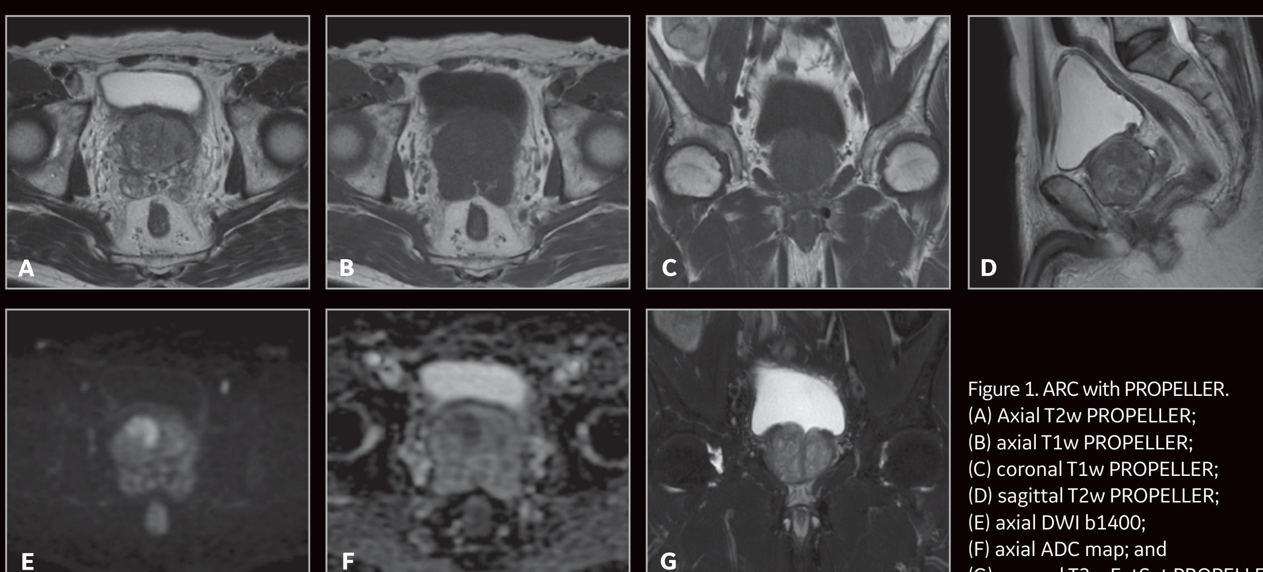

Figure 1. ARC with PROPELLER.
(A) Axial T2w PROPELLER;
(B) axial T1w PROPELLER;
(C) coronal T1w PROPELLER;
(D) sagittal T2w PROPELLER;
(E) axial DWI b1400;
(F) axial ADC map; and
(G) coronal T2w FatSat PROPELLER.

Case 2

Patient history

A 77-year-old man with persistent, high PSA and history of benign prostatic hyperplasia. Patient previously underwent surgery on his left femoral head and has an artificial joint.

MR findings

Prostate cancer, enlargement of prostatic intraepithelial neoplasia.

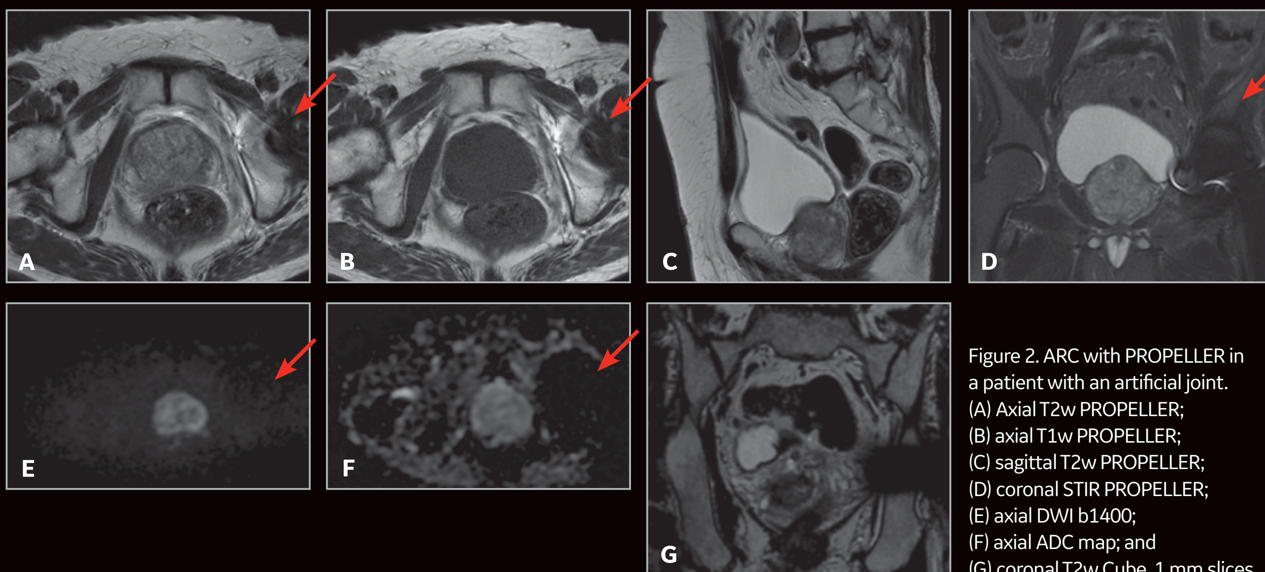

Figure 2. ARC with PROPELLER in a patient with an artificial joint. (A) Axial T2w PROPELLER; (B) axial T1w PROPELLER; (C) sagittal T2w PROPELLER; (D) coronal STIR PROPELLER; (E) axial DWI b1400; (F) axial ADC map; and (G) coronal T2w Cube, 1 mm slices.

Case 3

Patient history

A 71-year-old man with persistent, high PSA and history of benign prostatic hyperplasia.

MR findings

Prostate cancer with PI-RADS® score 4.

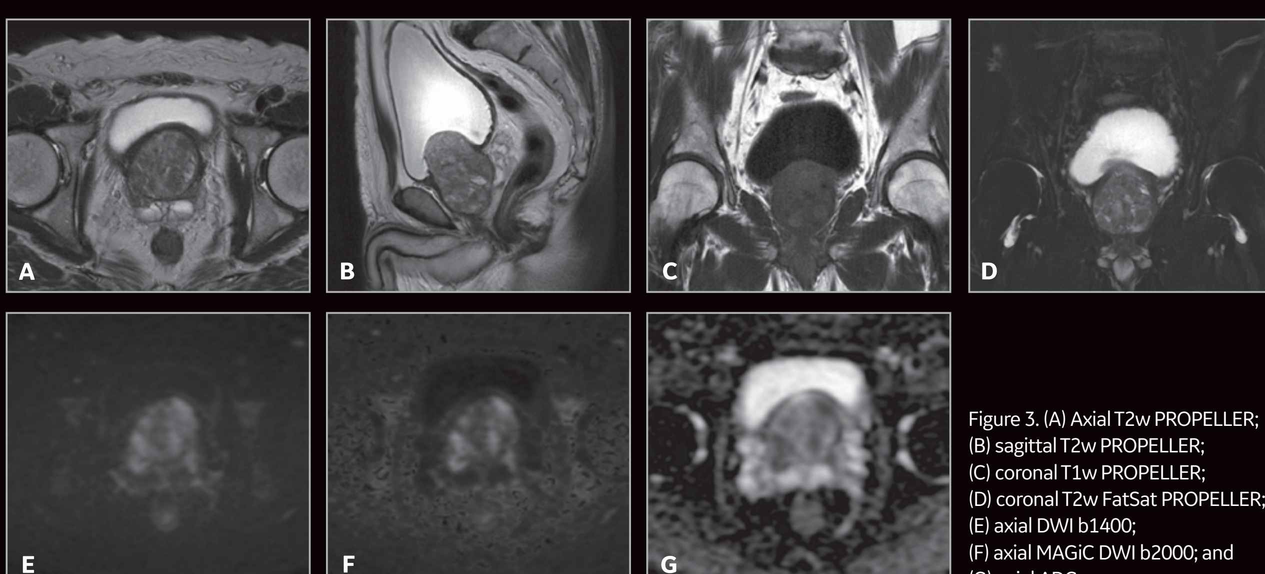

Figure 3. (A) Axial T2w PROPELLER; (B) sagittal T2w PROPELLER; (C) coronal T1w PROPELLER; (D) coronal T2w FatSat PROPELLER; (E) axial DWI b1400; (F) axial MAGiC DWI b2000; and (G) axial ADC map.

Case 4

Patient history

A 84-year-old man referred for MR exam for follow-up one month after an endovascular aneurysm repair. Metal artifacts obscured the anatomy on CT, necessitating the use of MR for suspected endoleak.

MR findings

Type III leak from stent graft in leg detected using non-contrast-enhanced blood vessel imaging. S

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SIGNA™ Creator — Case 4

PARAMETERS

	Coronal 2D FIESTA FatSat	*Axial 2D FIESTA FatSat*	*Coronal 2D FIESTA Cine*	*Axial 2D FIESTA Cine*
TR (ms):	4.8	4.4	3.97	3.97
TE (ms):	2.2	2	1.77	1.77
FOV (cm):	38 x 38	38 x 38	38 x 38	38 x 38
Slice thickness (mm):	6	6	8	8
Frequency:	316	256	224	224
Phase:	320	256	256	256
NEX:	1	1	1	1
Scan time (min.):	15 sec.	16 sec.	2:12	5:44

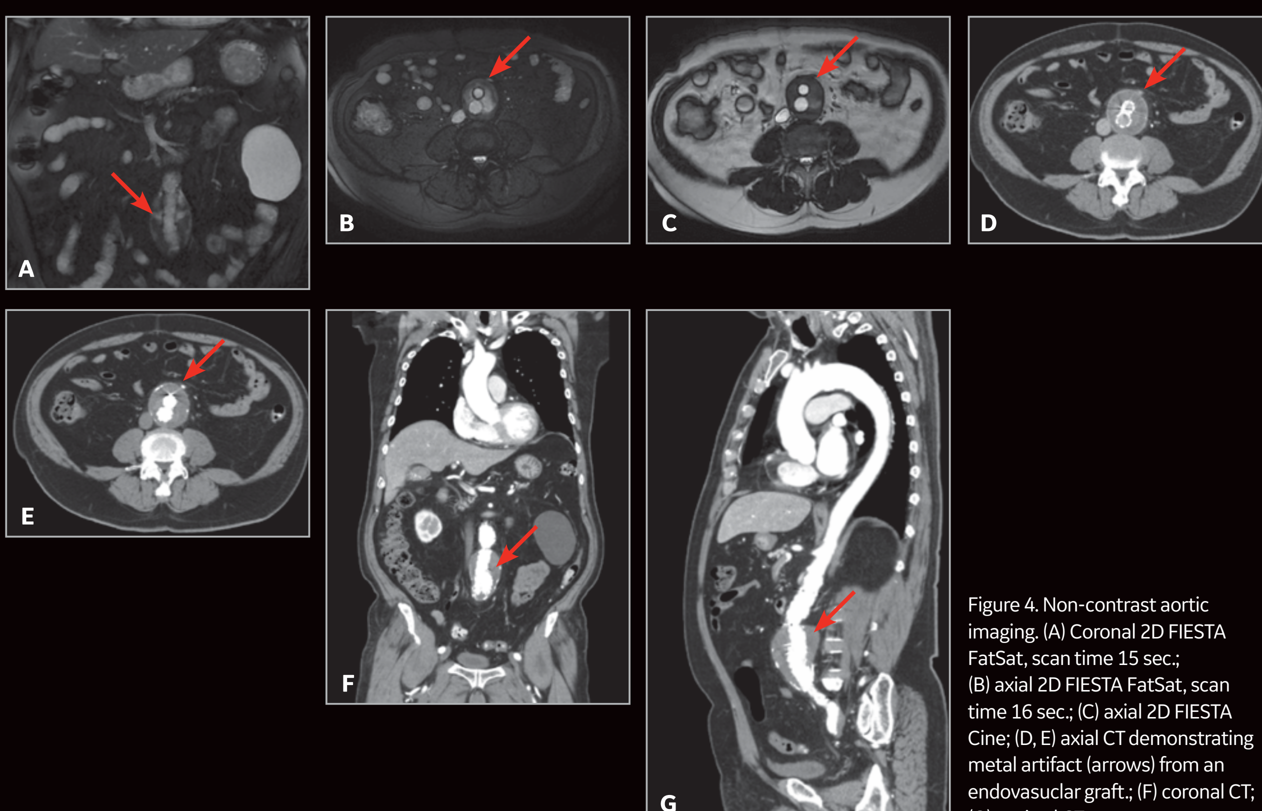

Figure 4. Non-contrast aortic imaging. (A) Coronal 2D FIESTA FatSat, scan time 15 sec.; (B) axial 2D FIESTA FatSat, scan time 16 sec.; (C) axial 2D FIESTA Cine; (D, E) axial CT demonstrating metal artifact (arrows) from an endovasuclar graft.; (F) coronal CT; (G) sagittal CT.

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Whole-body imaging for oncology patients

By Costy Kheir, MD, Head of the Medical Imaging Department, Haykel Hospital, Tripoli, Lebanon

SIGNA™ Voyager

PARAMETERS

	Coronal LAVA Flex	*Coronal T2 SSFSE FatSat*	*Axial DWI*
TR (ms):	6.5	1500	6064
TE (ms):	Min. full/4.3	110	68.6
FOV (cm):	50	50	48
Slice thickness (mm):	5	5	6
Frequency:	320	288	80
Phase:	256	256	80
NEX:	1	1	
Scan time (min):	0:53	1:13	3:14
b-value:			b50 NEX 1 b900 NEX 4
Options/other:	4 stations	4 stations	6 stations
Total scan time (min):	4	5	28 min. without MAGiC DWI 20 min. with MAGiC DWI (22% scan time reduction)

Whole-body MR imaging has been utilized in clinical practice for over a decade. However, recent improvements in system hardware and sequences, particularly diffusion-weighted imaging (DWI), have increased image quality and reduced acquisition time. Several recently published studies demonstrated the high sensitivity and specificity of this technique that surpasses those of bone scintigraphy and rivals those of PET/CT and PET/MR for cancer detection, staging and treatment monitoring.[1-4] Whole-body MR is also being used for the diagnosis and evaluation of systemic and inflammatory diseases.[5,6] Some centers venture to use it as a screening tool for healthy patients. Furthermore, it is an important tool for cancer detection and monitoring in children and pregnant women.

In Lebanon, access to PET/CT is limited and it is often not reimbursed by third-party payers. In fact, our country continues to suffer from an economic crisis that has impacted national health policy and left many patients without proper medical coverage. As the incidence of all types of cancer continues to increase in our country, whole-body MR is emerging as an alternative exam for diagnosing these patients at less cost than PET.

To provide more rigorous diagnostic and treatment pathways for our patients, we installed SIGNA™ Voyager in May 2018.

Whole-body MR provides non-ionizing radiation and non-contrast exams. In the case of oncology patients, it can be repeated often to monitor treatment response without the added concern for a patient's total exposure to ionizing radiation. MR can scan the entire body for physical abnormalities, depict tumors in early formative stages and deliver an overall snapshot of a patient's general health.

A whole-body MR exam typically consists of the following core sequences: T1-weighted, T2-weighted STIR, T2 Single Shot Fast Spin Echo (SSFSE), FatSat and DWI. Combined, these sequences allow the radiologist to thoroughly assess the anatomy, body composition and functional information of the whole body.

There are certain considerations to address when implementing whole-body MR. The protocol must be robust and accurate to deliver the information the radiologist needs for interpretation. It should also be as fast as possible to ease the patient's experience.

Scan orientation is typically in the coronal plane. The radiologist will need to adapt to viewing the anatomy in this plane if no multi-planar reconstruction is available. Patient motion and magnetic field distortions, such as susceptibility effects, are common issues impacting image quality and resolution. Also, exam times can take up to 60 minutes, which can be difficult for the patient even when using a wide bore magnet.

To overcome these burdens, we worked with GE Healthcare clinical applications specialists to implement our whole-body MR protocols and achieve gains in spatial and temporal resolution. We opted to use T1 LAVA Flex, which provides excellent reliability for fat/water separation to enable the assessment of body composition. Instead of T2 STIR we selected T2 SSFSE FatSat, which provides shorter acquisition times compared to FSE and better resolution with excellent FatSat homogeneity. We were able to acquire a slice thickness of 5 mm with consecutive cuts, preserving a high SNR.

In July 2019 we upgraded our SIGNA™ Voyager to expand the SIGNA™Works productivity platform, including HyperWorks. The upgrade provides value-added technologies that are flexible and customizable to meet our imaging needs and workload.

While we have integrated HyperSense and HyperCube in many of our daily protocols, we found that MAGiC DWI had the most significant impact in whole-body MR exams. With MAGiC DWI, we can shorten acquisition times by using two b-values with low NEX values and then synthesize the higher b-value images. Previously, conventional whole-body DWI exams would take 60 minutes; now, by incorporating MAGiC DWI instead of the conventional DWI, the total exam time is down to 45 minutes, on average. The results of calculating multiple b-values from a single MAGiC DWI scan are more than satisfactory.

There is a saying that it takes a village to raise a child. When it comes to healthcare, it takes a community to make a difference in patient care. The GE MR community, through continued innovation and the sharing of best practices, is helping us to deliver higher quality care for our patients.

Case 1

Patient history

A 61-year-old man weighing 90 kg (198 lbs.) was referred to our institution for follow-up of multiple myeloma while undergoing treatment. No prior exams (e.g., PET/CT) were available; comparison was performed with a prior whole-body MR performed at another hospital.

MR findings

Restriction on eDWI sequence receded on the scapular and rib lesions that were described in the prior MR exam and on both parotid glands and thoracic spine. However, there was accentuated diffusion restriction showing multiple lesions of the pelvic girdle and both femurs, proximally. Several active lesions were also noted on the lumbar spine.

These findings are consistent with disease progression, although several lesions in the upper body did respond to treatment. As a result of this whole-body MR exam, the treatment protocol was adjusted accordingly.

Figure 1. (A) Coronal whole-body DWI and (B) sagittal spine STIR.

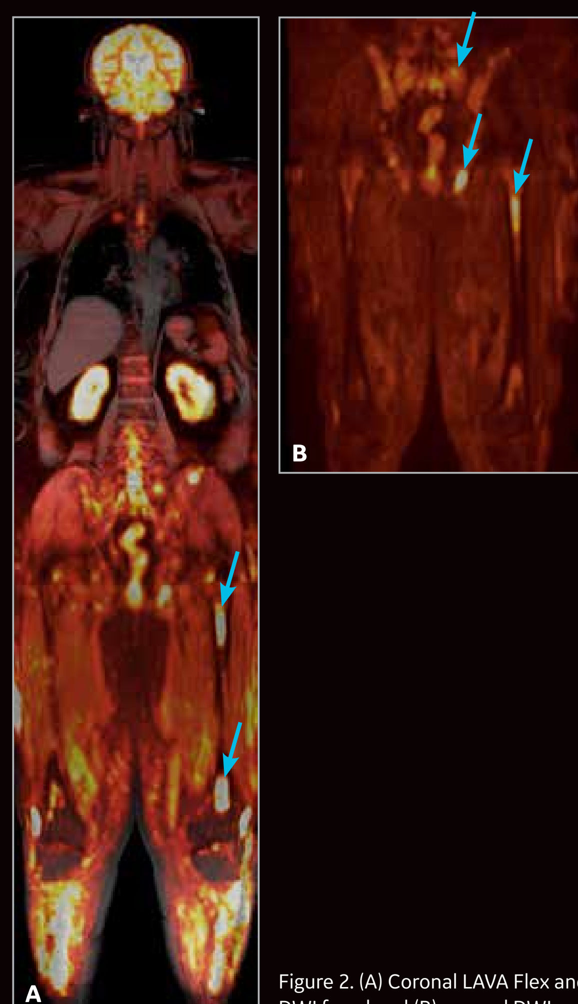

Figure 2. (A) Coronal LAVA Flex and DWI fused and (B) coronal DWI.

Case 2

Patient history

A 60-year-old woman weighing 45 kg (99 lbs.) was referred for a whole-body MR for investigation of a pelvic mass. No other prior history was known.

MR findings

Whole-body DWI depicted a complex pelvic mass measuring approximately 10 cm, most likely of right adnexal origin that could represent a cystadenocarcinoma requiring histological confirmation. There were multiple peritoneal metastatic seedings but also metastases in the lymph nodes, the liver and bones as shown by the whole-body DWI with ADC map confirmation. Abundant ascites were found around the liver and the pelvis. A large left renal simple cyst was also noted.

Most interesting was that the whole-body DWI demonstrated the pelvic lesion and metastases in the same exam. While whole-body MR is not typically recommended for diagnosis of primary lesions, the acquisition depicted the disease and its spread in the abdominal and pelvic cavities. In one exam, MR provided the clinician with a detailed status of visceral and bone spread, removing the need for additional imaging tests such as CT or bone scintigraphy.

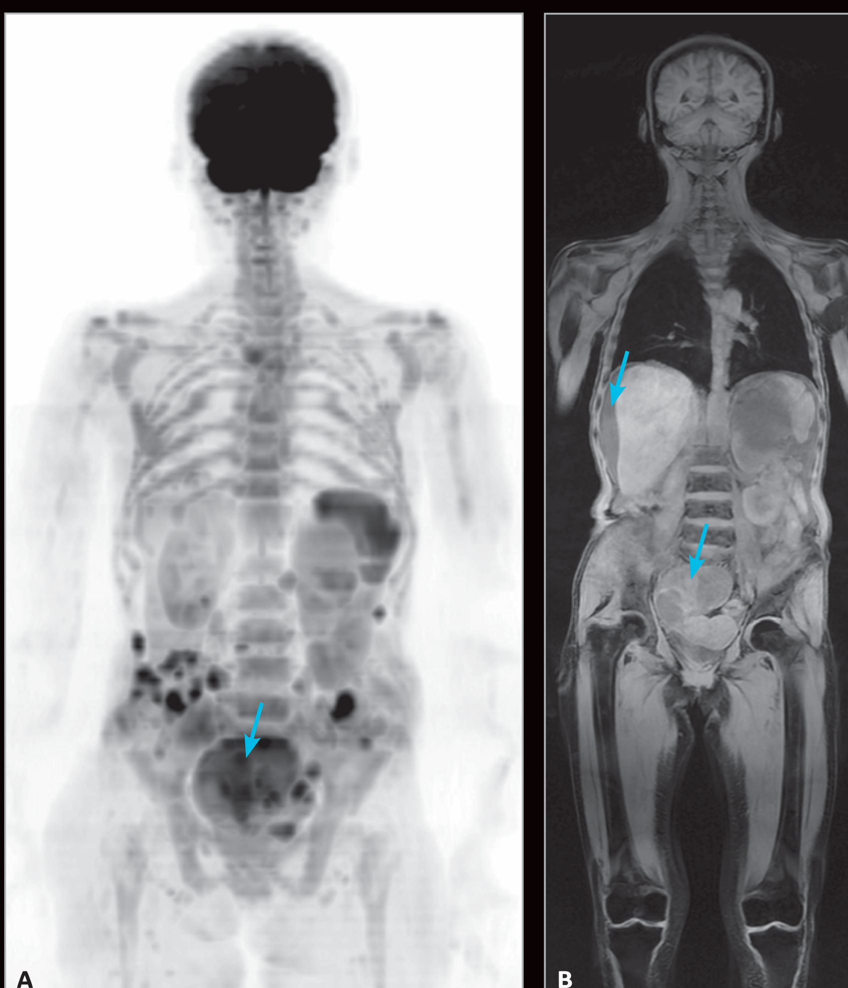

Figure 3. (A) Inverted coronal whole-body DWI and (B) coronal whole-body LAVA Flex.

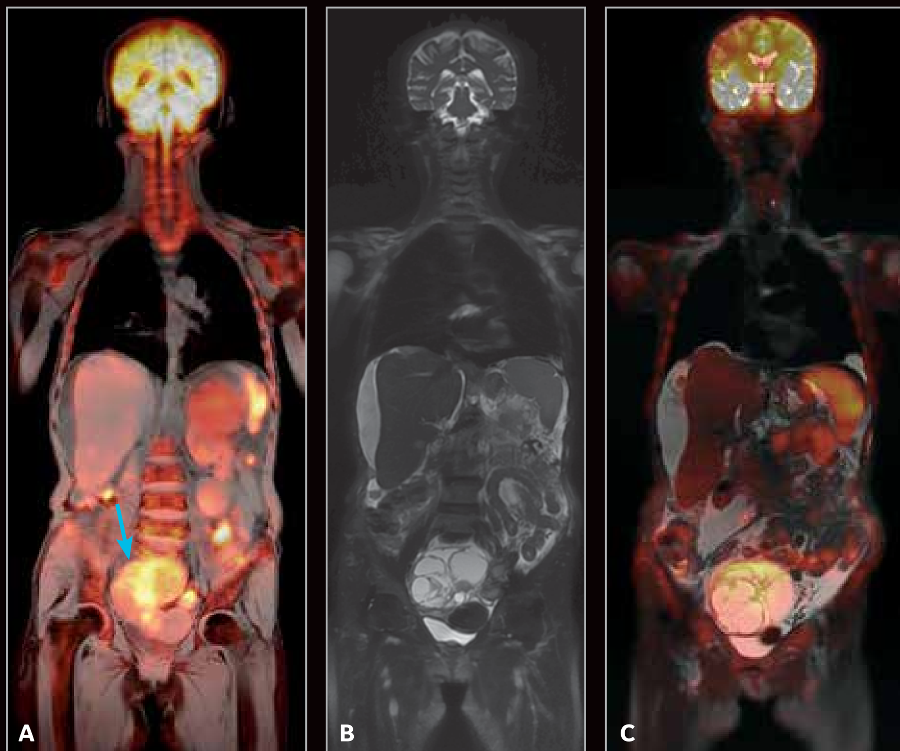

Figure 4. (A) Coronal LAVA Flex and DWI fused; (B) coronal T2 SSFSE FatSat; and (C) coronal T2 SSFSE FatSat and DWI fused.

Figure 5. (A) Coronal T2 SSFSE FatSat and DWI fused and (B) coronal whole-body DWI.

Discussion

The benefit of whole-body MR being accessible and repeatable with no radiation, contrast media or other side effects will affect and reshape treatment processes in oncology imaging. We anticipate this will impact patient response and outcomes, as well as enable lower costs in our healthcare system by alleviating the need for additional tests and shortening treatment duration.

The approach of combining multiple sequences in the whole-body MR protocol provides the information the radiologist needs to be more confident about the anatomy, inflammatory changes and pathological correlation with the diffusion restriction. Interestingly, fusing the eDWI and the T1 LAVA Flex images delivers a similar appearance as PET/MR images, with the difference being the absence of nucleic secretion in the kidneys and bladder, which prohibits the detection of lesions in these areas. Normal diffusion restriction of the spleen was not an issue for depicting a lesion.

SIGNA™ Voyager has great potential to deliver diagnostic images with high SNR while allowing us to maintain shortened exam times for the whole-body protocol. New emerging protocols that deliver shorter acquisition times and better resolution, as well as new higher channel arrays, such as the AIR™ Coils, will further boost these qualities and help promote whole-body MR for oncology imaging. S

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A 10-minute comprehensive cardiac MR exam with flow quantification

By Rashid Al Umairi, MD, FRCR, FSCMR, cardiothoracic radiology consultant, The Royal Hospital, Muscat, Oman

SIGNA™ Artist

PARAMETERS		
	4D Flow	*FIESTA Cine*
TR (ms):	4.7	3.8
TE (ms):	2.14	Min Full
FOV (cm):	36	38
Slice thickness (mm):	2.2	8
Frequency:	170	200
Phase:	170	192
NEX:	4	1
Scan time (min):	7:25	0:09
Options/other (b value, no-phase wrap, etc.):	ZIP2	

Aortic valve regurgitation, also known as aortic valve insufficiency or aortic valve incompetence, is a valvopathy that describes leaking of the aortic valve during diastole that causes blood to flow in the reverse direction from the aorta and into the left ventricle. Patients with valvular conditions are referred to MR following an inconclusive Doppler ultrasound exam. While Doppler ultrasound is the current gold standard, it cannot always provide a precise answer on whether the patient should undergo surgery in cases with a poor acoustic window.

A cardiac MR (CMR) exam is comprised of various sequences that can provide a detailed assessment of the aortic valve and left ventricular function. It is a highly accurate method to determine the size of the aortic root, assess regurgitant parameters, determine ejection fraction, measure left ventricular size and detect underlying etiologies. However, acquiring quality cardiac sequences to quantify cardiac function and flow has historically been a complex and time-consuming exam to perform, requiring technologist expertise and physician supervision with little room for error when capturing constantly moving anatomy. Conventional CMR techniques like 2D phase contrast require multiple slice acquisitions that are perpendicular to the flow of the blood. For some pathologies, this would require the patient to hold their breath — in many cases greater than 20 times in an exam. Considering that patients who typically receive a CMR exam often have heart disease, it can be difficult for them to repeatedly hold their breath and, therefore, exams may suffer from sub-optimal or non-diagnostic image quality. Despite the value of CMR, these limitations continue to complicate image acquisition.

New technology could shift this paradigm. Several techniques enabling free-breathing flow acquisitions are under investigation. Real-time CMR is one approach to image acquisition during free-breathing that is analogous to echocardiography, or cardiac ultrasound. Using acceleration

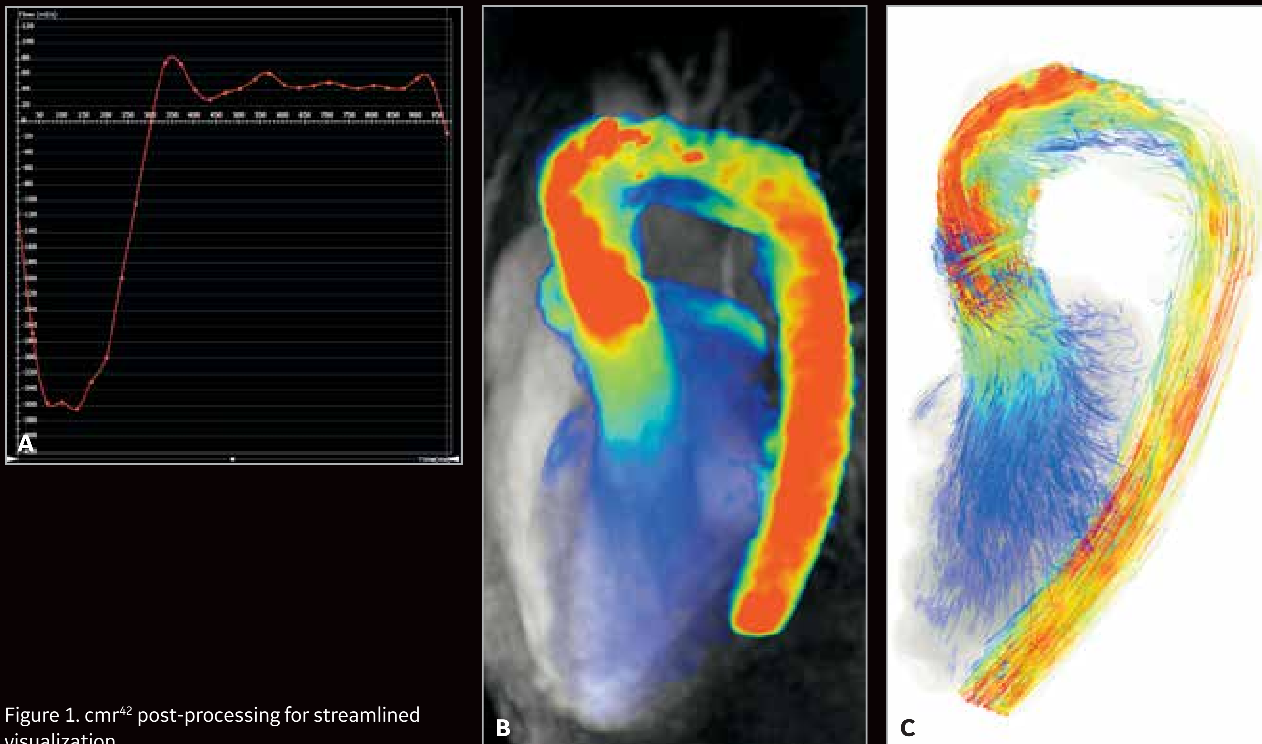

Figure 1. cmr[42] post-processing for streamlined visualization.

techniques, the data is rapidly acquired throughout the breathing cycle and then reconstructed to provide an average heartbeat. Alternatively, 3D CMR data can be acquired during free-breathing over several minutes using respiratory motion compensation, with data then reconstructed retrospectively.

To improve data acquisition in our institution, we have implemented the ViosWorks 4D Flow sequence in standard CMR exams. With this technique, the technologist simply places the imaging volume over the patient's chest and data acquisition is completed with no breath-holds. There is little interaction necessary on the front end and immediate reconstruction of the images in order to review instantly, which is helpful to ensure the proper velocity encoding (VENC) of the vessel before the patient gets off the table. The image can be reformatted to an arbitrary plane and blood flow in the entire volume can be quantified retrospectively in offline processing.

The 4D Flow data can be used to measure blood flow velocity and direction in any part of the cardiovascular system, including flow quantification in the ascending aorta and main pulmonary artery, as well as in patients with congenital heart disease. This approach is particularly attractive because these patients frequently require flow measurements to be made in multiple vessels and at various levels within that vessel. Using traditional 2D CMR sequences, flow in each location is measured from a separate acquisition that needs to be set up precisely from separately acquired localizer images, resulting in prolonged scan times.

With ViosWorks 4D Flow, the volume of data is enough to cover the entire chest. Isotropic images are gated and timed to the breathing cycle to provide high spatial resolution with 2 mm^3 slices, enabling retrospective reformatting in any image orientation.

Patient history

A 24-year-old male with an unremarkable medical history presented with recurring shortness of breath on exertion. On auscultation, the patient was found to have a heart murmur. He was referred for further assessment with echocardiogram, which revealed severe aortic regurgitation with dilated left ventricle and systolic dysfunction. The patient underwent CMR for an accurate measurement of aortic regurgitation and to investigate the cause of left ventricle dilatation.

Technique

The ViosWorks 4D Flow sequence was performed on a 1.5T SIGNA™ Artist and was completed in as little as 10 minutes with the patient free-breathing. This technique provides quantitative cardiac measurements including flow, regurgitant fraction, stroke volume, ventricular volumes and ejection fraction.

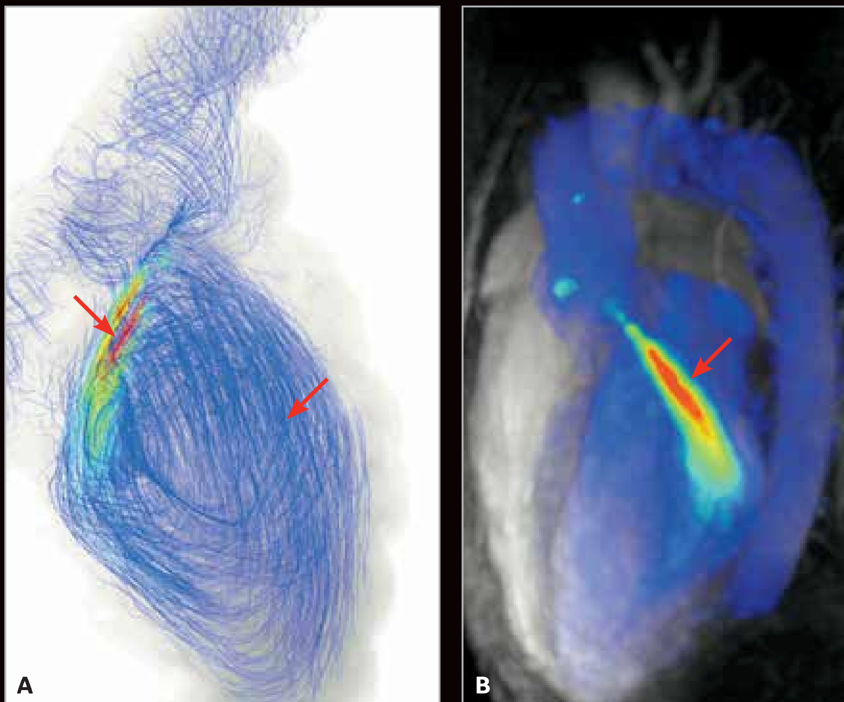

Figure 2. Using cmr[42] it is possible to detect regurgitation flow (arrows).

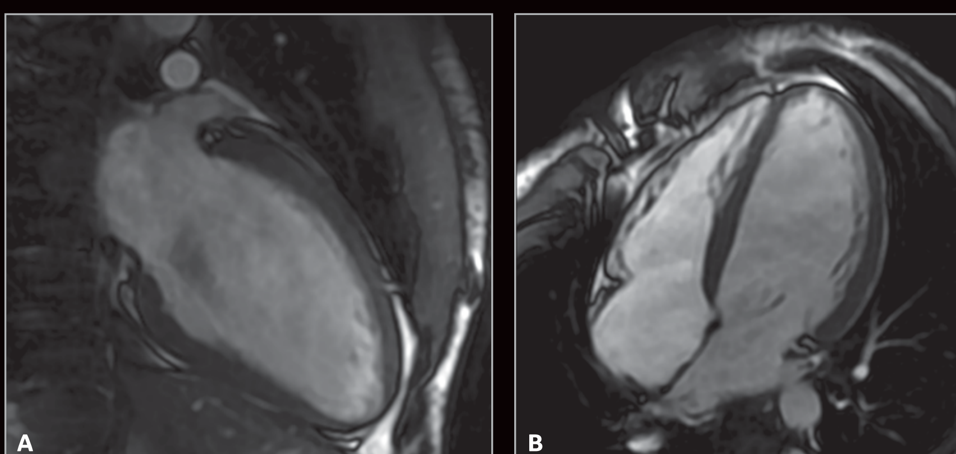

Figure 3. (A) 2-chamber FIESTA Cine and (B) 4-chamber FIESTA Cine.

MR findings

Patient diagnosed with bicuspid aortic valve, a congenital disorder, and vortex, or twisted, flow.

Aortic flow (obtained by analyzing 4D Flow):

- Total forward volume: 93 ml
- Backward volume: 35 ml
- Forward volume: 58 ml
- Regurgitation fracture: 38%

Left ventricle function and volume:

- Ejection fraction: 60%
- LVEDV/BSA: 141 ml/m^2 (dilated)

ViosWorks 4D Flow provided a complete view of anatomy of the heart, including the flow within the four chambers and large vessels. This allowed us to study flow patterns throughout the cardiac cycle and to visualize turbulences and quantify flows such as regurgitations. As a result, we were able to diagnose vortex, or twisted flow, which is a blood flow that has separated from the central streamlines within a vessel and countercurrent to the main flow direction. This condition was only diagnosed by using 4D Flow and was not seen on conventional 2D phase contrast or echocardiography.

Discussion

The 4D Flow technique provides the information needed for basic flow quantification and appears promising for more advanced hemodynamic analysis, including pressure gradients,

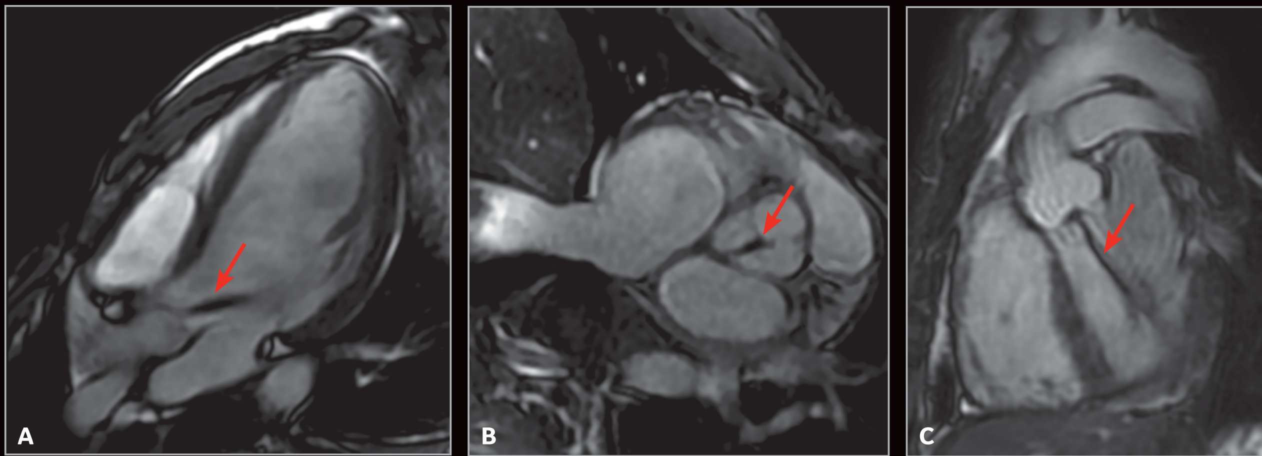

Figure 4. (A) 3-chamber LVOT FIESTA Cine for evaluating function; (B) short axis FIESTA Cine; and (C) sagittal oblique FIESTA Cine perpindicular to the aortic valve demonstrating the flow jet from regurgitation.

Figure 5. (A) 2-chamber, (B) 4-chamber and (C) short axis PS MDE, post-contrast.

wall shear stress, pulse wave velocity and kinetic energy. It delivers high-resolution images depicting volumetric, cardiac-motion-resolved heart anatomy and blood flow with improved exam efficiency and minimal or no breath-holding, addressing many of the challenges facing CMR today. With ViosWorks, for the first time all seven dimensions of information — 3D in space, 1D in time and 3D in velocity — can be captured in a 10-minute or less free-breathing cardiac exam.

ViosWorks 4D Flow has enabled us to accurately measure trans-stenotic pressure gradients non-invasively in aortic coarctation. Previously, this could only be measured invasively in the cardiac catheterization lab.[1] It may also be possible to identify alterations in hemodynamics that can affect the growth of aneurysms or development of atherosclerotic plaque.

As important, 4D Flow has simplified image acquisition and reduced overall exam time in patients with congenital and valvular heart disease. The use of an acceleration technique has played a significant role in reducing scan time by exploiting data correlations in space. Prescription of the image plane is important to obtain a true double oblique image. Otherwise it is possible for the flow data to be incorrect. Further, a key benefit of 4D Flow is that it acquires comprehensive flow data for the entire data set. We can then go back and process the data retrospectively; if a clinical question is raised after the exam, we can go back and perform additional measurements and process additional flow information from the vessel in the field of view without rescanning the patient.

We are also using the Circle cvi^{42} cmr^{42} post-processing software based on deep learning for faster image analysis. What once took hours of computer processing time now can be accomplished in minutes.

Today, ViosWorks 4D Flow is preferred clinically at The Royal Hospital Muscat. 4D Flow is a technology that may change our cardiac imaging practice and we are convinced that this technique will play a more important role in the near future for evaluating patients with cardiac disease. S

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How MUSE is changing diffusion MRI

By Iain P. Bruce, PhD, and Christopher Petty, Duke University, Durham, North Carolina

The acquisition of ultra-high spatial resolution data with sufficient SNR has always been a challenge in DWI. MUSE not only addresses this issue by enabling sub-millimeter isotropic resolutions with high spatial fidelity, it also provides a framework for incorporating additional tools and sampling techniques such as 3D acquisitions, simultaneous multi-slice imaging and reversed polarity gradients. With these capabilities, MUSE opens new avenues for structural, connectivity and tissue microstructure analyses of the brain and spinal cord.

The ability to achieve high-resolution data with high SNR and high spatial fidelity within a reasonably short amount of time has been a longstanding challenge in diffusion weighted MRI (DWI). To preserve SNR, many DWI protocols acquire data with isotropic voxels on the order of 1.5-2 mm, producing data that is limited in its ability to accurately characterize complex microstructures in organs such as the human brain. Signal decay and spatial distortion artifacts have long been limiting factors in achieving high-resolution DWI with single-shot echo planar imaging (EPI), while shot-to-shot motion artifacts have always hampered the potential SNR and spatial resolution benefits of multi-shot EPI (ms-EPI).

With the advent of MUltiplexed Sensitivity Encoding (MUSE), however, the inter-shot motion induced phase inconsistencies in ms-EPI diffusion data can be accurately accounted for. Included as part of GE Healthcare's latest SIGNA™Works software releases, MUSE enables the routine acquisition of DWI data at sub-millimeter spatial resolutions with sufficient SNR to conduct reliable diffusion tensor imaging (DTI) analyses, opening new avenues for investigations of complex tissue microstructures.

At the Duke University Brain Imaging and Analysis Center, MUSE DWI scans have become a standard protocol in multiple studies exploring structural connectivity in patients with Alzheimer's disease, autism, epilepsy, cerebral palsy, traumatic brain injury and post-traumatic stress disorder (PTSD). Through MUSE, many of these studies can now routinely acquire data with isotropic spatial resolutions on the order of 0.8-1.0 mm. In Connectome analyses, whole-brain DWI data at this resolution has proven invaluable for both accurately resolving tightly curved intercortical association fibers as well as the delineation of crossing fiber bundles. Furthermore, sub-millimeter DWI has opened the door for more detailed analyses in gray matter, where streamlined fiber tracts and tissue characteristics can be investigated in multiple voxels across the relatively thin cortical layers (Figure 1).

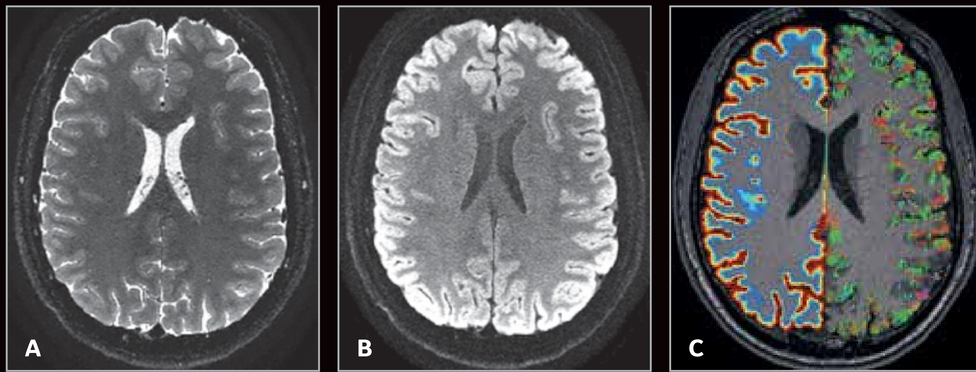

Figure 1. Whole-brain 4-shot MUSE DWI data acquired at a 0.8 mm isotropic spatial resolution with (A) b0 and (B) b800 s/mm^2 (averaged over 18 directions). Imaging with sub-millimeter voxels enables (C) fiber tracking and detailed DTI analysis across multiple cortical layers.

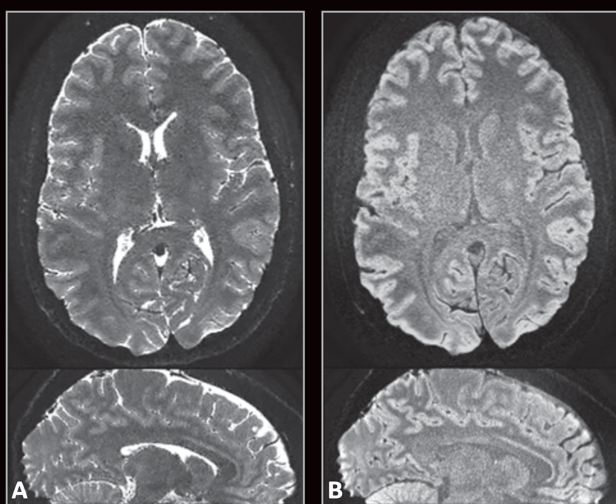

Figure 2. Whole-brain 0.7 mm MUSE DWI data acquired with (A) b0 and (B) b800 s/mm^2 (averaged over 18 directions) in a SIGNA™ Premier 3.0T system with an ultra-high powered 60 cm torque and force balanced gradient coil‡ (peak strength of 115 mT/m) specifically designed for high-resolution DWI.

When coupling MUSE with the ultra-high-powered prototype gradient coil‡ in the SIGNA™ Premier 3.0T system at Duke University, the spatial resolution limits of diffusion data can be pushed even further, with whole brain DWI images acquired with 0.7 mm isotropic voxels (Figure 2). Although highly beneficial in brain imaging, MUSE's ability to account for motion artifacts in sub-millimeter diffusion images is equally significant in body imaging. Figure 3 compares a simple MUSE DWI abdominal scan using 1 mm^3 isotropic voxels to that of 0.6 x 0.6 x 2.0 mm, where the anatomical specificity in both the spinal cord and kidneys is immediately apparent in the sub-millimeter scan.

Beyond the increase in achievable spatial resolutions, one of the most appealing aspects of the MUSE framework is the foundation it provides for incorporating additional imaging tools and techniques. For example, the traditional 2D MUSE model has been expanded to acquire and reconstruct 3D ms-EPI data, where an additional SNR advantage is gained by Fourier encoding thick slabs across the imaging volume to produce images with increased anatomical detail (Figure 4).‡

Although the shortened readout and echo spacing of ms-EPI does reduce distortion artifacts in DWI, a recent adaptation of MUSE (marked by GE as PROGRES) to incorporate reversed polarity gradients (RPG) between shots has shown great promise in eliminating both residual static field inhomogeneities as well as dynamic gradient-induced eddy currents. While traditional RPG distortion corrections require additional imaging volumes with opposing phase encoding directions (PE), RPG-MUSE simply reverses PE in the odd/even shots of a typical ms-EPI scan. This approach requires no additional volumes or increase in scan duration, as it allows for field inhomogeneities to be estimated directly from the ms-EPI data and incorporated into the reconstruction. As shown in Figure 5, the resulting RPG-MUSE images exhibit tremendous anatomical specificity when compared with a traditional correction of data with a single PE.

With its small cross-sectional area, another region that has benefited greatly from the high resolution afforded by MUSE is in the spinal cord. Unlike traditional ms-EPI, where each shot is separated by the duration of a predefined TR, spinal cord imaging often employs cardiac gating (CG) in an effort to mitigate cerebrospinal fluid pulsation artifacts. Although CG both increases and varies the time between shots, MUSE remains fully capable of accounting for intershot motion artifacts. As illustrated in Figure 6, the sub-millimeter spatial resolution and SNR achieved by MUSE facilitates the delineation of complex microstructures in the brain stem, such as the bifurcation of corticospinal tracts and the decussation of medullary pyramids.

‡ Technology in development that represents ongoing research and development efforts. These technologies are not products and may never become products. Not for sale. Not cleared or approved by the U.S. FDA or any other global regulator for commercial availability.

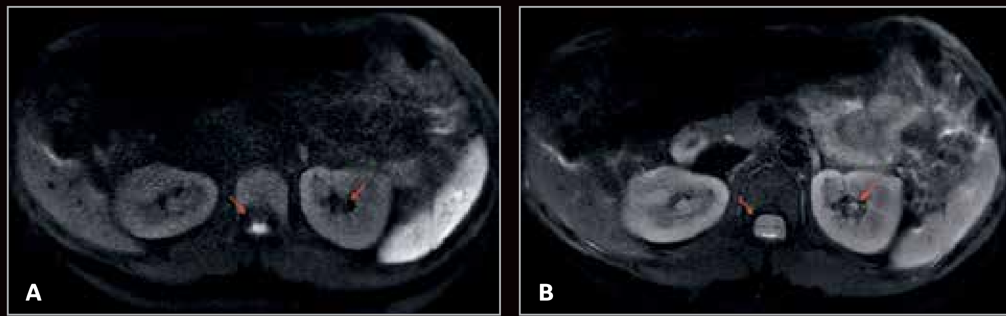

Figure 3. MUSE abdominal scan with (A) 1 mm^3 and (B) 0.6 x 0.6 x 2 mm voxels offer high fidelity images free of motion artifacts.

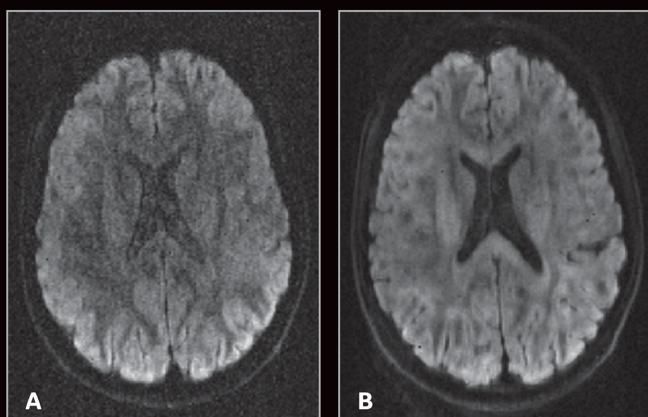

Figure 4. 1 mm^3 MUSE DWI images with b1000 s/mm^2 using (A) 2D and (B) 3D encoding.‡

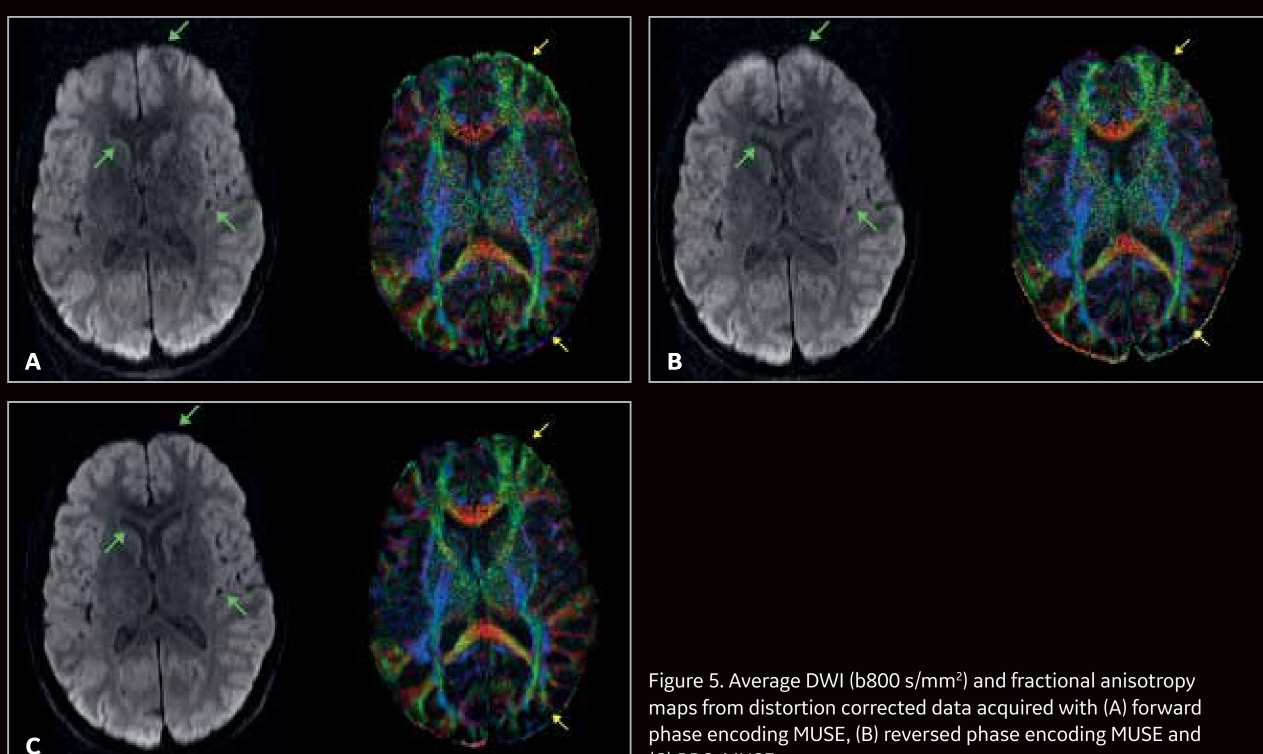

Figure 5. Average DWI (b800 s/mm^2) and fractional anisotropy maps from distortion corrected data acquired with (A) forward phase encoding MUSE, (B) reversed phase encoding MUSE and (C) RPG-MUSE.

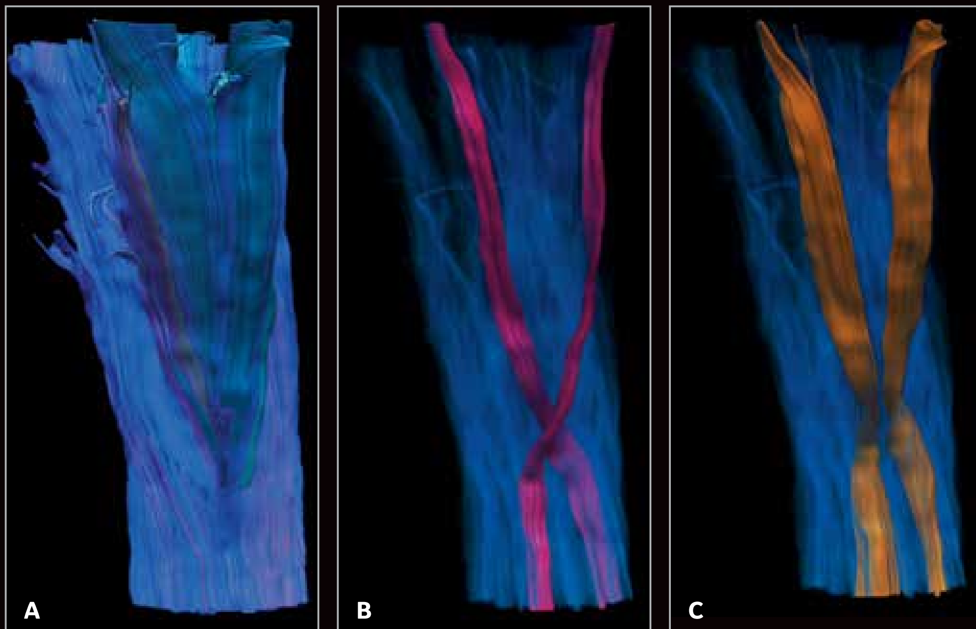

Figure 6. Using MUSE DWI data with a 0.8 mm isotropic spatial resolution, (A) fibers passing through the brain stem can be shown to bifurcate into (B) lateral and (C) anterior corticospinal tracts.

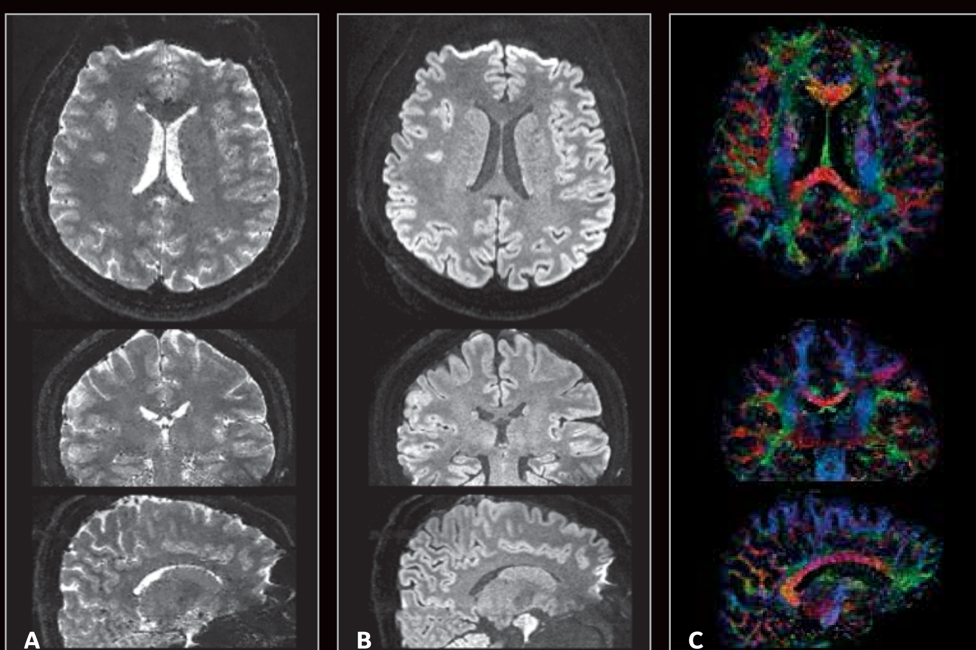

Figure 7. Whole-brain (A) b0 and (B) b800 s/mm^2 (averaged over 18 directions), and (C) fractional anisotropy maps derived from MUSE with HyperBand data acquired with 4 shots and 2 bands at a 1 mm^3 spatial resolution.

Despite its remarkable advantages, the one remaining drawback of ms-EPI is the prolonged acquisition time. To that end, the MUSE framework has since been expanded to incorporate simultaneous multi-slice imaging, or HyperBand. Through HyperBand, a whole brain 1 mm^3 MUSE scan with 4 shots and 25 diffusion volumes can be reduced from approximately 20 minutes to around 7 minutes, while preserving both the increased SNR and spatial fidelity of ms-EPI (Figure 7). Alternatively, MUSE with HyperBand can also be used to extend the coverage achieved within a given scan time. This is of particular use in applications such as spinal cord imaging, as it would enable fiber bundles to be tracked at sub-millimeter isotropic spatial resolutions from their origins within the brain as they extend down into the spinal cord.

Although MUSE has only been available on GE scanners for a short time, its impact in the field of DWI has been great. The increased spatial resolution, fidelity and SNR achieved through MUSE has already broadened the scope of many structural and connectivity studies. As its utility continues to grow with the inclusion of tools such as HyperBand, it will soon become a staple in many DWI protocols.

Optimized RF coil and receive chain architecture that enables the use of higher RF channels

Advancements in academic and clinical research, along with continued innovation by manufacturers, have steadily progressed MR imaging technology. Perhaps no other MR hardware subsystem has advanced as much as the radio frequency (RF) coils and receiver technology. Beginning with the invention of the phased array RF coil technology, MR systems image the anatomy with higher SNR and also cover large volumes with multiple coil elements to deliver excellent image quality[1]. Over the last two decades, a large number of accelerated imaging techniques have delivered improved image quality with decreased scan times. These accelerated imaging techniques provide the current impetus for the design of modern MR scanners capable of 128+ channel imaging. To achieve this level of modern system functionality and performance requires a careful orchestration of both RF coils and the RF receiver system design.

It is not surprising, given the rapid speed of technical development in this area, that there is a fair amount of confusion in the industry. This article discusses some basic definitions and design approaches used in the industry today. GE Healthcare SIGNA™ MR systems provide the ideal combination of receiver system and RF coil technology that results in the highest, industry-leading usable number of MR channels.

Number of RF coil elements connected simultaneously = M

M is the maximum number of coil elements connected simultaneously to the MR system.

In everyday practice in the context of RF coils, people tend to use the terms 'elements' and 'channels' interchangeably. However, there are very important distinctions between these two terms. Failing to recognize the difference, notably when selecting an MR platform, could lead one to select a system that is less capable than assumed.

Number of RF receiver channels = analog-to-digital converters = N

An RF channel has a one-to-one relationship with the number (N) of analog to digital converters (ADC), also referred to as digital receivers. An ADC digitizes the analog signal received by a coil element that is used to contribute to the final image.

The MR receive chain architecture is comprised of multiple RF coil elements, preamplifiers, digitizers and a reconstruction computer (Figure 1). Each independent MR channel produces a partial image; these images are combined to form the composite image. To obtain an MR image of the area of interest in a single scan, the RF coil elements must contribute to the SNR and acceleration factor of the image[2]. It is important to understand that an MR channel cannot be established if one of the components, such as the digitizer or reconstruction computer, is missing.

Now, let's examine the choices of architectures in the design of MR systems.

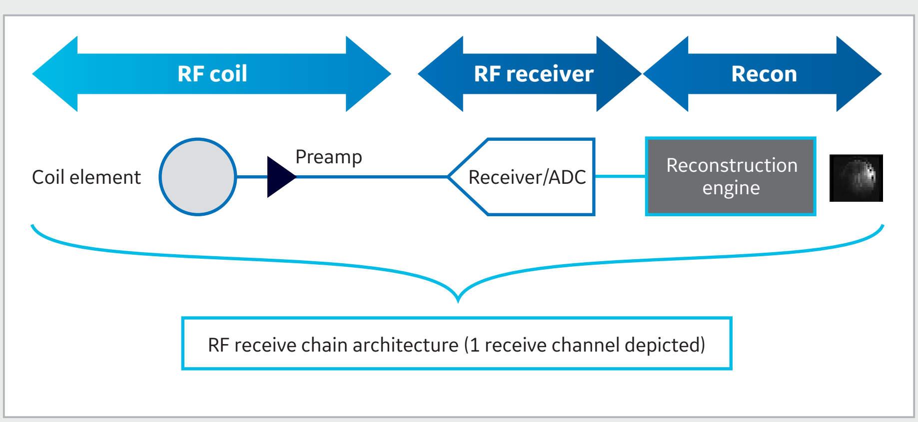

Figure 1. RF receive chain architecture.

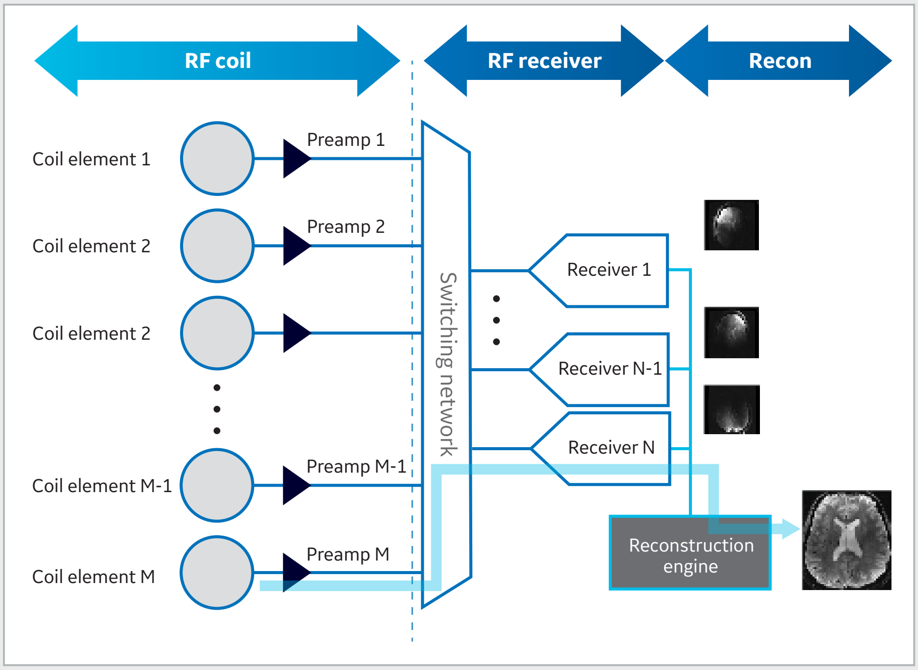

Figure 2. M x N receive chain architecture.

Conventional M x N MR receive chain designs

Most conventional MR systems utilize a limited receive chain design to minimize the cost of digital receivers/ADCs, which limits capability. By definition, the number of connected coil elements (M) is much larger than the number of elements that can be digitized at one time by a receiver/ADC (N). The signal from the coil elements (M) is routed to the receivers (N) with the use of a switching network (Figure 2). It is common for such systems to be identified as M x N receive systems, i.e., 204 x 48. Based on this architecture, the number of MR channels will be limited by the number of available receivers/ ADCs, N. Continuing this example, where M = 204 and N = 48, regardless of how many coil elements are connected to the system, the number of MR channels cannot exceed 48. In this design, it is the number of receivers/ ADCs in the receive chain architecture that limits the number of MR channels.

These types of systems typically are sold with a set of limited RF coils that cannot push the limits of RF channels beyond that number. Therefore, in the example (M = 204 and N = 48), this MR system would not be able to utilize all elements of a 60-element torso RF coil without an upgrade.

While this type of conventional MR system design served the industry well for many years, it is not compatible with the emergence of coils with a higher number of elements and cannot enable the utilization of multiple connected coils simultaneously when the total element count exceeds the number of receivers (see section on AIR™ Coils).

Modern M x M receive chain design

In modern MR receive chain design, the shortcomings of a conventional design are avoided by significantly increasing the number of receivers/ ADCs. In this system design, each independent coil element connected to the system is furnished with its own receiver/ADC (Figure 3). The number of simultaneously digitized elements is not limited and, therefore, can be equal to the number of connected coil elements (M). Any and all connected elements can be digitized simultaneously to form a full MR imaging channel. GE has pioneered this type of receive chain design with the introduction of Total Digital Imaging (TDI) on all newer generation MR systems.

The primary benefit of this system architecture is that it results in the largest possible number of MR channels for a given set of connected coils. It also allows for the adoption of new, higher element count RF coils as they are introduced into the clinical market. For example, a 146-channel SIGNA™ Premier system can connect and simultaneously digitize a maximum of 146 elements.

AIR™ Coils: Versatility with enhanced patient comfort

AIR™ Coils are extremely flexible and lightweight, leading the industry in these two areas. To achieve this evolution in coil design, the conventional rigid copper RF coil loop, bulky preamp and feedboard (Figure 4A) were replaced with a flexible lightweight wire loop and miniaturized RF electronics (Figure 4B).

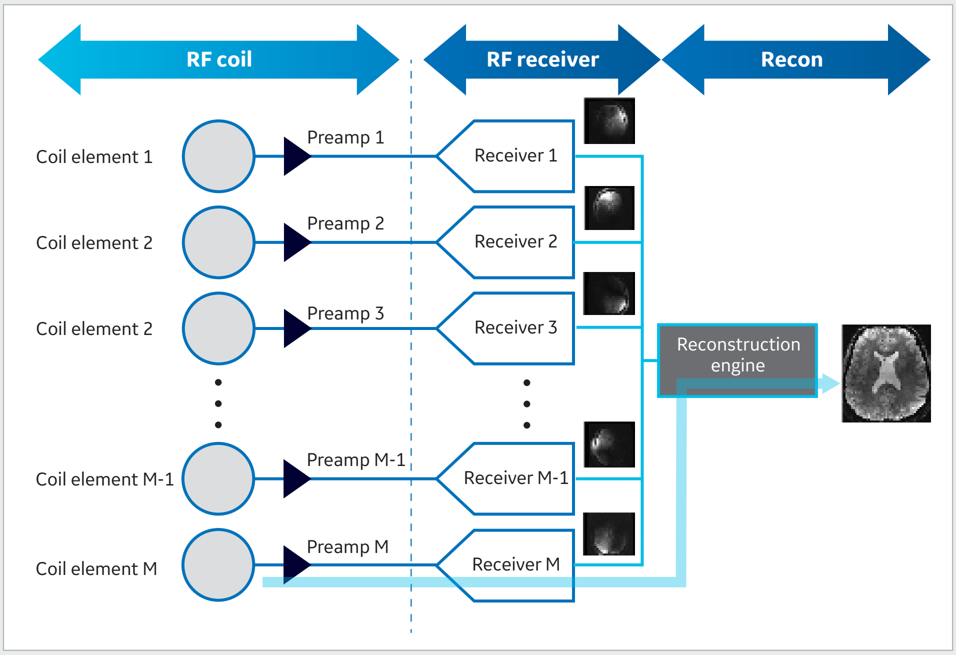

Figure 3. M x M receive chain architecture.

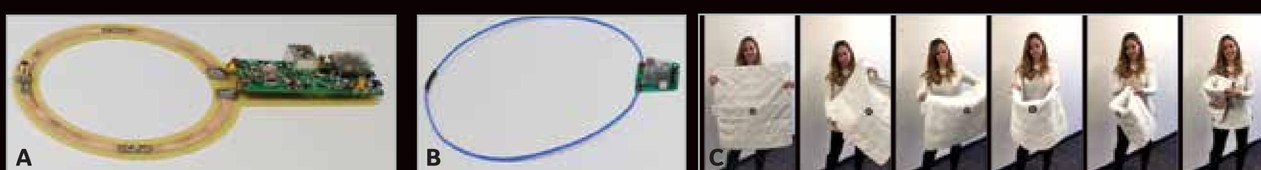

Figure 4. Conventional vs. AIR™ Coil loop. (A) Conventional design. (B) AIR™ Coil element loop design. (C) AIR™ Coil.

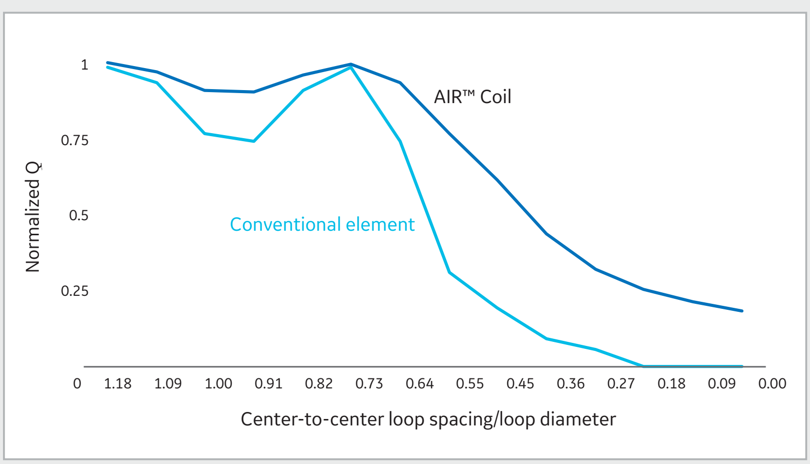

Figure 5. Conventional vs. AIR™ Coil overlapping capability.

This innovative combination allows for an RF coil which looks and feels like a lightweight blanket (Figure 4C). Perhaps more importantly, the miniaturized AIR™ electronics allow for greater overlap between neighboring loops without the instabilities or signal destruction that would result with conventional RF coil designs. This allows for wrapping of the anatomy, for example a knee or an elbow, without loss of signal because the RF coil conforms very closely to the anatomy[3]. Figure 5 illustrates the Q factor, a measurement proportional to SNR, of two conventional RF elements in comparison to two AIR™ Coil elements as they are moved closer together and ultimately overlap. Conventional RF coil elements deliver the best SNR at the critical overlap; however, SNR degrades significantly when the loop overlap increases (Figure 5). AIR™ Coil elements are

Figure 6. Patient setup with multiple overlapped AIR™ Coils.

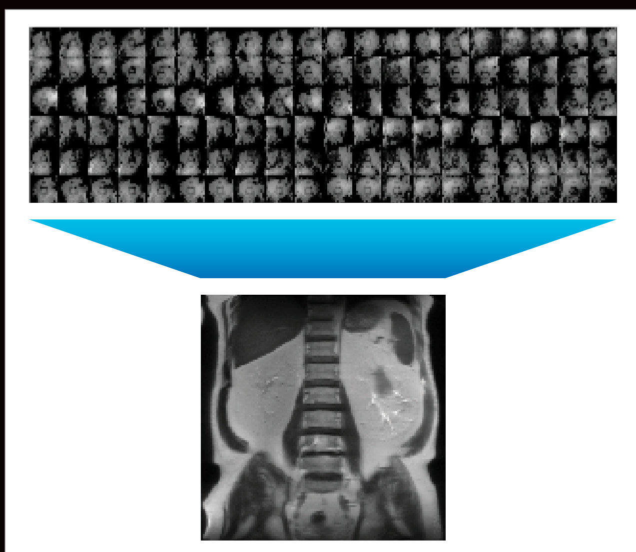

Figure 7. Sample 120 channel image generated with 120 RF elements and digitized simultaneously with 120 receivers/ADCs.

much less sensitive to the amount of overlap and significantly outperform conventional RF loops when the overlap is less than optimal.

This property allows AIR™ Coils to be used in conjunction with each other to combine for either larger coverage or higher coil density in clinical practice.

Figure 6 demonstrates patient setup using multiple AIR™ Coils that are overlapped and combined with the 60-element AIR™ Posterior Array Coil embedded in the table. Figure 7 takes this a step further and highlights AIR™'s unique immunity to overlapping elements within the FOV. For this demonstration, four AIR™ Coils, comprised of 120 individual coil elements, were combined with the TDI receiver architecture to independently digitize the signal from each coil element for reconstruction. The result is the final 120-channel abdominal image shown. In other words, Figure 7 demonstrates the use of 120 simultaneous RF receive channels within an imaging FOV.

It should be noted that the high channel count body image shown in Figure 7 was acquired and reconstructed on a commercially available GE MR system, without adding specialized hardware or software. This is due to the fact that AIR™ Coils and GE's TDI receive chain architecture were designed to provide a flexible, yet simple and consistent approach for high channel count imaging in today's clinical setting.

In conclusion, all recent GE SIGNA™ MR systems include the most advanced receive chain architecture, TDI, and provide true high-channel-count performance. In many cases, the number of available receivers/ADCs well exceed today's clinical RF element counts. This ensures the seamless introduction of higher element count RF coils and density per unit imaging volume with these systems, as they become available, without requiring any upgrades in hardware or software. S

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A vision for bringing connectome to the clinic

Ten years have passed since the launch of the Human Connectome Project (HCP), a National Institutes of Health (NIH) funded project to map the human brain and aim to connect its structure to function and behavior. The Medical College of Wisconsin (MCW) has successfully incorporated the Connectome protocols into the SIGNA™ Premier, a 70 cm bore system, and is collaborating with GE Healthcare and other leading research sites to translate neuroscience research to the clinic.

In 2014, when the NIH extended the project with a call for proposals to characterize the connectome of specific diseases, MCW was awarded two grants in partnership with the University of Wisconsin: the Epilepsy Connectome Project and the Alzheimer's Disease Connectome Project.

The demanding diffusion and functional MR protocols in the Connectome initiative also fostered a need for sophisticated reconstruction, including a technique called simultaneous multislice excitation (SMS) that can support high acceleration factors during acquisitions on high-performance gradient hardware.

Over the past decade, there has been a strong effort to acquire a much faster whole-brain resting-state (rs) fMRI study. For example, one snapshot of activation in a whole-brain study can be captured in just 0.75 seconds using high HyperBand (SMS) factors of 6-8.

"We are trying to get inside the physiological window, so that we can map brain activity faster than the body can make changes that confound those measurements," explains Kevin Koch, PhD, Associate Professor of Radiology & Biomedical Engineering and Director, Center for Imaging Research at MCW.

Similarly, research in diffusion imaging is geared towards multi-shell diffusion tensor imaging with a push towards higher b-values in the outer shell. In this case, HyperBand technology is needed to be able to acquire images of the whole brain for many different diffusion encoding directions. The other challenge with these diffusion protocols is that higher b-values need longer diffusion preparation time which increases the echo time (TE), consequently reducing the SNR. This has created a need for more powerful hardware gradients that can enable shorter TEs and, hence, higher SNR at high b-values. Most researchers were performing these studies on specialized research MR systems equipped with high-performance gradients.

"This was the aggressive approach that the Connectome group put together in 2010 on systems that were specifically designed to do this," Dr. Koch adds. "Being able to do this on a conventional MR system has been the goal and challenge that we have been working on for the last five years."

MCW successfully obtained both NIH Connectome grants using Discovery™ MR750, a 60 cm commercially available MR system. The deployed protocol utilizes blipped CAIPI HyperBand factor of 8 rs-fMRI with 2 mm isotropic images

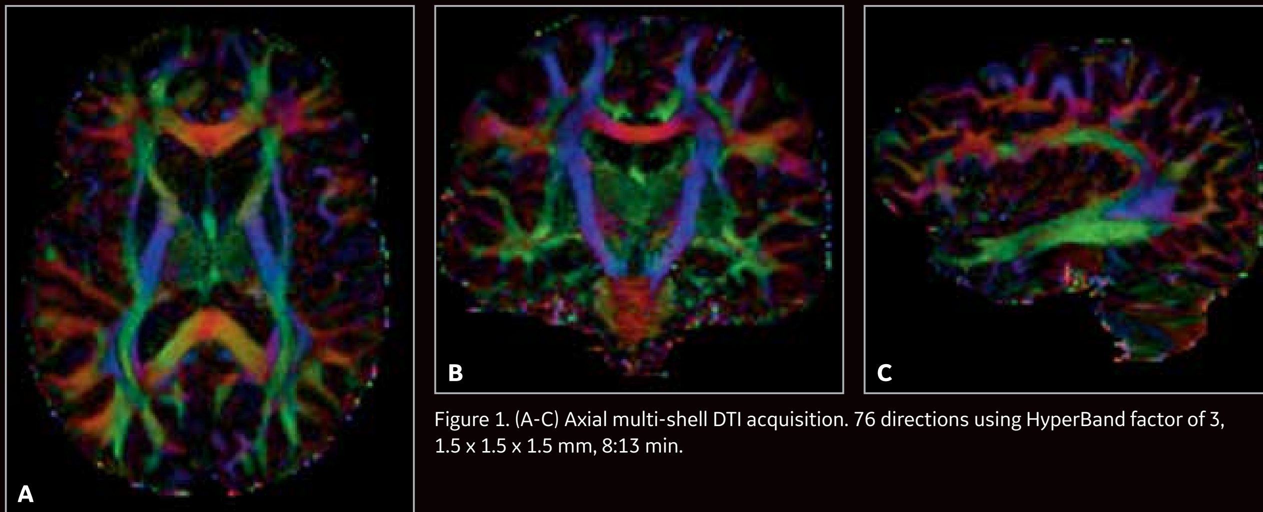


Figure 1. (A-C) Axial multi-shell DTI acquisition. 76 directions using HyperBand factor of 3, 1.5 x 1.5 x 1.5 mm, 8:13 min.

at 800 ms TR and a 4x blipped CAIPI diffusion tensor imaging (DTI) with 1.5 mm isotropic images and 2 shells at a b-value of 1,000 s/mm^{2}and 3,000 s/mm^2.

Translating research from the bench to the bedside is certainly the ultimate goal, albeit a difficult one. In a clinical environment, patients are not necessarily compliant during the study — a stark contrast to the healthy college-aged students used in the Connectome project. But that has been a focus for the researchers at MCW with the Alzheimer's Disease Connectome and other projects.

While diffusion tractography is being used as a guiding tool by neurosurgeons at MCW in an intra-operative setting, Connectome protocols are still quite far removed from the clinics. For rs-fMRI, there are still questions in the research and clinical MR communities about how to best interpret the complex and indirect measurements generated by the technology.

"Some of the technology that is being developed with the SIGNA™ Premier, however, may be a step in the right direction," says Andrew Nencka, PhD, Assistant Professor of Radiology and Associate Director, Center for Imaging Research at MCW. "With the higher temporal resolution acquisitions that we can perform on SIGNA™ Premier, we can better manage patient motion in the fMRI acquisitions."

As the fourth site in the world to install a SIGNA™ Premier and the first site worldwide to incorporate the Connectome protocol into this system, MCW has taken a leadership role in the GE research community.

While moving the Connectome protocols to a 70 cm bore such as SIGNA™ Premier is not an easy task, a 60 cm bore system also poses its own challenges. Imaging larger patients and having access points for high-end research may be limited at 60 cm. An uncomfortable patient, or one who may barely fit in a 60 cm bore, is more prone to move, which creates image artifacts.

"Having a wide bore MR system that can perform at the level of the 60 cm Discovery™ MR750 is a real enabler for translational research. There is some interesting work being done on lower gradient systems, and if we want to push to the forefront in research, SIGNA™ Premier is an optimal way to do that with high performance, patient access and comfort. The fact that we've been able to show parity of a high-end 70 cm system like SIGNA™ Premier with the homogeneity and gradient stability of the 60 cm Discovery™ MR750 is really impressive."

Dr. Kevin Koch

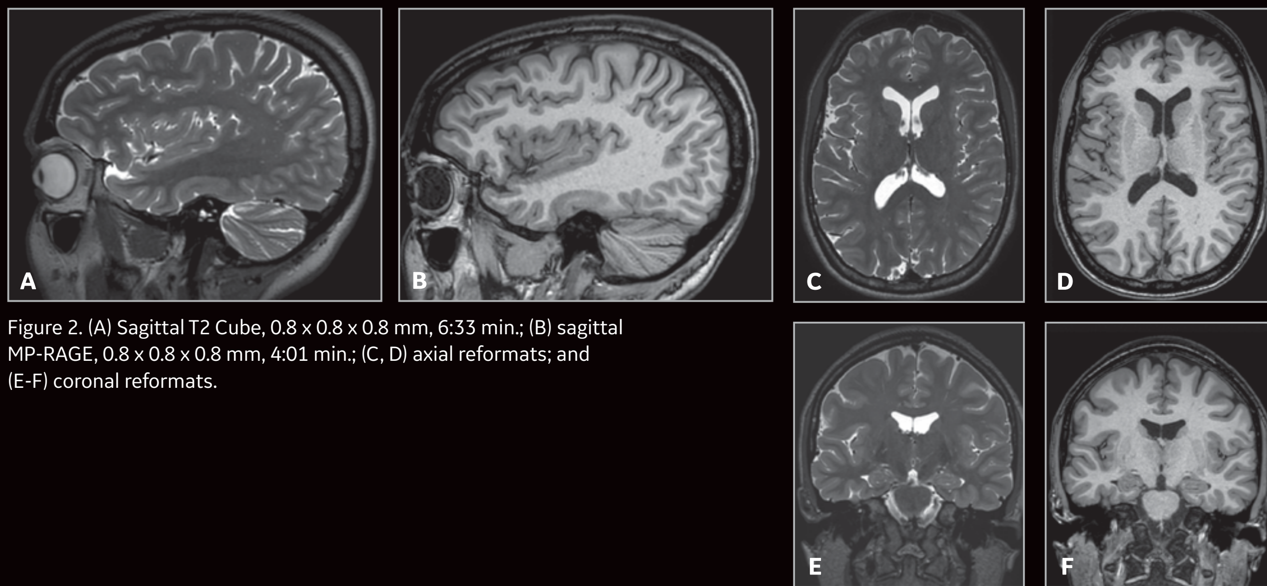


Figure 2. (A) Sagittal T2 Cube, 0.8 x 0.8 x 0.8 mm, 6:33 min.; (B) sagittal MP-RAGE, 0.8 x 0.8 x 0.8 mm, 4:01 min.; (C, D) axial reformats; and (E-F) coronal reformats.

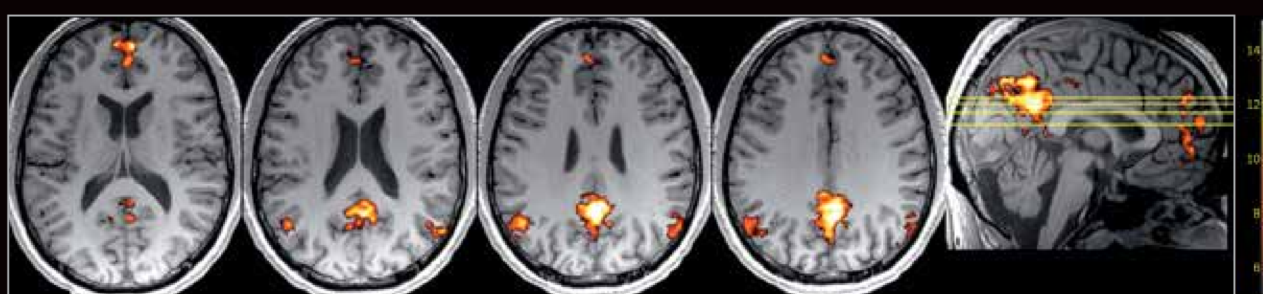


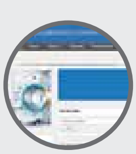
Figure 3. rs-fMRI study, 2 x 2 x 2 mm, 727 ms TR, 4:34 min.

MCW is working on several other innovative technologies in collaboration with GE, such as multi-echo BOLD ASL that can be used to probe cerebral vascular activity by measuring both BOLD activation and cerebral blood flow contrast simultaneously. It utilizes the multi-band acquisitions developed in the Connectome project and with modest acceleration factors enables whole-brain imaging with the potential to examine physiologic questions like neurovascular coupling, which could be relevant in distinguishing between dementia and vascular dementia.

The big picture, however, is the impact on the GE MR research community that can tap into the knowledge and expertise in protocol development and translational research from MCW and other institutions.

"The GE Collaboration Portal is a great place to tie together all the research being done on GE MR systems worldwide. It is fairly straightforward to get the sequences to other sites that want to use it. There is also a Connectome workgroup that we hope will continue these conversations in exploring neuroscience research."

Dr. Andrew Nencka



If you are a GE MR customer, learn how you can participate in the GE MR Collaboration Community by visiting: collaborate.mr.gehealthcare.com

Fat: when to suppress, saturate or separate it

By Heide Harris, RT(R)(MR), Global Product Marketing Director, MR Applications and Visualization, Steve Lawson, RT(R)(MR), Global MR Clinical Marketing Manager and Rob Peters, PhD, Global Product Marketing Director, MR Applications and Visualization

Fat or adipose tissue is an important tissue in clinical MR, but is often seen as a nuisance and requires special management when you don't want the signal from it. Fat signal often appears bright in many MR imaging sequences, which can obscure underlying pathology.[1] The goal of fat suppression techniques is to lessen the signal of fat so radiologists can more easily visualize the water-bearing signal regions.

Most standard clinical protocols — fast spin echo (FSE), spoiled gradient echo (SPGR) and steady-state free suppression — use a form of fat suppression to improve visualization of abnormalities such as edema, inflammation and enhancing tumors.

There are also pathologies where the visualization of fat may be needed, such as fatty tumors (adrenal adenomas, angio-myolipomas, liposarcomas and other fat-containing mesenchymal tumors), and where quantification of the amount of visceral adipose tissue or fatty infiltrative diseases (hepatic steatosis) is critical to diagnose. In these cases, the separation of water and fat signals can be achieved with water-only or fat-only images.[2]

Physics behind FatSat

Fat suppression pulses are typically applied right before the initial excitation pulse, at the start of a sequence. Methods for water-fat suppression are either based on chemical-shift, the short T1 of fat or a hybrid of these. Even within these different methods, various techniques exist for suppressing the high signal of fat. Choosing the right method and technique for each patient depends on several factors: the clinical question, the body part being imaged, use of gadolinium contrast, off-isocenter location, MR system field strength and the vicinity of MR-Conditional implants.[3] Each technique has advantages and disadvantages. This guide will provide an overview of each and explain where each works best.

Fat saturation or suppression is based on the Larmor equation that magnetic dipoles precess around the direction of an applied magnetic field. The frequency of the precession is directly proportional to the magnet field strength $f_0 = \gamma B_0$, where f_0 is the precession frequency, B_0 is the strength of the externally applied field and γ is the gyromagnetic ratio, a constant specific to each particle or nucleus. The gyromagnetic ratio is 42.58 MHz/T for 1H nuclei, the most commonly imaged nuclei. For example, in a field (B_0) at 1.5T, the resonance frequency of 1H would be (42.58 MHz/T) x (1.5T) = 63.87 MHz. At 3.0T, the resonance frequency would be twice as high, or 127.74 MHz.

Field strength and field homogeneity impact the effectiveness of the fat suppression, saturation or separation. Inhomogeneity is the fractional deviation of the local magnetic field from the average value of the field. The gyromagnetic ratio causes a frequency shift, causing distortions in geometry and intensity of the MR images.[4]

B_0 inhomogeneity results in geometrical distortions or nonuniformity of the signal in MR imaging. B_1 inhomogeneity can also contribute to regions being more or less saturated, when using such techniques. Some magnets are designed to provide excellent B_0 homogeneity to ensure uniform signal and fat suppression over a larger field of view (FOV). A good indication of the system's performance can be indicated by how homogenous the fat suppression is over a large 50 cm FOV (Figure 2).

Typically, at low field strengths, STIR or Dixon fat/water separation methods should be used. At high fields, if magnetic homogeneity is poor then spectral fat suppression may be inadequate. Performing shimming prior to imaging can minimize inhomogeneity effects, such as those that occur at tissue interfaces with different magnetic susceptibilities or irregularly shaped structures.

At 3.0T, precise control over the RF environment in a 70 cm patient bore has been challenging until now. The RF transmit architecture, MultiDrive, consists of two liquid-cooled 15 kW solid-state RF power amplifiers. By optimizing the phase and amplitude of each RF amplifier output channel that is applied to GE's 70 cm whole-body RF transmit coil, the RF uniformity and signal homogeneity improves regardless of patient shape, size, and/or body habitus.

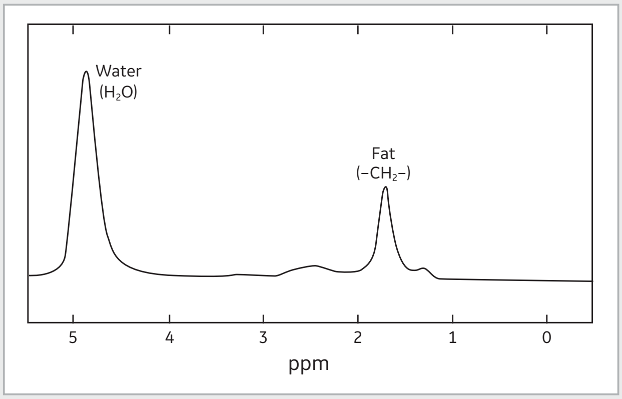


Figure 1. Representative proton MR spectrum showing water and fat. The Larmor frequency of fat is approximately 3.5 ppm lower than that of water. Traditionally, MR spectra are plotted with fat to the right of water.

LV-vrms homogeneity specifications‡

Diameter of Spherical Volume – DSV	*Guaranteed ppm*	*Typical ppm*
10 cm		0.005
20 cm	< 0.050	0.02
30 cm	< 0.150	0.06
40 cm	< 0.500	0.25
45 cm	< 1.500	0.7
40 (z) x 50 cm	< 3.000	1.73
50 (z) x 50 cm	< 4.000	2.29

Figure 2. SIGNA™ Premier homogeneity specifications.

‡ Measured on the magnet, after passive shimming. Specifications correspond to forward production systems.

Figure 3. Sagittal knee exam (A) Chemical FatSat, (B) IDEAL (3 pt Dixon) and (C) STIR.

Chemical FatSat

Chemical fat saturation applies a frequency selective saturation pulse at the frequency of fat before the imaging excitation pulse with the intent to suppress the fat signal prior to excitation. The result is an image consisting primarily of water. It works best at high fields, such as 1.5T and 3.0T.

The chemical fat saturation RF pulse is applied to null the signals from fat prior to the excitation pulse and readout. Chemical fat saturation can decrease the number of slice locations per TR due to the additional time required to apply the RF pulse and its contribution to SAR.

Although chemical fat saturation is a versatile technique, in the presence of metal it provides poor or incomplete suppression. The chemical saturation pulses are referred to as Fat, Fat Classic, SPECIAL and Water. SPECIAL supports manual tuning for center frequency adjusting (more later on this).

Inversion recovery suppression

STIR is an inversion recovery method that takes advantage of the T1 difference between water and fat, which is another effective approach to suppressing fat. In order to eliminate the signal from fat, the T1 time must match the null point of fat during its inversion recovery. Since T1 relaxation times are different for both 1.5T and 3.0T scanners, a T1 of 150 ms and 180 ms is recommended for each respective field strength.

However, STIR should not be used with post-contrast sequences since the T1 of lesions is shortened. This would make enhancements dark just like fat.

Spectral inversion techniques

SPECtral Inversion At Lipid (SPECIAL) is a specific GE Healthcare term to denote a hybrid fat suppression technique that incorporates features from both the frequency selective FatSat and the STIR techniques by using a spectrally selective inversion pulse that inverts only the fat magnetization and leaves only the water peak available for excitation. This technique is also referred to as Adiabatic SPectral Inversion Recovery (ASPIR), which can be used in sequences such as 2D FSE or 3D Cube. ASPIR is also more robust for B_1 inhomogeneities compared to chemical fat saturation. As noted above, it's recommended to use manual tuning to ensure that center frequency is centered on water.

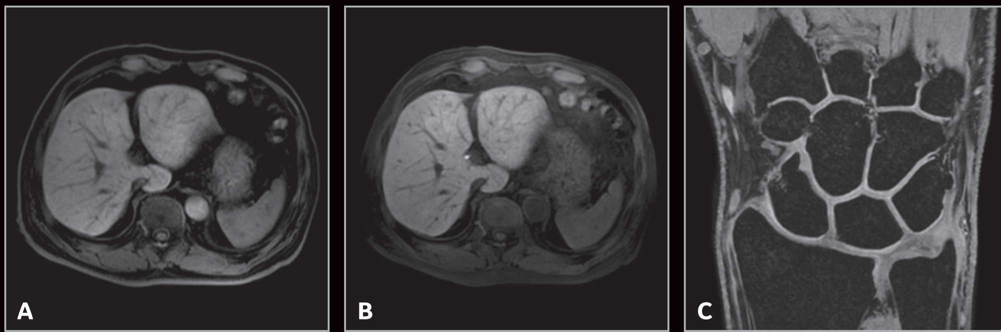


Figure 4. (A) Flex (2 pt Dixon), (B) Fat SPECIAL and (C) SSRF (water excitation) image of the wrist.

Fat suppression techniques

		B_0 sensitivity	B_1 sensitivity	Scanning time	Sharpness	Other concerns	Recommended anatomy
Water excitation		X	✓	✓	X	–	Breast
Spectral FatSat		X	X	✓	✓	–	All except: C-spine, metal implants
ASPIR		X	✓	X	✓	–	Breast, abdomen, pelvis, ankle, shoulder
STIR		✓	✓	X	X	Low SNR	Head and neck, chest, abdomen, extremities, spine, large FOV
Dixon	*(2 pt) Flex*	✓	✓	X	✓	Fat/water swap	Breast, abdominal, pelvis, ankle, spine
	(3 pt) IDEAL	✓	✓	X	X	Fat/water swap	Breast, spine, ankle

Figure 5. Fat suppression technique recommendations for anatomical areas.

Spectral spatial (SSRF) is a method that applies selective pulses for water excitation only, while fat is left untouched. Note that ASPIR is used (by default) for Cube and is selectable as "SPECIAL" for 2D FSE.

Dixon fat-water separation techniques

IDEAL (iterative decomposition of water and fat with echo asymmetry and least squares estimation) is a 3-point Dixon technique that acquires three images at slightly different echo times to generate phase shifts between water and fat. The water/fat separation method is very efficient in regions of poor B_0 and B_1 homogeneity. One acquisition provides four contrasts: water, fat, in-phase and out-of-phase images.

Flex is a 2-point Dixon technique delivering faster scan times compared to IDEAL, a 3-point Dixon technique. Flex uses a dual echo fat-water separation technology to provide robust and homogeneous fat suppressed images. Flex is compatible with ARC acceleration and HyperSense and can be used with Cube for significant scan time reduction. Enhanced uniformity and control of fat-water swaps allow large field of view and off-center imaging where uniformity is a challenge. Delivering fast 2D and 3D acquisitions with reconstructed in-phase, out-of-phase, water and fat images, Flex represents productivity gains in all clinical areas.

Despite a growing trend towards 3D imaging techniques, 2D FSE retains a prominent role in high-resolution MSK. In addition, non-uniform fat suppression is a top clinical concern when imaging joints. 2D FSE Flex is best suited for balancing uniform fat suppression, scan time, SNR and image sharpness. One of the major benefits of using the Flex technique is that you get both a fat separated and in-phase image in one scan, which is particularly useful when a non-fat saturated and fat saturated sequence are requested post-contrast. S

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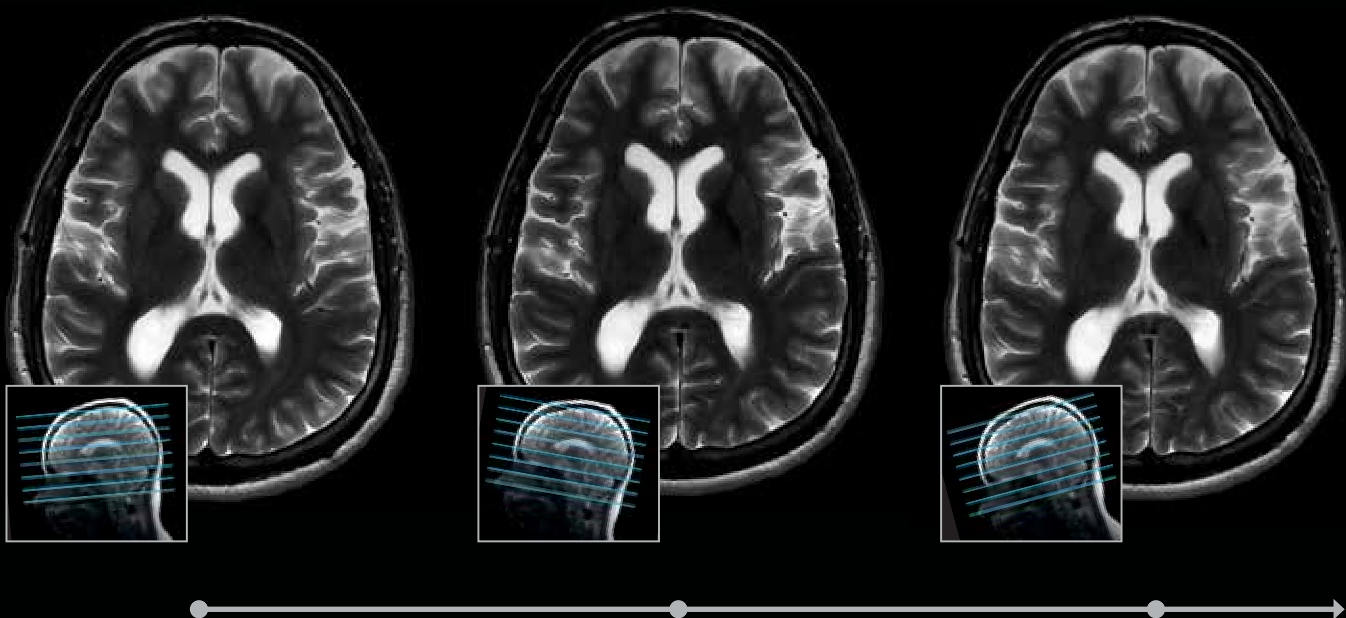

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