AIR™ Recon DL: Simply better image quality

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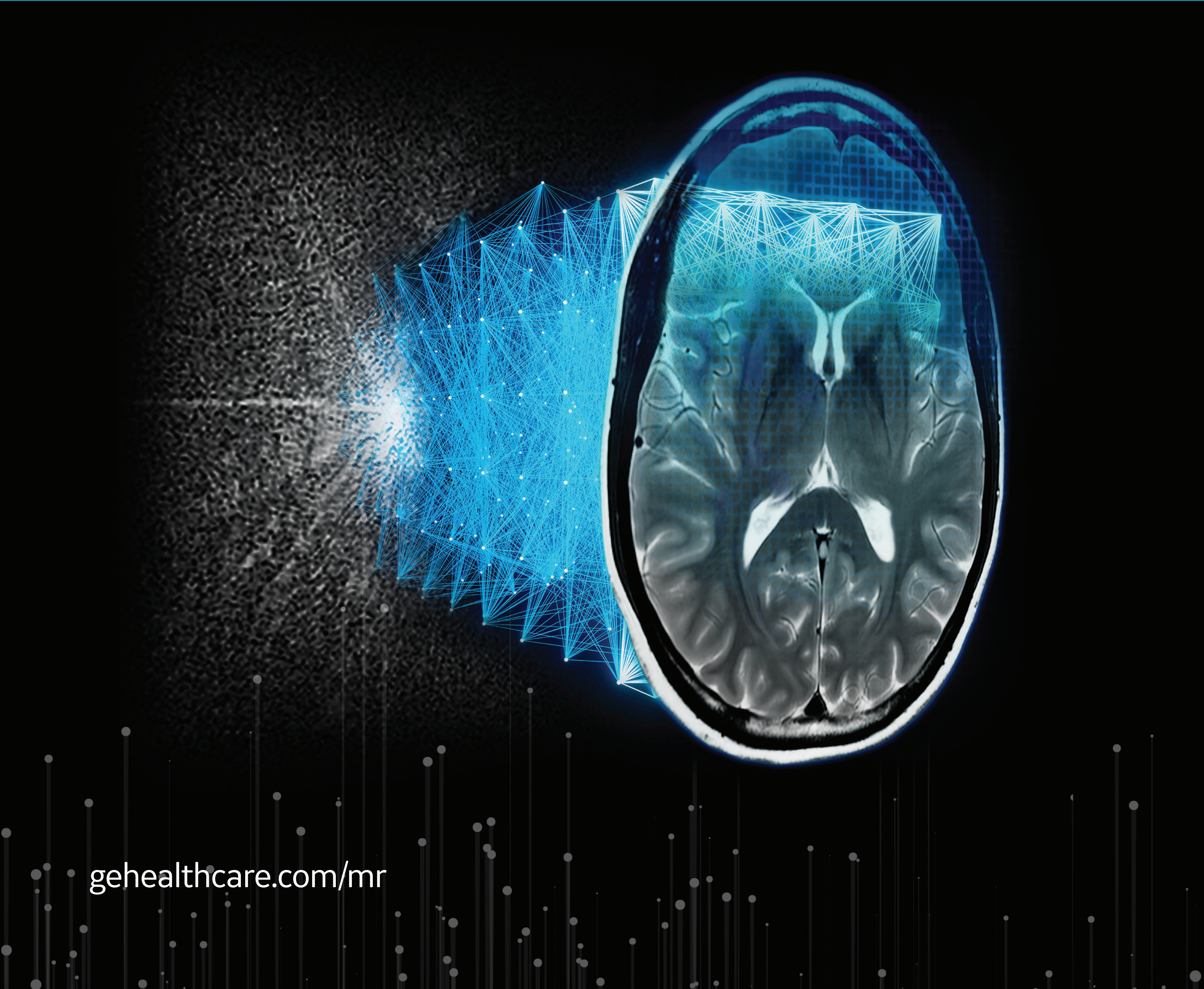

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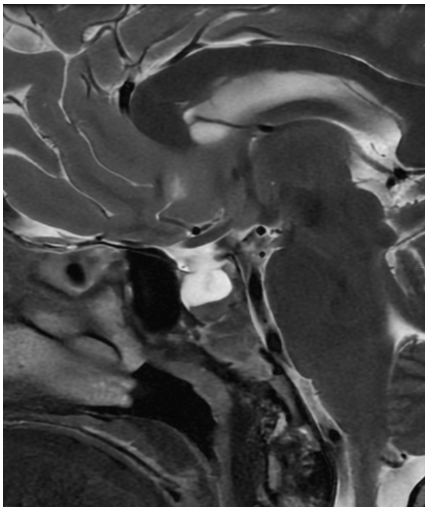
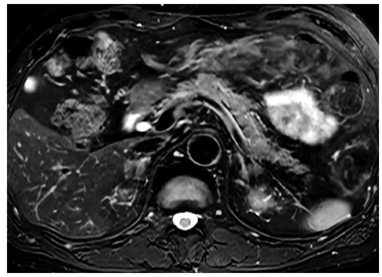
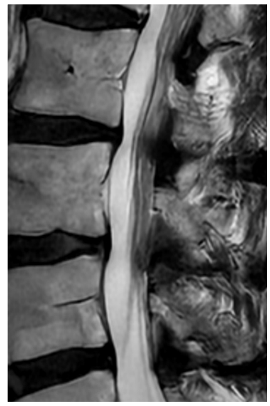




In Practice

Case Studies



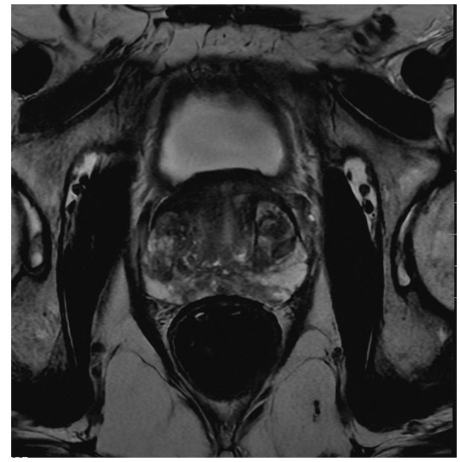


Image Gallery

Tech Trends

The power of deep learning in image reconstruction

There is much excitement, and some trepidation, surrounding the use of artificial intelligence (AI) and deep learning (DL)/machine learning (ML) in medical imaging. While computer-aided diagnosis has been in use for decades (e.g., CAD for mammography), the continued development of AI technologies and advancements in computing power are bringing forward the potential of DL/ML in radiology in areas such as protocol identification, image reconstruction, anomaly detection and image analysis.

One area where the promise of AI and DL is being realized is in image reconstruction. And for those who want to take their imaging up a level, GE Healthcare's latest software package, SIGNA™Works AIR™ IQ Edition, introduces AIR™ Recon DL. The DL stands for deep learning, and this pioneering software is the more advanced option of AIR™ Recon in that it uses a deep-learning-based reconstruction algorithm that improves SNR and image sharpness with Intelligent True Resolution, enabling shorter scan times. It's not a DICOM image post-processing technique. It improves image quality at the foundational level by making use of raw data to remove image noise and ringing. With the ability to set your preferred SNR improvement level at low, medium or high, you can acquire higher SNR without a time penalty and get images virtually free of artifact.

Trained on over 10,000 images using GE's Edison™ AI Platform, the network employs a cascade of over 100,000 unique pattern recognitions for noise and low resolution to reconstruct only the ideal object image. The network includes a tunable SNR improvement level to suit the user's preference, and an innovative Intelligent True Resolution technology that recognizes common artifacts like Gibbs ringing and truncation and recasts it into improved image detail.

MR radiologists and technologists have long known that there is an inherent trade-off between resolution, SNR and scan time. Simply put, the longer the scan time, the better the SNR, but unfortunately that model doesn't align well with reality. Radiologists and technologists have to meet demanding schedules and balance the added variability of patient shape, size and cooperation. The end result can be unsatisfying because when practitioners spend more time on patient setup, less time is left for the actual scan. Shorter scan times result in decreased SNR and poor image quality, and that can lead to patient call-backs and rescans.

Consider that MR scans are increasing, with the 40 million MR procedures in 2019 being the all-time high in the US[1]. Combine this increase in demand with inefficiencies due to repeat scans – 20% of all MR exams require a repeated sequence, accounting for 10% of additional MR scan/table time[2] – and it becomes clear that facilities need to optimize MR imaging workflow for patient/staff satisfaction and business operations.

In fact, early adopters of AIR™ Recon DL – 21 radiologists from 11 different sites and six countries – all reported that images are sharper and more detailed, display less noise and can enable prescription changes to shorten scan time. Ninety-five percent said the technology improves lesion conspicuity, improves diagnostic confidence and may help reduce the number of repeat series. Nine out of 10 said AIR™ Recon DL may allow for prescription changes to increase spatial resolution and, with this technology, the images are easier and quicker to read, and lead to reduced eye fatigue.

AIR™ Recon DL helps you navigate the traditional trade-offs between scan time, SNR and image resolution, so you can maximize your MR imaging investment.

To see how AIR™ Recon DL works, visit:

tinyurl.com/AIRReconDL

References

1. IMV 2020 MR Market Outlook report.
2. Andre JB, Bresnahan BW, Mossa-Basha M, et al. Toward Quantifying the Prevalence, Severity, and Cost Associated With Patient Motion During Clinical MR Examinations. J Am Coll Radiol. 2015 Jul;12(7):689-95. doi: 10.1016/j.jacr.2015.03.007.

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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 True-Fidelity™ 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

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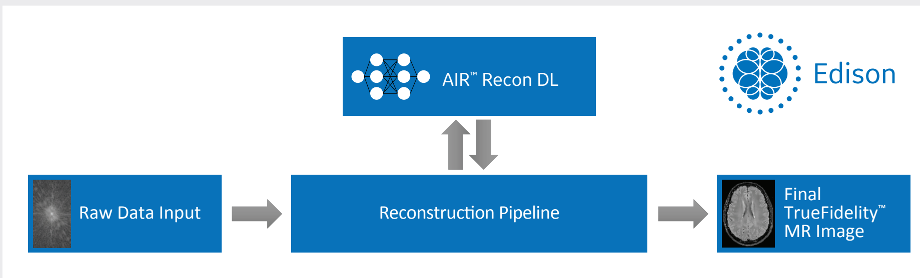

Figure 1. AIR™ Recon DL is integrated directly into the MR image reconstruction pipeline to intelligently reconstruct a final image with high SNR and sharpness.

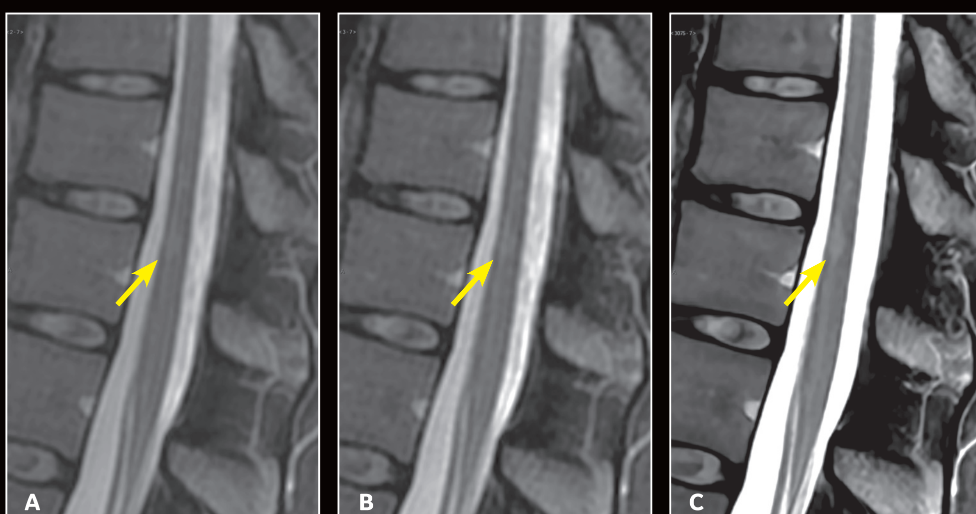

Figure 2. AIR™ Recon DL improves SNR to help depict lesions. (A) Existing protocol: sagittal T2 FSE, 0.9 x 1.0 x 3.5 mm, 4 NEX, 2:50 min. (B) Revised protocol: sagittal T2 FSE, 0.9 x 1.0 x 3.5 mm, 2 NEX, 1:28 min. (C) Image in 2B reconstructed with AIR™ Recon DL at maximum noise reduction to enable shorter 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 images and low-SNR, low-resolution images. The

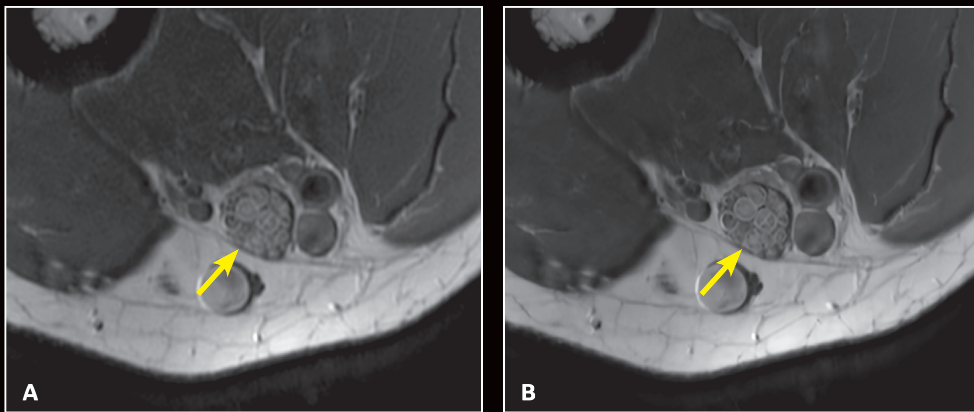

Figure 3. Spontaneous median neuropathy of the elbow. Axial PD 2D FSE. (A) Image acquired with standard protocol, 512 x 352, 12 cm FOV, 2 NEX; (B) image reconstructed with AIR™ Recon DL at maximum SNR improvement. Note the clarity of the median nerve in the AIR™ Recon DL image.

Images courtesy of HSS

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

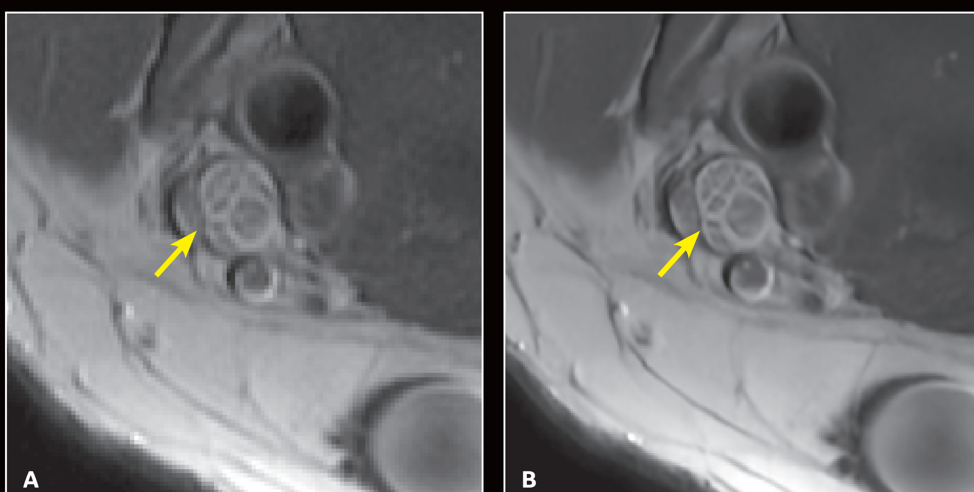

Figure 5.Axial PD 2D FSE image through the arm in a patient with a severe, spontaneous median neuropathy. (A) 512 x 352, 12 cm FOV, 2 NEX; (B) AIR™ Recon DL at maximum SNR improvement more clearly depicts fascicular detail and enlargement.

Images courtesy of HSS

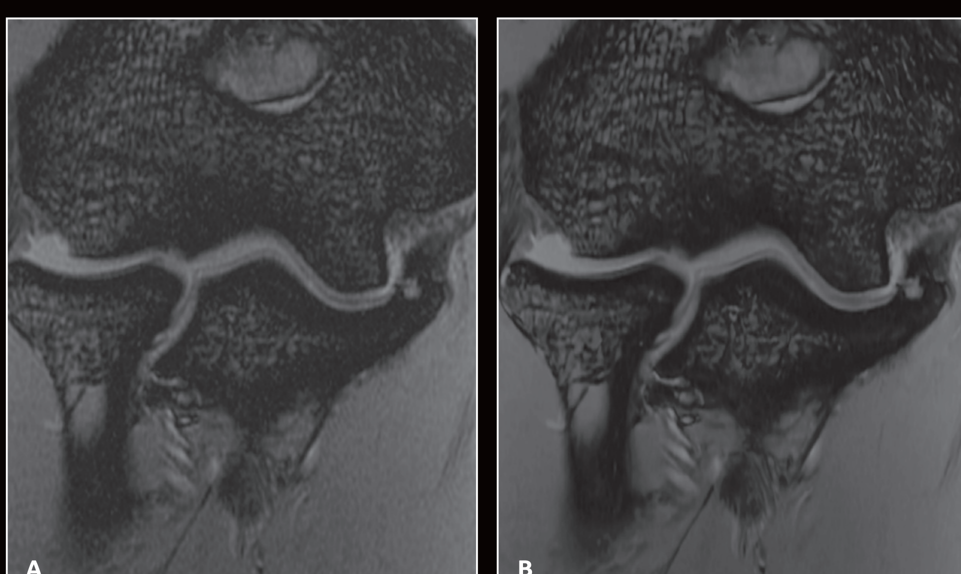

Figure 6. (A) Standard protocol. Coronal T2* GRE, 0.3 x 0.6 x 1.7 mm; (B) AIR™ Recon DL at maximum SNR improvement.

Images courtesy of HSS

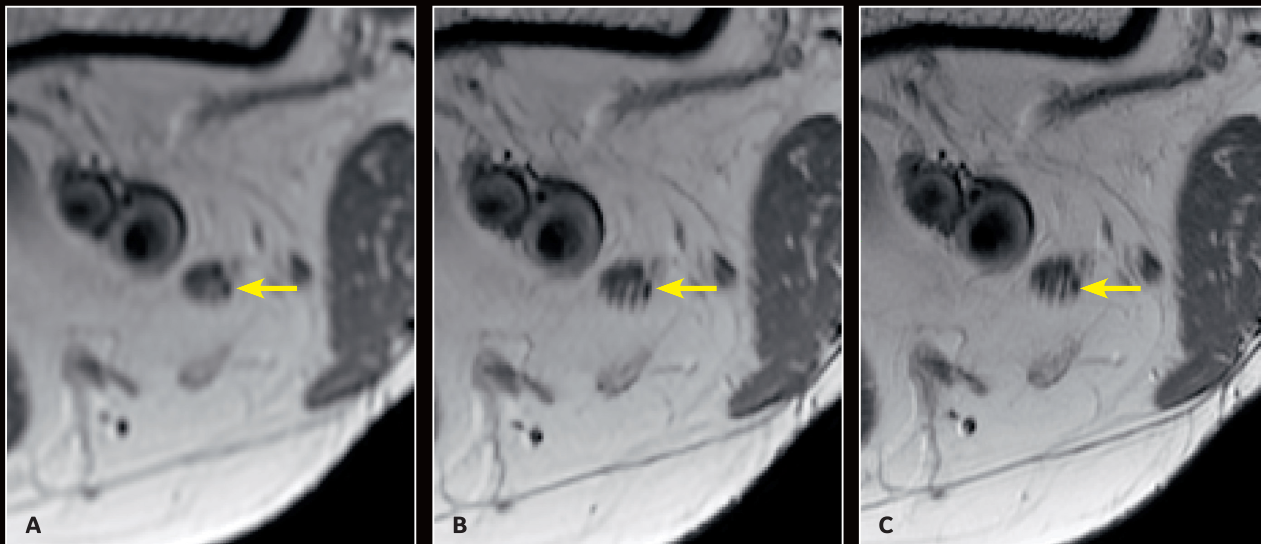

Figure 7. Elbow. (A) Unfiltered, axial 2D FSE, 256 x 180, 1 NEX, 1:10 min. (B) AIR™ Recon DL at maximum-plus SNR improvement, 256 x 180, 1 NEX, 1:10 min. (C) Reference unfiltered, 512 x 352, 2 NEX, 4:09 min.

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. Ⓢ

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.

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Deep-learning-based MR reconstruction designed to address compromise between SNR, scan time and resolution

There is an inherent compromise in MR between image quality and scan time. Higher image quality, achieved through higher SNR and/or spatial resolution needed to show anatomical detail, necessitates long scan times, whereas faster scans compromise image quality and diagnostic confidence. The University of Yamanashi Hospital evaluated a prototype version of AIR™ Recon DL and reported shorter scan times and higher resolution across 80 patient cases.

AIR™ Recon DL is a pioneering, deep learning-based reconstruction software designed to improve SNR and image sharpness, enabling shorter scan times. It improves image quality at the early reconstruction level by removing image noise and ringing artifacts, making use of the raw image data. It uses a neural network trained on over 10,000 images to recognize patterns characteristic of noise and low resolution to reconstruct only the ideal image. The result is TrueFidelity™ MR images for clinical excellence without conventional compromises.

Utaroh Motosugi, MD, PhD, an Associate Professor in the Department of Radiology at University of Yamanashi Hospital, one of the first clinical sites to evaluate a prototype version of AIR™ Recon DL, believes it's a solution that could offer a considerable clinical impact.

Located in the central valley city of Yamanashi in the shadow of Mount Fuji, the hospital installed the AIR™ Recon DL prototype on their Discovery™ MR750 in March 2019 to explore high-quality upper body scans and scan time. Since then, the facility has used the software for approximately 80 cases.

"Compared to clinical routine protocols, AIR™ Recon DL provides much better SNR due to the noise-reduction performance. Now we can visualize quite small anatomy in detail with less blurring."

Dr. Utaroh Motosugi

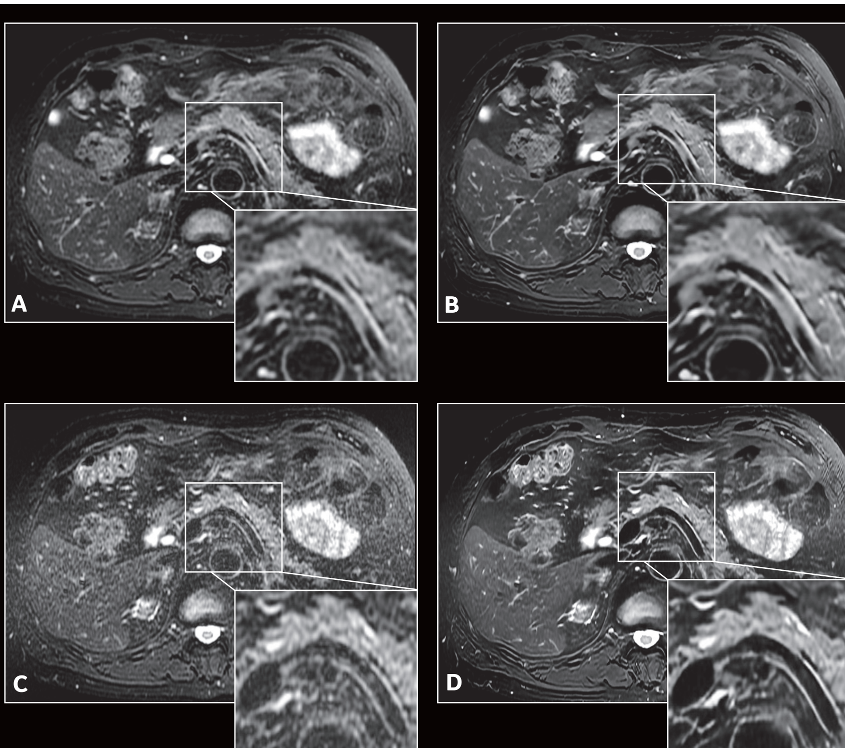

Figure 1. Improved spatial resolution and slice resolution images are acquired while maintaining SNR. (A, C) Conventional reconstruction and (B, D) AIR™ Recon DL. (A, B) Acquired at 1.1 x 1.8 x 5 mm and (C, D) acquired at 0.8 x 1.8 x 2.5 mm.

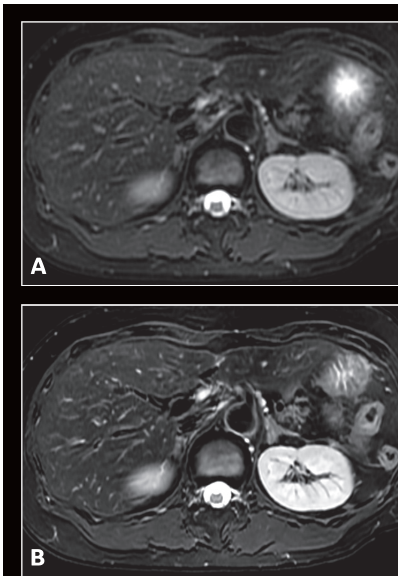

Figure 2. AIR™ Recon DL improves spatial resolution and also reduces scan time, in this case by 45 percent. (A) Conventional reconstruction, 1.1 x 1.8 x 5 mm, 2 min. and (B) AIR™ Recon DL, 0.8 x 1.8 x 5 mm, 1:05 min.

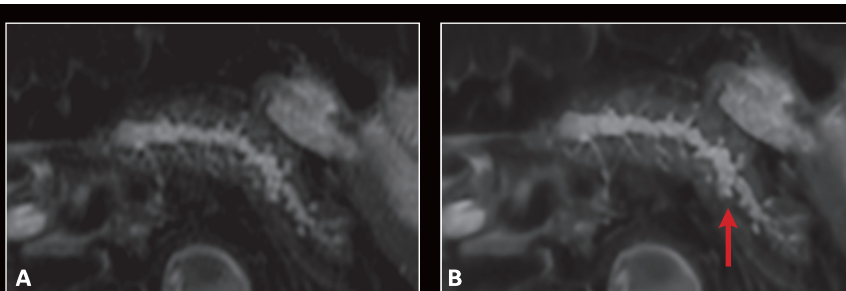

Figure 3. AIR™ Recon DL improves visualization of the main pancreatic duct. (A) Conventional reconstruction and (B) AIR™ Recon DL. Images reconstructed from the same raw data.

He notes the facility applied a higher frequency matrix to deliver higher resolution, but maintained the same phase matrix to preserve scan time. Dr. Motosugi believes that AIR™ Recon DL can enable a 36 percent smaller voxel size without impacting SNR.

Dr. Motosugi adds that a 2D thin slice (0 mm gap) MPR can provide a better image with AIR™ Recon DL than a 3D scan without AIR™ Recon DL. “We can clearly see SNR improvement with AIR™ Recon DL,” he continues. “It can be used for both scan time reduction and higher spatial resolution.”

AIR™ Recon DL, according to Dr. Motosugi, may also reduce the number of excitations (NEX) as a means of reducing scan times.

With respect to lesion detection, Dr. Motosugi explains, “AIR™ Recon DL provides better diagnostic confidence by helping the clinician differentiate between normal structures and lesions, helping clinicians better understand the relationship between them.”

Due to its small size and location in the body, the pancreas requires thinner slices and higher SNR to capture clear images. With AIR™ Recon DL, Dr. Motosugi uses a thin slice 2D T2-weighted acquisition to solve this challenge and visualize the relationship between cysts and the pancreatic duct location.

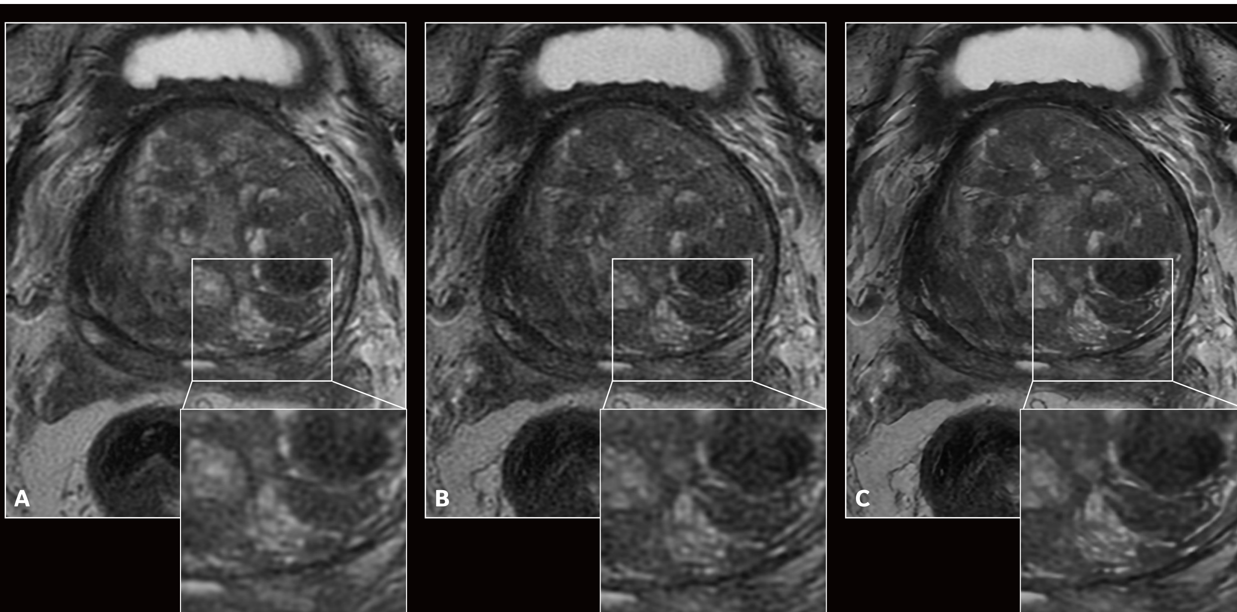

Figure 4. AIR™ Recon DL delivers higher SNR and enables the use of low NEX in small FOV imaging. Case of a 77-year-old patient with benign prostatic hyperplasia. (A) NEX value of 5 leads to blurring due to organ motion during the long scan. (B) Lowering the NEX value to 2 removes blurring and reduces scan time, however, images have a low SNR. (C) AIR™ Recon DL enables the use of a low NEX value of 2 with good SNR to improve image quality.

Lesions on the adrenal gland can be difficult to image due to the organ's small size, but with AIR™ Recon DL, Dr. Motosugi hopes to overcome these challenges.

Prostate imaging is particularly impressive. "We've found that small nodules due to prostate cancer can be clearly visualized with AIR™ Recon DL," he said. "It's very important to see detailed structures inside the prostate because sometimes small cancers can be hidden by surrounding structures, and AIR™ Recon DL helps with this."

He previously used a higher NEX factor for high-resolution imaging of the prostate, which added scan time and often introduced respiratory motion artifacts into the images. "AIR™ Recon DL allows us to scan the prostate with higher resolution, shorter scan times, lower NEX and less blurring artifact without compromising SNR."

Dr. Motosugi's goal is to continue using AIR™ Recon DL to further reduce scan times and address motion artifacts in routine scans.

"We found clear image quality improvement and high resolution imaging coming from the SNR improvement so far. In the future, we will try to get both better image quality and shorter scan times with AIR™ Recon DL."

Dr. Utaroh Motosugi

He does not believe there will be a "technology barrier" to combine AIR™ Recon DL with other applications and pulse sequences in the future.

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Elevating neuroimaging with AIR Recon DL

Based on an ASNR 2020 webinar by Javier Villanueva-Meyer, MD, Assistant Professor, Neuroradiology, University of California, San Francisco

A patient with suspected compressive myelopathy is transferred to a tertiary institution for an advanced neurological evaluation. Unfortunately, the quality of the patient's MR exam from the other facility limits the neuroradiologist's interpretation of the existing exam. A repeat scan is requested and the results are slightly better, though still suboptimal. This is a scenario that often occurs at institutions across the world, where a lack of consistency and uniformity across imaging providers can lead to duplicate or unnecessary imaging exams and increase healthcare costs.

The reality is that adequate neuroradiological diagnosis often hinges on identifying subtle changes or lesions in small anatomies – such as the hippocampus or sella turcica – as well as determining tumor margins for surgical planning. While technological advances in MR imaging have enhanced neuroimaging capabilities, image quality is also dependent upon patient compliance. Patients may be clinically unstable or suffer from a neurodegenerative disease that makes it difficult to control movement and therefore remain still for the duration of an MR exam. A suboptimal exam can make evaluating small structures a difficult – and sometimes nearly impossible – task.

Enter AIR™ Recon DL, GE Healthcare's novel MR image reconstruction method that uses a deep learning-based convolutional neural network to reconstruct MR images at 3.0T and 1.5T. It delivers both SNR improvement and image sharpening for higher spatial resolution and improved image detail.

"When we look at the enhanced AIR™ Recon DL image side-by-side with the conventional image, we can really see a significant improvement," says Javier Villanueva-Meyer, MD, Assistant Professor of Neuroradiology at the University of California, San Francisco (UCSF).

As with many new reconstruction techniques that enhance image quality, a key question is whether lesion conspicuity is maintained. At RSNA 2019, Dr. Villanueva-Meyer and colleagues presented a multi-rater evaluation study[1] on the difference between conventional and AIR™ Recon DL reconstructed images of the cervical spine. The raters were asked to evaluate signal-to-noise ratio (SNR), anatomic structure definition, diagnostic certainty, overall image quality and artifacts. In each category except artifacts, where the rating was nearly equivalent, the AIR™ Recon DL images were rated higher with a significant improvement in both SNR and anatomic structure.

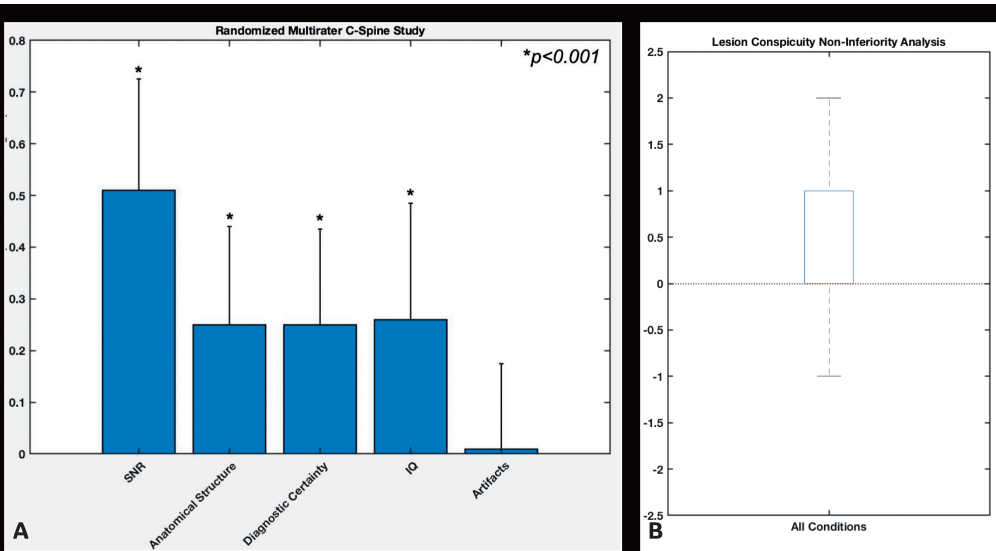

Figure 1. A multi-rater evaluation study presented at RSNA 2019 reported that the AIR™ Recon DL images were rated higher with a significant improvement in both SNR and anatomic structure. Y-axis is the mean of the difference between AIR™ Recon DL and the conventional image.

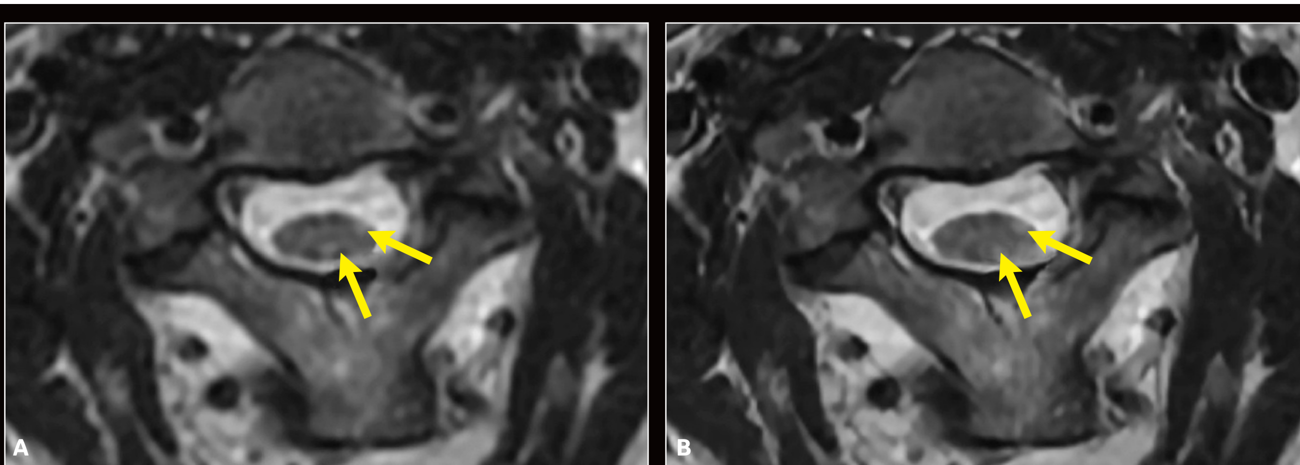

Figure 2. AIR™ Recon DL improves image quality and maintains lesion conspicuity. (A) Conventional and (B) AIR™ Recon DL reconstructed images.

"It was important to ensure that we could still see pathology and we were happy to find that AIR™ Recon DL maintained lesion conspicuity in a non-inferiority analysis," he adds.

"One clinical scenario that we are often asked by surgeons is whether or not there's involvement of the cavernous sinus in pituitary tumors," Dr. Villanueva-Meyer explains. "Another is to evaluate for mesial temporal sclerosis. Sometimes we have difficulty seeing these small structures unless we have a truly optimal exam. This is where technology like AIR™ Recon DL can be really helpful in the diagnosis by making the anatomy a little bit more clear."

The image clarity and sharper detail provided by AIR™ Recon DL is noticeable when zooming in to view these small structures, such as in the hippocampus (Figures 3 and 4) or when evaluating small structures like the anatomy near the vertex of the brain, the brain CSF interface or within the subarachnoid space. It's also helpful when evaluating tumor features and lesion margins, as well as areas of edema.

"I want to clearly see that the infiltrative margins are maintained (in brain tumor cases) or have the ability to identify texture differences, which is helpful for making the distinction between true vasogenic edema and infiltrative edema," says Dr. Villanueva-Meyer.

AIR™ Recon DL is also helpful for enhancing images of the skull base in orbital exams to provide sharper detail within the interorbital contents, or imaging of the extracranial vessels, where images often have relatively low SNR.

"We can use this tool to speed imaging up and actually use that to add another facet of value to the MR exam. Similarly, we can use the shortened scan time to reduce the possibility of patient motion and therefore improve diagnostic confidence."

Dr. Javier Villanueva-Meyer

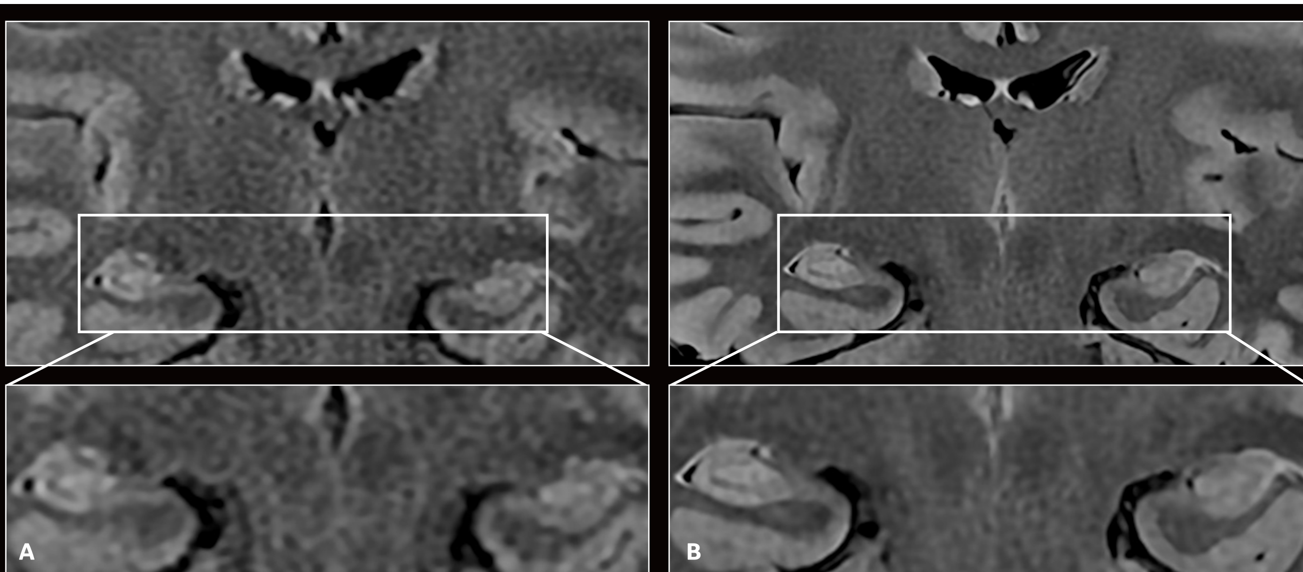

Figure 3. AIR™ Recon DL is useful for denoising small structures such as the hippocampus. (A) Conventional and (B) AIR™ Recon DL reconstructed images. Images courtesy of Columbia University Medical Center.

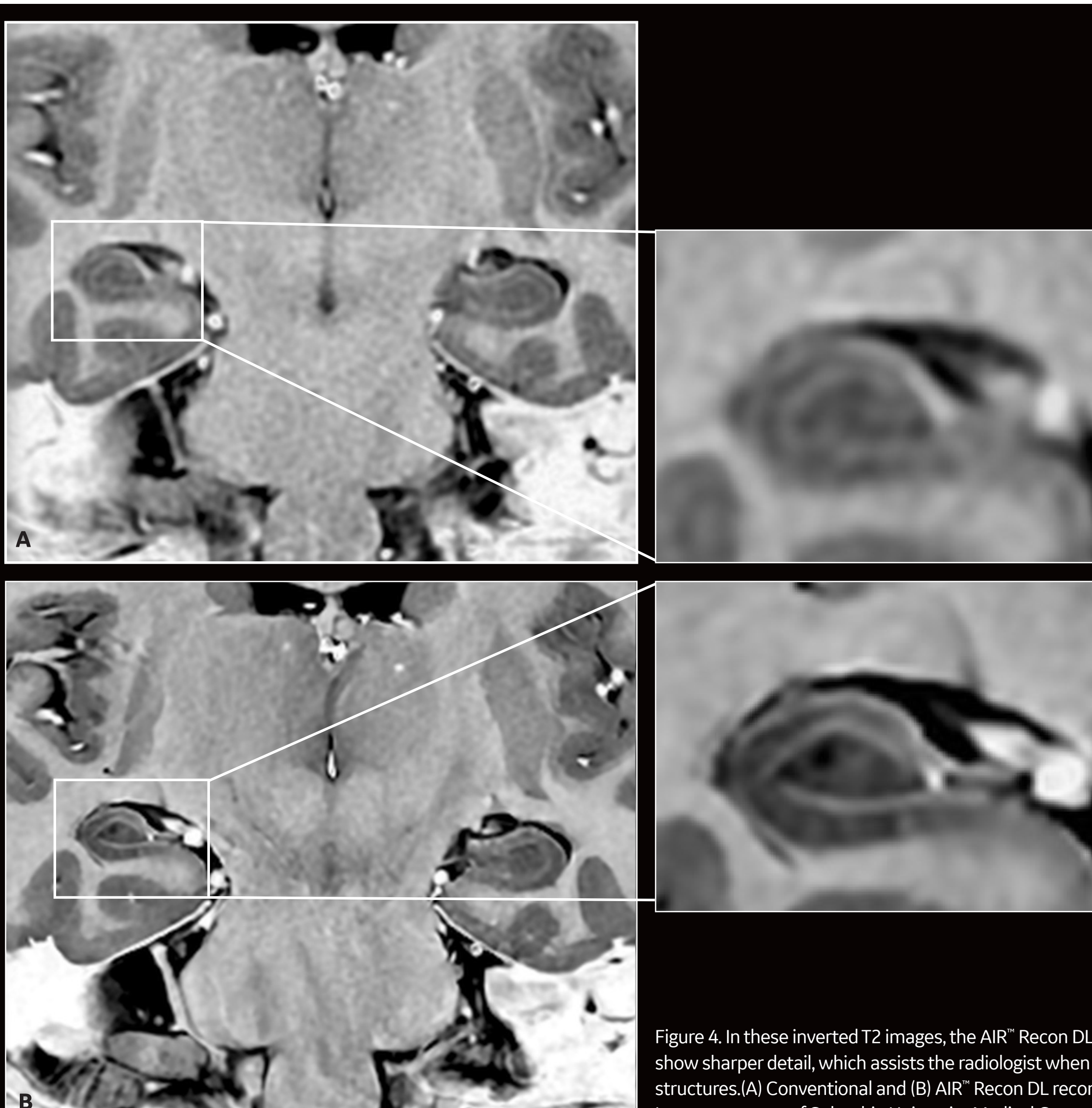

Figure 4. In these inverted T2 images, the AIR™ Recon DL zoomed images show sharper detail, which assists the radiologist when evaluating small structures.(A) Conventional and (B) AIR™ Recon DL reconstructed images. Images courtesy of Columbia University Medical Center.

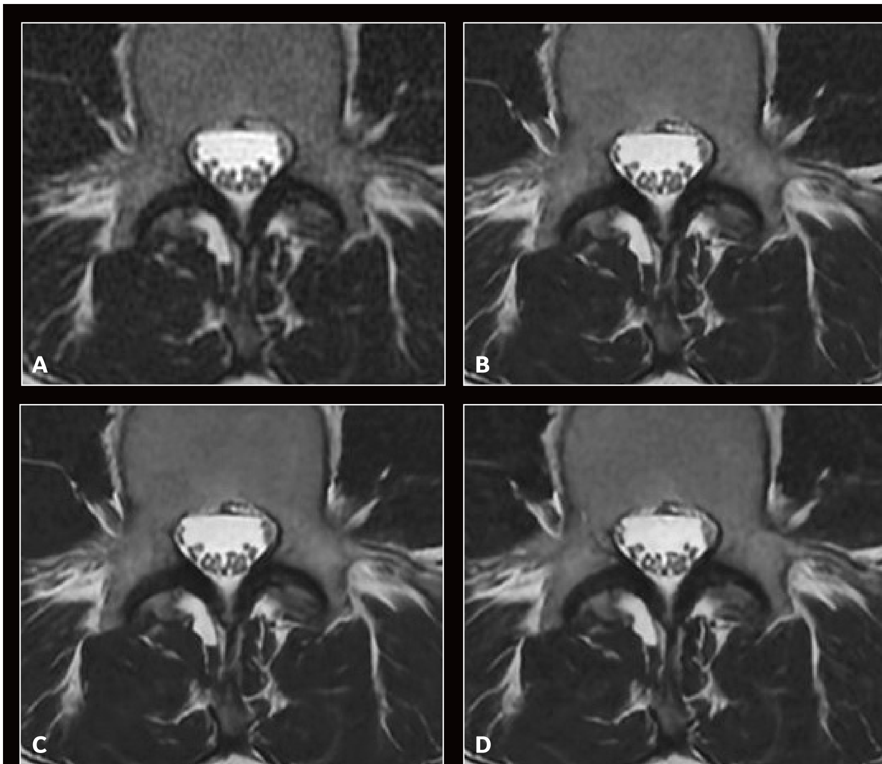

Figure 5. In addition to improving image quality, AIR™ Recon DL can also be used for faster imaging, including reducing NEX. (A) Original image, 2 NEX, 2:17 min. (B) AIR™ Recon DL low, 2 NEX, 2:17 min. (C) AIR™ Recon DL medium, 2 NEX, 2:17 min. (D) AIR™ Recon DL high, 1 NEX, 1:12 min.

For example, rather than utilize a T2 Flex scan that takes 2:40 minutes, Dr. Villanueva-Meyer suggests a T2 STIR that takes 1:51 minutes with AIR™ Recon DL and is similar in quality to the longer T2 Flex scan. Another example involves reducing NEX from 2 to 1 to cut scan time nearly in half while using AIR™ Recon DL to enhance the image – in some cases better than the original 2 NEX image – at a fraction of the scan time.

Implementing AIR™ Recon DL can be tailored to a specific institution's preferences, as well. Dr. Villanueva-Meyer advises that if the initial enhancement or change in image quality is perhaps too much or something the clinicians aren't accustomed to, the SNR improvement factor can be reduced and then gradually increased as the radiologists gain more experience with it.

"There is broad utility for using AIR™ Recon DL in diagnosis," Dr. Villanueva-Meyer adds. "Whether it is scanning the unstable patient, reducing scan time, reducing the artifacts from motion that occur, or bringing up the image quality and SNR, there's opportunity for improving throughput on an MR system."

For some institutions, the additional time savings afforded by AIR™ Recon DL can also facilitate research activities by increasing available scanner time.

"I'm really excited about applying this tool to cut the time for some sequences while maintaining diagnostic quality and, therefore, allowing more time for investigational sequences within the allotted scan time."

Dr. Javier Villanueva-Meyer

Conversely, Dr. Villanueava-Meyer adds there's a safety perspective as well, where facilities can speed up imaging and decrease exposure between patients and staff during the current pandemic setting.

References

1. Villanueva-Meyer J, Shin D, Li Y, et al. Denoising MR Images of the Cervical Spine: Multi-Reader Assessment of a Deep Learning Approach. Radiological Society of North America 2019 Scientific Assembly and Annual Meeting, December 1 - December 6, 2019, Chicago IL. archive.rsna.org/2019/19018947.html. Accessed October 7, 2020.

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Pushing the boundaries of MR by addressing limitations in SNR and scan time

by Mohyi Eldin Fahmy, MD, Consultant Radiologist, Head of Medical Imaging Department, Unison Group Hospitals, Sharjah, UAE

In 2016, Unison Group Hospitals collaborated with Abu Dhabi International Medical Services Company (ADI), a leading healthcare solutions provider representing some of the world's renowned medical equipment and pharmaceutical companies, and GE Healthcare, a global provider of transformational medical technologies and services. Under the terms of the contract, the operations and management of radiology services were outsourced to ADI at 11 affiliated hospitals, including Al Qassimi Hospital.

Al Qassimi Hospital, one of the largest government hospitals in Sharjah, United Arab Emirates (UAE), installed a SIGNA™ Pioneer 3.0T in December 2017. As part of the Unison collaboration (see sidebar), the system was upgraded to SIGNA™Works AIR™ Edition, which includes AIR™ Recon and AIR Touch™. The hospital also received the AIR™ Anterior Array (AA) Coil. In November 2020, the SIGNA™ Pioneer was upgraded to SIGNA™ Works AIR™ IQ Edition, which includes AIR™ Recon DL, HyperSense extensions and DISCO Star. As part of the evaluation agreement, we performed the same exams on a female pelvis and an ankle with the SIGNA™Works AIR™ Edition (PX28) and SIGNA™ Works AIR™ IQ Edition (PX29), and pulled

SIGNA™ Pioneer 3.0T with improvements due to AIR™ Recon DL

Exam	*Conventional pre-upgrade protocol* Total exam time (min.)	*AIR™ Recon DL protocol* Total exam time (min.)	*Exam time reduction*	*Average voxel size reduction*
Brain	14:45	8:24	42.6%	10%
Cervical spine	12:18	7:09	42%	16%
Lumbar spine	16:02	9:20	42%	33%
Shoulder	12:38	8:52	30%	17.6%
Knee	14:12	9:20	34%	15%
Ankle	14:44	7:54	42%	42%
Prostate	24:25	12:42	48%	24%
Female pelvis	25:34	16:23	36%	30%

comparison exams from the original installed software (PX26). Figures 1 and 2 illustrate the difference between these software versions.

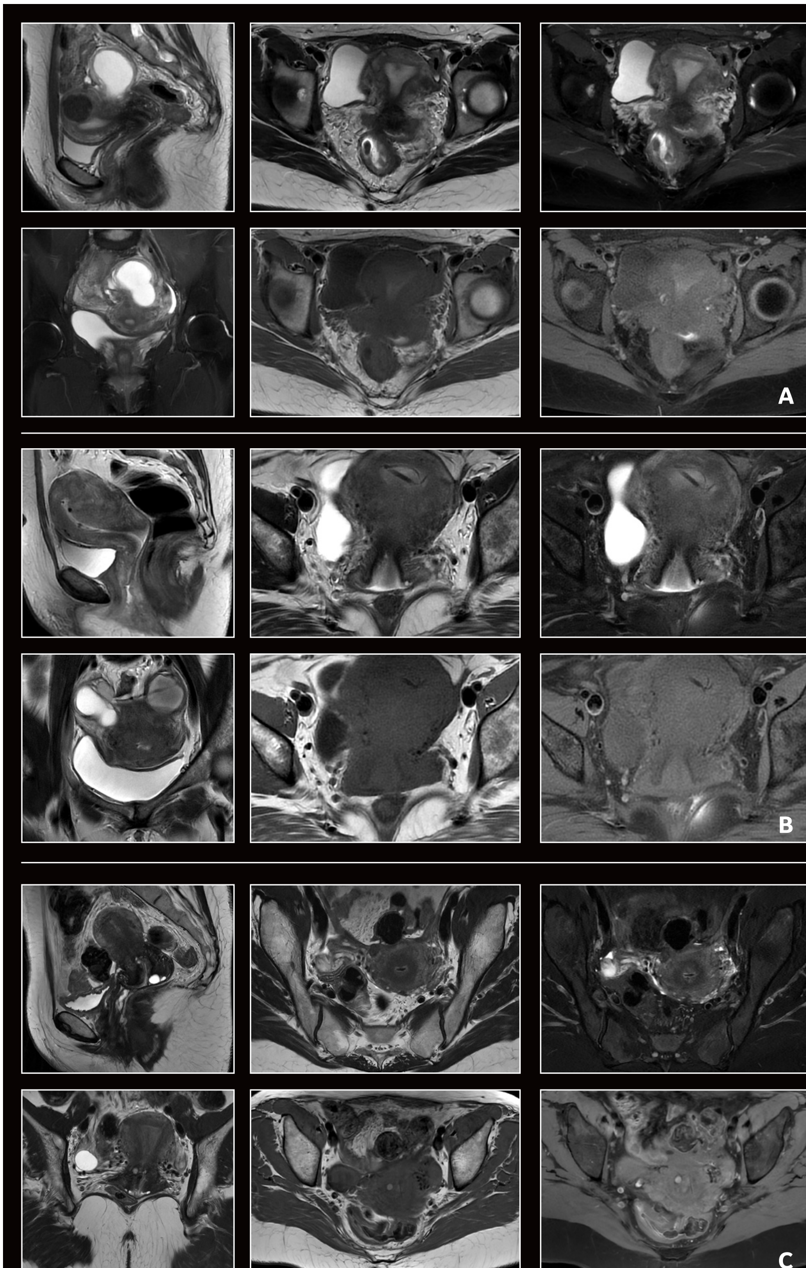
With the first upgrade to SIGNA™Works AIR™ Edition (PX28), we saw improvement in the image resolution and scan time reduction using AIR™ Recon and the AIR™ AA Coil:

- Female pelvis: 24% increase in resolution and 11% scan time reduction (Figure 1B).
- Ankle: 15% increase in resolution and 47% scan time reduction (Figure 2B).

With the second upgrade to SIGNA™ Works AIR™ IQ Edition (PX29), featuring AIR™ Recon DL, we experienced further improvement in resolution and scan time reduction:

- Female pelvis: 41% increase in resolution and 43% scan time reduction (Figure 1C).
- Ankle: 61% increase in resolution and 59% scan time reduction (Figure 2C).

AIR™ Recon DL, an innovative, deep-learning reconstruction technology from GE Healthcare, changes our approach to MR imaging and how we utilize the



Standard protocol (conventional pre-upgrade)

Female pelvis	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Sagittal T2	3:36	0.81	0.81	4
Axial T2	3:04	0.75	0.75	4
Axial T2 FatSat	3:08	0.83	0.83	4
Coronal T2 FatSat	3:19	0.83	0.83	4
Axial T1	3:20	0.83	0.83	5
Axial T1 FatSat	3:20	0.9	0.9	5
Total scan time	19:47			

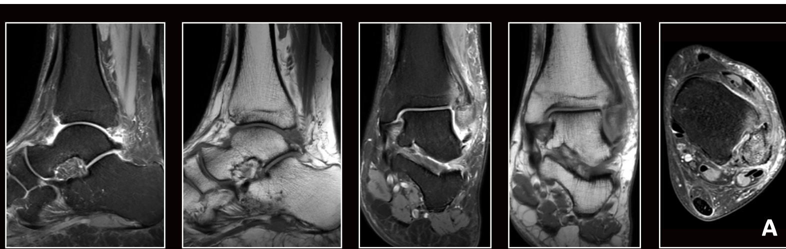
High-resolution protocol (with AIR™ Recon)

Female pelvis	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Sagittal T2	3:08	0.75	0.75	4
Axial T2	2:42	0.6	0.6	4
Axial T2 FatSat	2:58	0.6	0.6	4
Coronal T2 FatSat	2:42	0.6	0.6	4
Axial T1	2:46	0.6	0.6	5
Axial T1 FatSat	3:26	0.85	0.9	5
Total scan time	17:42	***A 24% decrease in voxel size from conventional***		

HyperSpeed protocol (with AIR™ Recon DL)

Female pelvis	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Sagittal T2	2:20	0.5	0.75	3
Axial T2	1:49	0.52	0.7	3
Axial T2 FS	2:10	0.56	0.75	3
Coronal T2 FatSat	1:51	0.56	0.7	3
Axial T1	1:14	0.8	0.8	4
Axial T1 FatSat	1:57	0.85	1	4
Total scan time	11:21	***A 41% decrease in voxel size from conventional***		

Figure 1. Comparison of image quality, resolution and scan time in female pelvis exams from (A) conventional, pre-upgrade software in December 2017 to (B) the SIGNA™Works AIR™ Edition in January 2020 and (C) SIGNA™Works AIR™ IQ Edition in November 2020. With the upgrade using AIR™ Recon, Al Qassimi increased resolution by 24% and simultaneously reduced scan time by 11%. After the second upgrade using AIR™ Recon DL, Al Qassimi increased resolution by 41% and simultaneously reduced scan time by 43%, cumulatively.

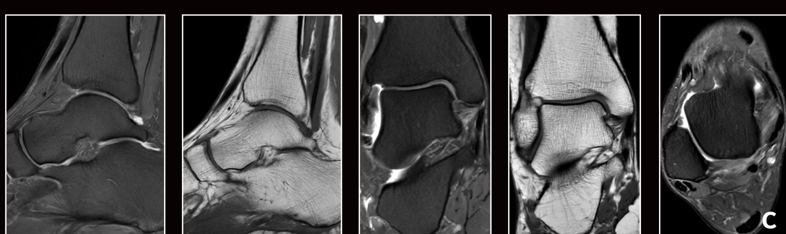


Standard protocol (conventional pre-upgrade)

Ankle	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Sagittal PD FatSat	4:40	0.81	0.81	3
Sagittal T1	3:40	0.55	0.55	3
Coronal PD FatSat	4:24	0.6	0.8	3.5
Coronal T1	2:15	0.46	0.57	3.5
Axial PD FatSat	4:08	0.55	0.6	3
Total scan time	19:07			

High-resolution protocol (with AIR™ Recon)

Ankle	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Sagittal PD FatSat	2:29	0.55	0.6	3
Sagittal T1	1:38	0.53	0.53	3
Coronal PD FatSat	2:04	0.5	0.75	3.5
Coronal T1	1:44	0.4	0.5	3.5
Axial PD FatSat	2:18	0.52	0.58	3
Total scan time	10:13	***A 15% decrease in voxel size from conventional***		



HyperSpeed protocol (with AIR™ Recon DL)

Ankle	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Sagittal PD FatSat	1:38	0.35	0.46	3
Sagittal T1	1:32	0.35	0.4	3
Coronal PD FatSat	1:40	0.37	0.4	3
Coronal T1	1:44	0.3	0.4	3
Axial PD FatSat	1:20	0.4	0.4	3
Total scan time	7:54	***A 61% decrease in voxel size from conventional***		

Figure 2. Comparison of image quality, resolution and scan time in ankle exams from (A) conventional, pre-upgrade software in December 2017 to (B) the SIGNA™Works AIR™ Edition and (C) SIGNA™ Works AIR™ IQ Edition. With the upgrade using AIR™ Recon, Al Qassimi Hospital increased resolution by 15% and simultaneously reduced scan time by 47%. After the second upgrade using AIR™ Recon DL, Al Qassimi increased resolution by 61% and simultaneously reduced scan time by 59%, cumulatively.

system due to its improvement in image quality and significant reduction in scan time.

The impact on reducing scan times is so pronounced that we refer to specific protocols in seconds, not minutes.

This is important when we have patients coming from the emergency room or intensive care unit. For example, we can now acquire an MR brain stroke protocol in just 137 seconds (2:17 minutes).

Previously with MR imaging, we could not achieve these HyperSpeed exams or obtain small slice thickness with high in-plane resolution in a very short scan time. The implementation of AIR™ Recon DL has changed the way we work on the SIGNA™ Pioneer and helped us appreciate what MR can be.

Another example of how the upgrade has changed our protocols and scanning techniques is a pituitary gland exam. Usually, we are looking for small slice thickness and field of view (FOV). Previously we were limited with changing the parameters on the system. After the upgrade with AIR™ Recon DL we are able to acquire uncal sella turcica for sagittal T2 using 12 cm FOV, 1.5 mm slice thickness in 2 minutes and 17 seconds. In our facility, acquiring with these parameters could not be done on any system before the SIGNA™ Works AIR™ IQ Edition (PX29) upgrade. Scanning with such ultra-high resolution and utilizing AIR™ Recon DL allows us to complete this exam using four sequences with 1.5 mm slice thickness, 12 cm FOV in 7:56 minutes compared to scanning one sagittal T2 sequence using the standard protocol with conventional reconstruction in 6:36 minutes (Figures 3 and 4).

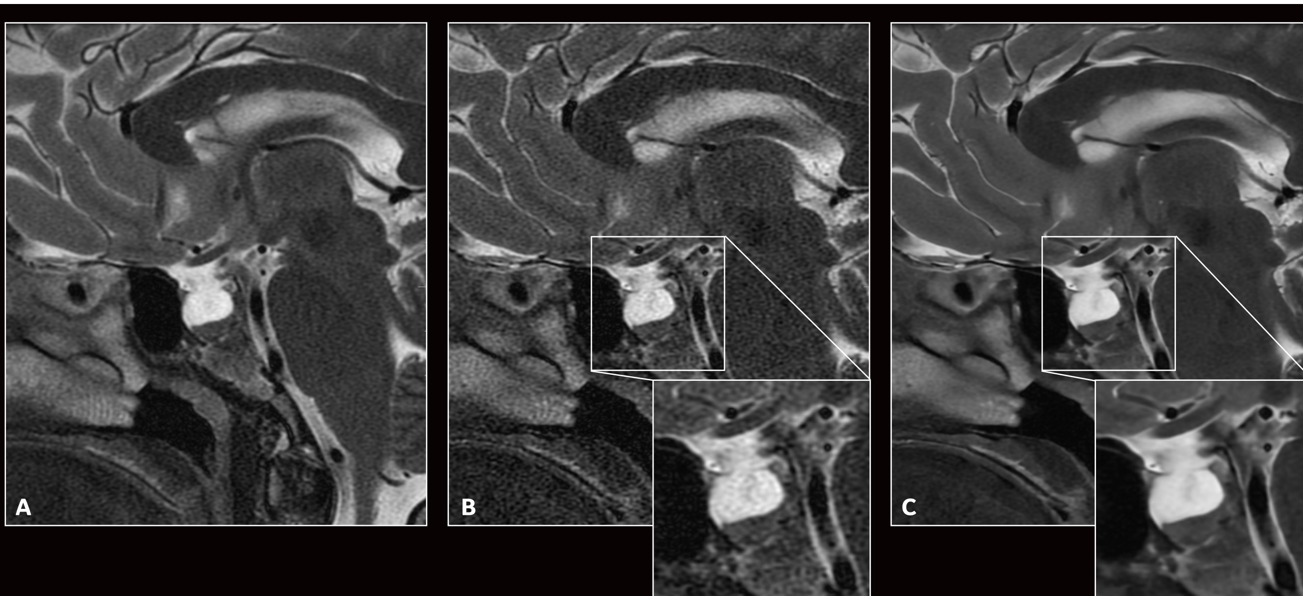


Figure 3. Using AIR™ Recon DL, Al Qassimi Hospital can reduce NEX from 6 to 1, resulting in exceptional SNR and image quality while also reducing scan time by 65%. (A) Sagittal T2, 0.4 x 0.5 x 1.5 mm, 6 NEX, 18 slices in 6:36 min. with conventional reconstruction; (B) sagittal T2, 0.4 x 0.5 x 1.5 mm, 1 NEX, 18 slices in 2:14 min. with conventional reconstruction; and (C) sagittal T2, 0.4 x 0.5 x 1.5 mm, 1 NEX, 18 slices in 2:14 min. with AIR™ Recon DL.

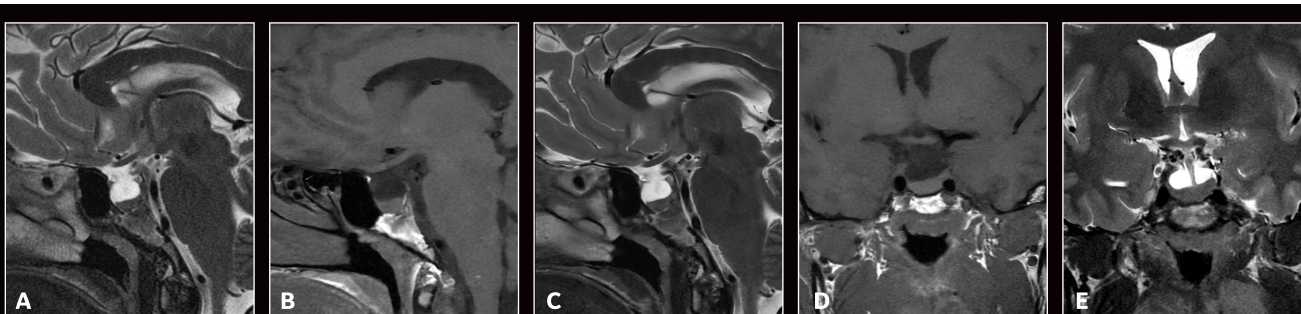


Figure 4. (B-E) Using AIR™ Recon DL allows Al Qassimi Hospital to capture more imaging data – 4 sequences – in approximately the same time it took to capture one sequence with (A) conventional reconstruction. (A) Sagittal T2, 0.4 x 0.5 x 1.5 mm, 6 NEX, in 6:36 min. with conventional reconstruction compared to AIR™ Recon DL reconstructed; (B) sagittal T1, 0.4 x 0.6 x 1.5 mm, 1 NEX, in 2:34 min.; (C) sagittal T2, 0.4 x 0.5 x 1.5 mm, 1 NEX in 2:17 min.; (D) coronal T1, 0.4 x 0.6 x 1.5 mm, 1 NEX, in 1:54 min.; and (E) coronal T2, 0.4 x 0.5 x 1.5 mm, 1 NEX, in 1:11 min.

We then applied this same concept on different anatomical body parts. In the lumbar spine exam, T1 acquisition with 2.5 mm slices would take around 6:12 minutes using 2 NEX. With AIR™ Recon DL, we have managed to decrease the scan time by reducing NEX to 1 for all our sequences. Instead of scanning one sequence in 6 minutes with very thin slices, we are now able to scan three sequences – sagittal T1, sagittal T2, and sagittal T2 FatSat – in a total scan time of 7:26 minutes (Figures 5 and 6).

In MR, there is an inherent compromise between image quality and scan time. Higher image quality, achieved through higher SNR and/or spatial resolution, necessitates longer scan times, whereas faster scans often compromise image quality and diagnostic confidence. Compared to conventional protocols, AIR™ Recon DL provides much higher SNR due to the noise-reduction performance and removal of ringing artifact. Now we can visualize quite small anatomy in detail with less blurring.

We have changed all the protocols on our SIGNA™ Pioneer system by increasing spatial resolution with significant scan time reduction. This has also changed our patient scheduling.

AIR™ Recon DL offers a fundamental shift in the balance between image quality and scan time. It provides the opportunity to adjust the protocol for each anatomical area. We have worked closely with the GE MR clinical team to optimize different protocols. For example, our conventional brain protocol before AIR™ Recon DL was 14:45 minutes. After the upgrade, we developed three different protocols utilizing AIR™ Recon DL (Figure 7):

- **Standard protocol** providing 42.6% scan time reduction and 10% voxel gain in the resolution.
- **High-resolution protocol** for a 55% decrease in voxel size compared to our conventional protocol. This is important to utilize in cases of multiple sclerosis or white matter disease.

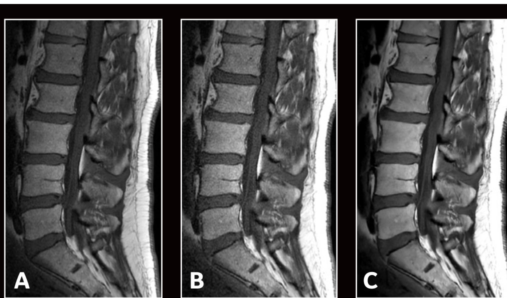


Figure 5. AIR™ Recon DL allows for higher SNR with a lower NEX for shorter scan times. Conventionally reconstructed (A) sagittal T1, 0.7 x 1 x 2.5 mm, 2 NEX, 6:12 min. and (B) sagittal T1, 0.7 x 1 x 2.5 mm, 1 NEX, 3:09 min. (C) AIR™ Recon DL reconstructed sagittal T1, 0.7 x 1 x 2.5 mm, 1 NEX, 3:09 min. Note the higher SNR between (B) the conventional reconstructed image and (C) the AIR™ Recon DL reconstructed image.

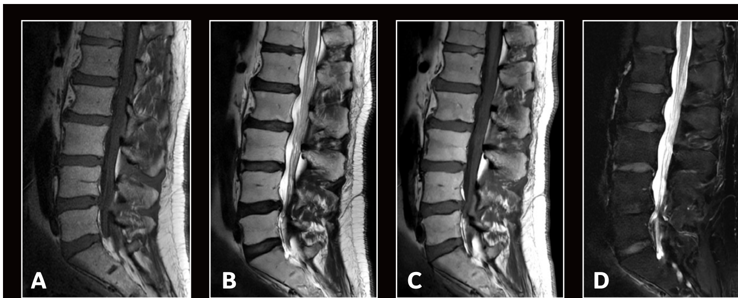
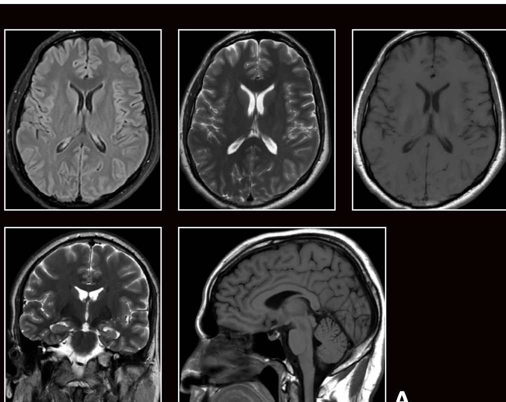
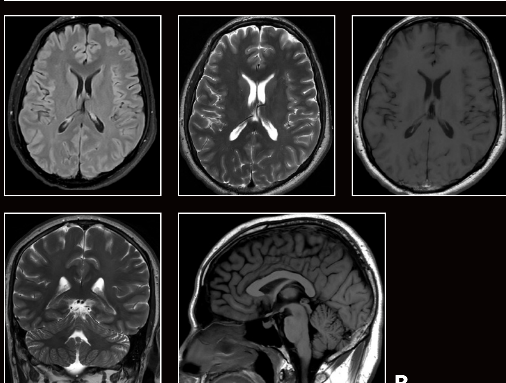


Figure 6. Using AIR™ Recon DL allows Al Qassimi Hospital to capture more imaging data – 3 sequences – in a slightly longer scan time than it took to capture one sequence with conventional reconstruction. (A) Conventionally reconstructed sagittal T1, 0.7 x 1 x 2.5 mm, 6:12 min. compared to the AIR™ Recon DL reconstructed images: (B) Sagittal T2, 0.6 x 0.7 x 2.5 mm, 2:08 min.; (C) sagittal T1, 0.7 x 1 x 2.5 mm, 3:09 min.; and (D) sagittal T2 FatSat, 0.7 x 0.8 x 2.5 mm, 2:09 min.



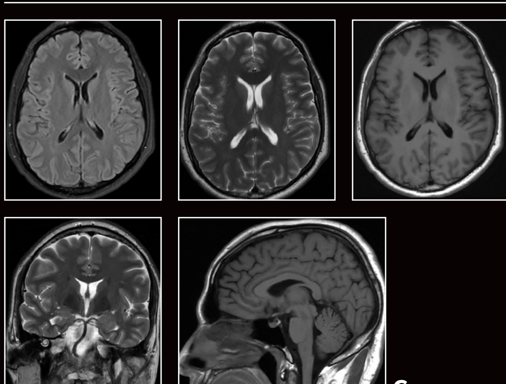
Standard protocol (conventional pre-upgrade)

Brain	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Axial T2 FLAIR	2:25	0.75	1.2	4
Axial T2 frFSE	1:04	0.6	0.6	4
Axial T1 FSE	1:27	0.7	1	4
Coronal T2 frFSE	1:18	0.6	0.6	4
Sagittal T1 FLAIR	1:18	0.7	0.9	4
Axial DWI	0:52	***Scan time reduction: 42.6%***		
Total scan time	8:24	***Voxel resolution gain: 10%***		



High-resolution protocol (with AIR™ Recon)

Brain	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Axial T2 FLAIR	3:33	0.6	1	3
Axial T2 frFSE	2:34	0.37	0.4	3
Axial T1 FSE	2:36	0.6	0.9	3
Coronal T2 frFSE	2:36	0.4	0.4	4
Sagittal T1 FLAIR	2:30	0.6	0.8	3
Axial DWI	0:52	***Voxel resolution gain: 55% with same time as conventional pre-upgrade protocol***		
Total scan time	14:41			



HyperSpeed protocol (with AIR™ Recon DL)

Brain	Scan time (min.)	In-plane resolution (mm)		Slice (mm)
		Frequency	Phase	
Axial T2 FLAIR	1:17	0.8	1.25	4
Axial T2 frFSE	0:48	0.6	0.9	4
Axial T1 FSE	0:51	0.75	1.2	4
Coronal T2 frFSE	0:48	0.6	1	4
Sagittal T1 FLAIR	0:56	0.7	1	4
Axial DWI	0:28	***Scan time reduction: 65%***		
Total scan time	5:08	***Voxel resolution gain: 10%***		

Figure 7. Using AIR™ Recon DL, Al Qassimi has developed three different brain imaging protocols: (A) standard protocol, (B) high-resolution protocol and (C) HyperSpeed (5:08 min.) protocol.

- **HyperSpeed protocol** enabling a complete brain scan in 308 seconds (5:08 minutes). This is a very important protocol for our institution because we have many patients from the ER or ICU who cannot stay still for a long scan. It matters when we tell our patients or attending physician that the exam will take seconds instead of minutes.

There is broad utility for using AIR™ Recon DL in diagnostic imaging. Whether it is scanning an unstable patient, reducing scan time, reducing motion artifacts that can occur or increasing the image quality and SNR, there is ample opportunity for improving the throughput on an MR system. Significant changes can be applied for certain anatomical regions, such as scanning the cartilage of the patella using an ultra-high matrix resolution. Now, we are able to reach a *micrometer* compared to the *millimeter* matrix we obtained before. We have performed an axial PD for the patella cartilage with 0.2 x 0.2 x 2 mm in only 2:27 minutes (Figure 8).

The enhanced performance of our SIGNA™ Pioneer system with SIGNA™Works AIR™ IQ Edition (PX29) is apparent when scanning very large or obese patients. In an ascites case, the homogeneity of the system allows us to scan a large FOV with FatSat with great results. Adding the capability of AIR™ Recon DL with the AIR™ AA Coil, we can acquire excellent images in a challenging exam with axial T2 FatSat, coronal T2 FatSat and 3D MRCP.

The addition of AIR™ Recon DL now offers exciting new methods to mitigate traditional compromises in MR imaging by reducing image artifacts and generating clearer, higher quality images than previously obtainable from the same MR data.

AIR™ Recon DL is an excellent tool to also improve workflow. With it, we can now increase the number of exams per hour, and the cumulative impact at the end of each day will be significant.

After the post-pandemic situation in the UAE, our volume has been increasing very fast and the innovations by GE have helped us to more easily accommodate this increased demand for MR imaging. AIR™ Recon DL is a game-changer and the future of MR for us.

It enables every MR technologist in our department to become an expert on the SIGNA™ Pioneer system. As radiologists, we appreciate the impact of high-resolution imaging and short scan times on patient care and the ability to push the boundaries of imagining what MR can be. Ⓢ

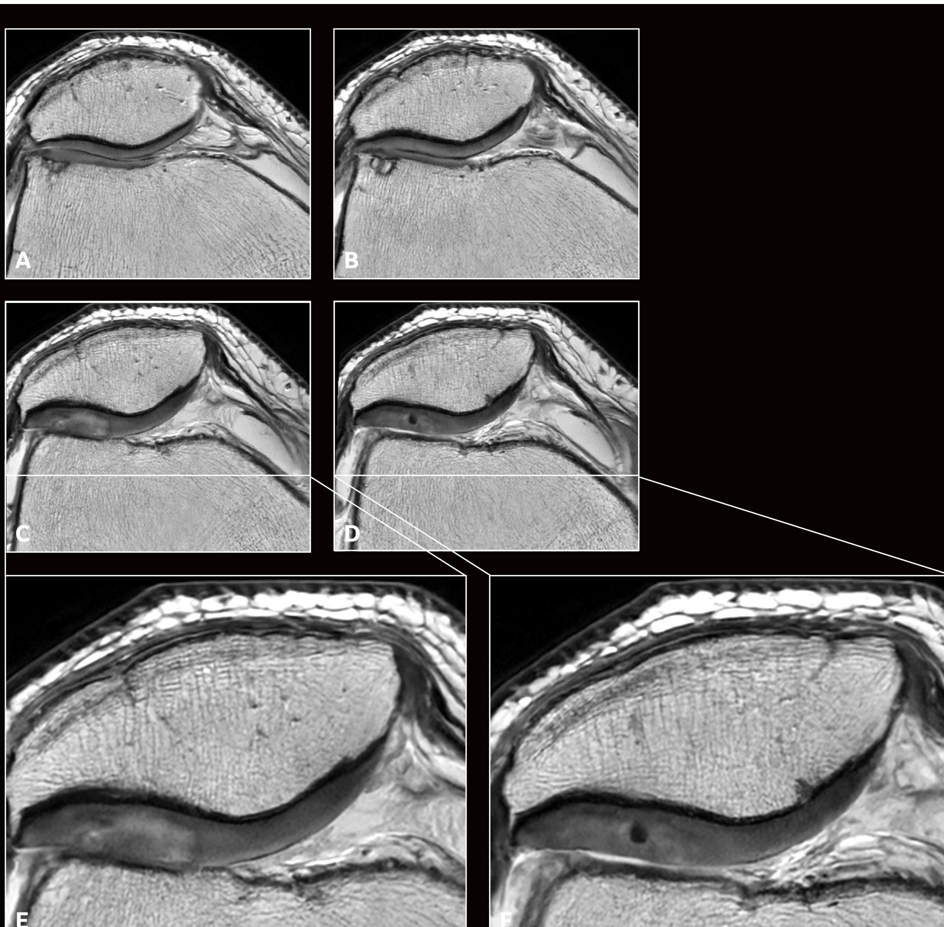


Figure 8. With AIR™ Recon DL in MSK imaging, Al Qassimi Hospital can obtain a micrometer matrix compared to the millimeter matrix we obtained before. These images show the cartilage of the patella using an ultra-high matrix resolution. (A-F) Axial PD, 0.2 x 0.2 x 2 mm, 2:27 min. with E and F being C and D magnified, respectively.

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High spatial resolution biliary tree imaging for the evaluation of cholangitis with focal steatosis

by Lionel Meyer-Bisch, MD, radiologist, and Fabien Lacour, RT(MR), technologist, Clinic Charcot, Lyon, France

Patients with inflammatory bowel disease such as ulcerative colitis and Crohn's disease are routinely followed using laboratory tests to detect primary sclerosing cholangitis. While liver biopsy is often employed for an initial diagnosis, it is invasive with the potential for complications, including bleeding and infection.

An MR exam is an ideal alternative to biopsy for diagnosis and monitoring the progression of disease, as well as treatment response assessment.

The MR exam requires high spatial resolution imaging for depiction of the biliary tree in order to detect multifocal short segmental strictures and mild dilatation in the intrahepatic and extrahepatic bile ducts alternating with normal ducts, which sometimes produce "beaded" appearance. As the fibrosis progresses and strictures worsen, the peripheral bile ducts are obliterated and become poorly visualized on MR cholangiography showing a "pruned tree" appearance.

SIGNA™ Pioneer 3.0T

	Coronal T2 SSFSE
TR (ms):	8000
TE (ms):	900
FOV (cm):	31
Slice thickness (mm):	20
Frequency:	512
Phase:	512
NEX:	1
Scan time (min):	1:14
Options/other (b-value, no-phase wrap, etc.):	FatSat, ARC

Therefore, using MR sequences that improve visualization of these small distal biliary ducts is essential to avoid overdiagnosis.

Recently, our clinic upgraded an existing SIGNA™ Pioneer 3.0T MR system with SIGNA™Works (PX26) software to SIGNA™Works AIR™ IQ Edition (PX29), featuring AIR™ Recon DL, a deep-learning-based reconstruction. We also added the 30-channel AIR™ Anterior Array (AA) Coil. The combination of the new coil and AIR™ Recon DL increased SNR and contrast-to-noise ratio (CNR), improving the overall quality of the study. We can now more clearly visualize the small structures, such as the very distal, tiny bile ducts, to help differentiate between obliterated ducts and poorly visualized ducts due to a lack of signal, for an accurate and confident diagnosis.

With the increase in SNR and CNR, we can increase the matrix from 512 x 352 to 512 x 512, as well as the acceleration factor (allowing scan time savings). Alternatively, we can maintain the same scan time and further increase resolution.

Patient history

A 31-year-old female with a history of ulcerative colitis. Since 2011, the patient has undergone yearly MR exams to monitor disease progression and detect complications, such as stones and colangiocarcinoma.

Discussion

Higher resolution and clearer depiction of the biliary tree provides the radiologist with added confidence in the diagnosis. In the patient's exam prior to the upgrade, it is difficult to determine whether the distal bile ducts are obliterated, or normal but not visualized. There is less resolution and signal compared to the quality of the images after the upgrade with AIR™ Recon DL.

Exam quality impacts not only clinical confidence, but also the time required to evaluate the images. An efficient and confident diagnosis is essential in these cases. In patient exams with questionable results, we will examine the pancreatic duct; good definition and depiction of it will help with the evaluation of the bile ducts, as well.

SnapShot SSFSE is a single-shot sequence for free-breathing, fast T2 imaging. It also delivers with better signal in the parenchyma with less shading and less noise, especially in the right liver.

The AIR™ AA Coil provides a larger anatomical field-of-view coverage, allowing the technologist to capture more anatomy with very good signal without repositioning the coil. It is more comfortable and lighter than conventional coils, which helps limit patient movement.

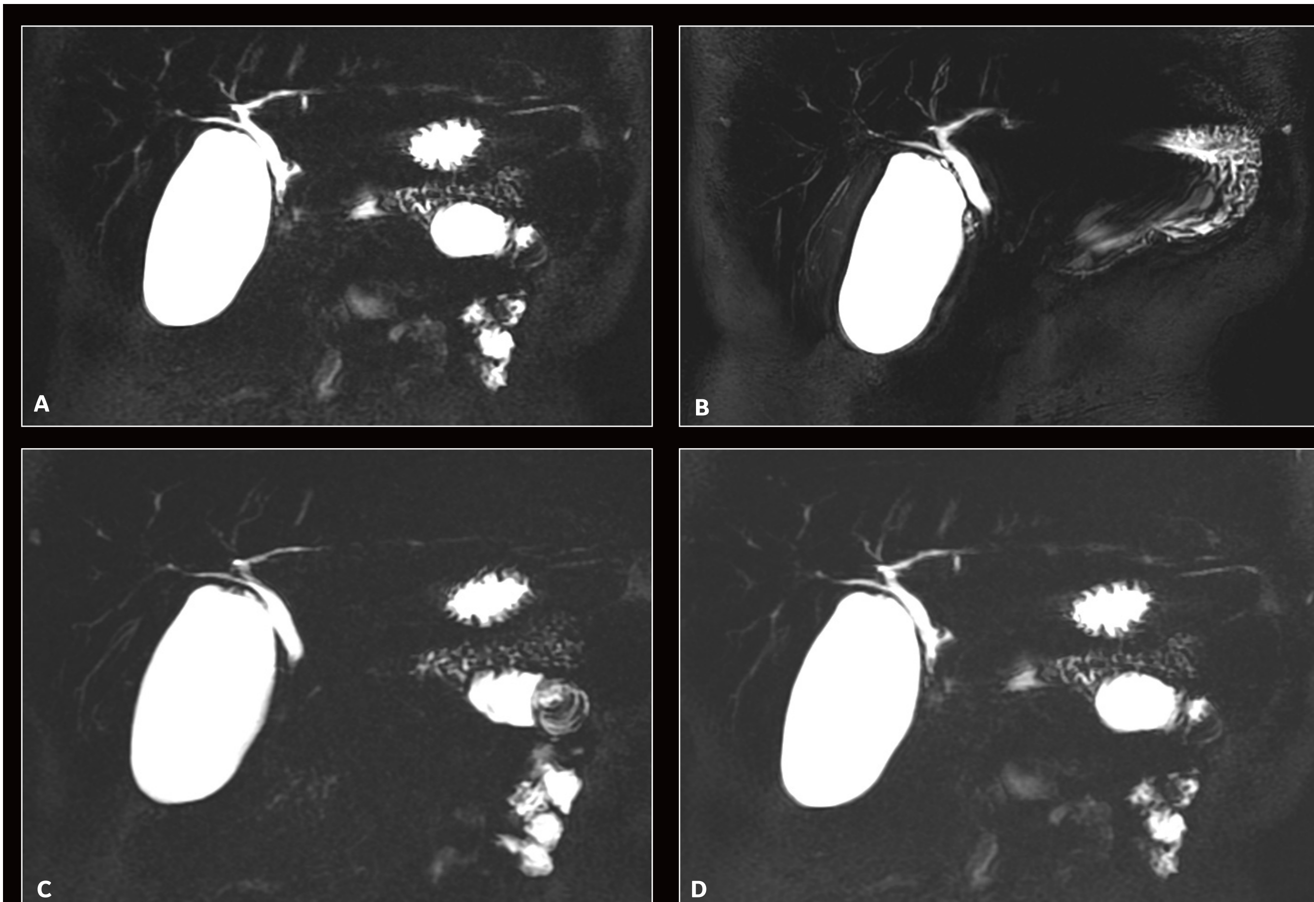

Figure 1. Comparison of coronal T2 SSFSE long TE from (A, C) a prior exam using SIGNA™Works (PX26) and (B, D) after the upgrade to SIGNA™Works AIR™ IQ Edition (PX29) featuring AIR™ Recon DL and the 30-channel AIR™ AA Coil. Note how much more clearly the biliary tree is visualized in the images post-upgrade using AIR™ Recon DL. Improvements include increased matrix and shorter scan time. (A) TR=8000, TE=800, 512 x 352 matrix, 1 NEX, 1:38 min. (B) TR=8000, TE=900, 512 x 512 matrix, 1 NEX, 1:14 min.

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High resolution and SNR with free-breathing, dynamic abdominal imaging

by Professor Ercan Karaarslan, MD, Director of Radiology, Maslak Acibadem Hospital, Istanbul, Turkey

A SIGNA™ Premier 3.0T MR system was installed at Maslak Acibadem Hospital in February 2020. As part of an early adopter program, the system was upgraded to the new SIGNA™Works AIR™ IQ Edition software in November 2020, providing the hospital with new imaging and reconstruction capabilities including: AIR™ Recon DL, HyperSense, DISCO Star and LAVA Star. Advanced utilization of our high-performance MR systems, including whole-body imaging, is essential for delivering differential diagnoses across clinical disciplines in our institution.

Case 1

Patient history

An 80-year-old female with abdominal pain and vomiting was diagnosed with a gallbladder tumor and gallstones in June 2020. FDG-PET showed no indication of distant organ metastasis. Surgery was not recommended by a hepatobiliary surgeon. The patient instead received transarterial radioembolization (TARE) and chemotherapy (GEMOX). A stent was also placed for the patency of obstruction. Two months later the patient was referred to MR with abdominal pain and fever.

Technique

In the initial exam, the patient was not able to tolerate even short breath-holds for the MR exam. Therefore, a combination of respiratory-gating and respiratory-triggered applications, such as SSFSE and DISCO with Auto Navigator, were utilized to enable motion-free data acquisitions. In a dynamic contrast-enhanced series, irregular breathing may cause slight motion artifacts; however, the images were diagnostic quality despite the difficult patient conditions (see Figure 1). The MR exam depicted an abscess on the right lobe with multiple pericholangitis hepatic abscesses most prominent at segment 8.

The patient was referred for a follow-up MR exam after a percutaneous abscess drainage was performed by an interventional radiologist. This occurred after the upgrade to SIGNA™Works AIR™ IQ Edition, which provides more motion-robust data acquisition techniques such as SnapShot SSFSE, DISCO Star and LAVA Star. Both DISCO Star and LAVA Star are less sensitive to respiratory motion. Patients with limited breath-hold capability or who are unable to follow breathing commands can now complete a free-breathing abdominal exam including dynamic imaging (Figures 2-3) or a single-phase abdominal imaging exam. Therefore, we utilized free-breathing dynamic DISCO Star and post-gadolinium delayed phase imaging with LAVA Star in this case (Figure 2).

Results

Utilizing the SnapShot SSFSE sequence using AIR™ Recon DL, and the DWI using AIR™ Recon, provided clear visualization of the lesion regression (Figure 3). AIR™ Recon DL is a deep-learning-based reconstruction algorithm that improves SNR and image sharpness while reducing scan times. AIR™ Recon is a reconstruction algorithm that uses data acquired during prescan and then weights the receive channels according to their noise level for cleaner, sharper images.

The increase in image quality after the upgrade to SIGNA™Works AIR™ IQ Edition can be best appreciated by comparing the patient's two MR exams conducted before the upgrade in September 2020 and after in November 2020 (Figure 4).

Case 2

Patient history

A 48-year-old female with uveal malignant melanoma that was surgically resected. She was referred for a follow-up post chemotherapy (Taxol) for liver metastasis.

Small and hypervascular lesions are challenging to depict with dynamic MR acquisitions. High temporal resolution is necessary to detect signal changes over time (phases) with thinner slice thickness in order to visualize smaller lesions, which can increase scan times. Previously, even when the patient complied, a conventional MR system may not be equipped to provide these imaging requirements.

SIGNA™ Premier 3.0T (Figure 1. Case 1.)

Image	*Scan Plane*	*Contrast*	*Application*	*Resolution (mm)*	*Scan Time (min.)*	*Date*
A	Axial	T2 FatSat RTr	PROPELLER	1.2 x 1.2 x 4.5	4:02	June 2020
B	Axial	T2 RTr	SSFSE	1.0 x 1.6 x 4.5	1:36	
C	Axial	DWI RTr	eDWI	3 x 2.4 x 4.5	1:42	
D	Axial	ADC	eDWI	3 x 2.4 x 4.5	1:42	

SIGNA™ Premier 3.0T (Figure 2. Case 1.)

Image	*Scan Plane*	*Contrast*	*Application*	*Resolution (mm)*	*Temp Res*	*Date*
A	Axial	Pre-contrast	DISCO Star	1.3 x 1.3 x 4	17 sec/phase	November 2020
B	Axial	Early arterial	DISCO Star	1.3 x 1.3 x 4	17 sec/phase	
C	Axial	Arterial	DISCO Star	1.3 x 1.3 x 4	17 sec/phase	
D	Axial	Portal	DISCO Star	1.3 x 1.3 x 4	17 sec/phase	
E	Axial	Delayed	LAVA Star	1.3 x 1.3 x 4	1:27	

SIGNA™ Premier 3.0T (Figure 3. Case 1.)

Image	*Scan Plane*	*Contrast*	*Application*	*Resolution (mm)*	*Scan Time (min.)*	*Date*
A (AIR™ Recon DL)	Coronal	T2 Nav	SnapShot SSFSE	1.1 x 1.7 x 4	1:31	November 2020
B (AIR™ Recon DL)	Axial	T2 Nav	SnapShot SSFSE	1.3 x1.9 x 1.5	1:39	
C (AIR™ Recon DL)	Axial	T2 FatSat Nav	SnapShot SSFSE	1.3 x 1.9 x 1.5	1:39	
D&E	Axial	DWI RTr	eDWI	3.3 x 2.6 x 5	2:57	
E	Axial	ADC	eDWI	3.3 x 2.6 x 5	2:57	
F	Axial	DWI b1500	MAGiC DWI	3.3 x 2.6 x 5	2:57	

SIGNA™ Premier 3.0T (Figure 4. Case 1.)

Image	*Scan Plane*	*Contrast*	*Application*	*Resolution (mm)*	*Scan Time (min.)*	*Date*
A (Conventional)	Coronal	T2 RTr	SSFSE	1.2 x 1.5 x 4.5	0:47	June 2020
B (AIR™ Recon DL)	Coronal	T2 Nav	SnapShot SSFSE	1.1 x 1.7 x 4	1:31	November 2020
C	Axial	T1 dynamic	DISCO Nav	1.6 x 2.1 x 4	17 sec/phase	June 2020
D	Axial	T1 dynamic	DISCO Star	1.3 x 1.3 x 4	17 sec/phase	November 2020

SIGNA™ Premier 3.0T (Figure 5. Case 2.)

Image	*Scan Plane*	*Contrast*	*Application*	*Resolution (mm)*	*Temp Res*
A	Axial	T1 dynamic	DISCO HyperSense	1.2 x 1.8 x 3.6	5 sec/phase
B	Axial	Pre-contrast	DISCO HyperSense	1.2 x 1.8 x 3.6	5 sec/phase
C	Axial	Multi-arterial	DISCO HyperSense	1.2 x 1.8 x 3.6	5 sec/phase
D	Axial	Multi-arterial	DISCO HyperSense	1.2 x 1.8 x 3.6	5 sec/phase
E	Axial	Portal	DISCO HyperSense	1.2 x 1.8 x 3.6	5 sec/phase
F	Axial	Equilibium	DISCO HyperSense	1.2 x 1.8 x 3.6	0:15
G	Axial	Delayed	LAVA-Flex HyperSense	1.1 x 1.5 x 4	0:12

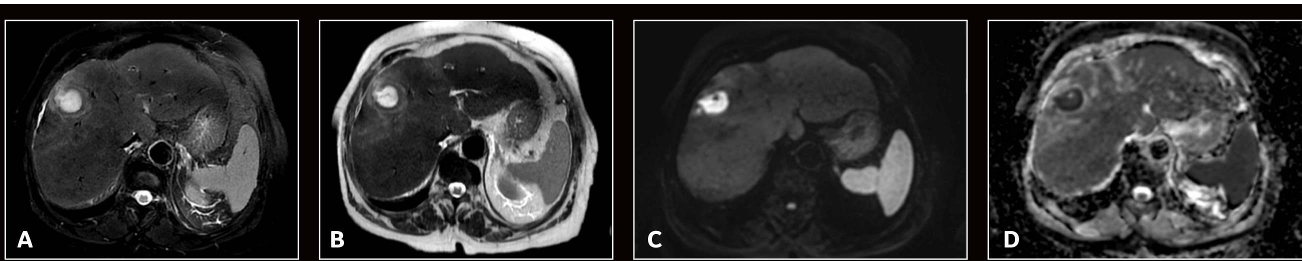

Figure 1. Case 1. (A) PROPELLER, (B) SSFSE, (C) DWI b=800 and (D) ADC on SIGNA™ Premier prior to the SIGNA™Works AIR™ IQ Edition software upgrade.

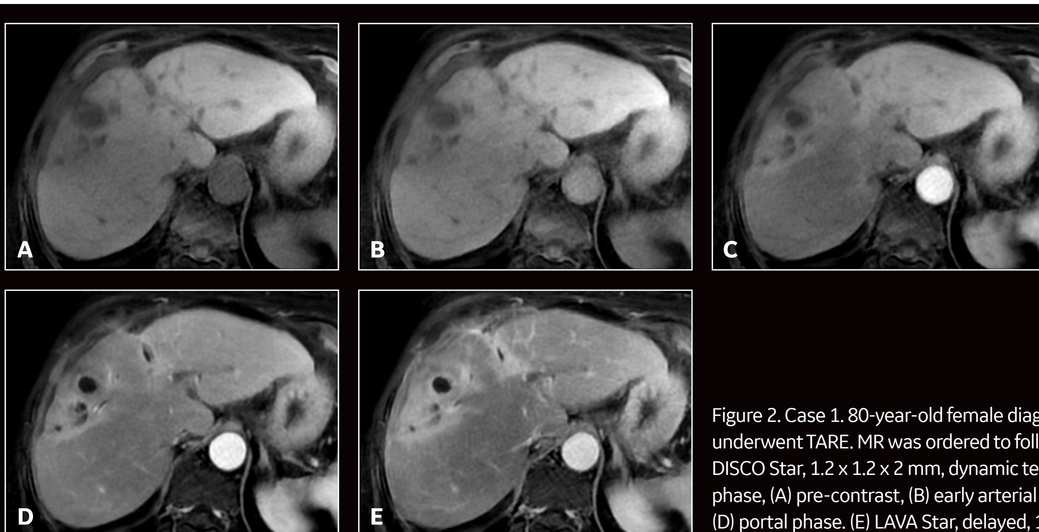

Figure 2. Case 1. 80-year-old female diagnosed with gallbladder tumor underwent TARE. MR was ordered to follow up R-lobe anterior abscesses. DISCO Star, 1.2 x 1.2 x 2 mm, dynamic temporal resolution=17 sec. per phase, (A) pre-contrast, (B) early arterial phase, (C) arterial phase and (D) portal phase. (E) LAVA Star, delayed, 1.2 x 1.29 x 2 mm, 3:21 min.

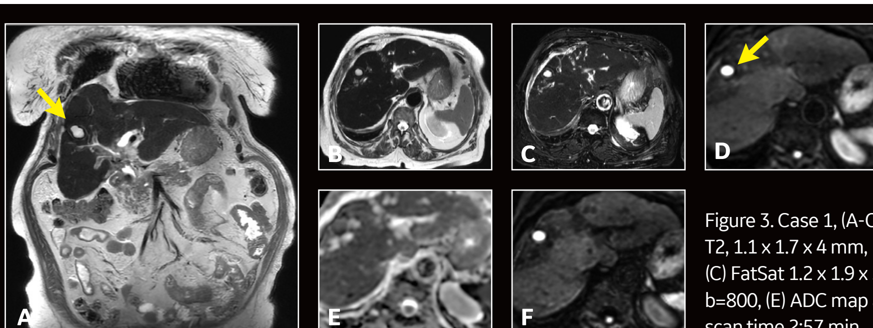

Figure 3. Case 1, (A-C) SnapShot SSFSE with AIR™ Recon DL. (A) Coronal T2, 1.1 x 1.7 x 4 mm, 1:31 min., (B) axial T2, 1.2 x 1.9 x 5 mm, 1:39 min. and (C) FatSat 1.2 x 1.9 x 5 mm, 1:39 min. (D) Axial DWI with Auto Navigator, b=800, (E) ADC map and (F) MAGiC DWI b=1500; (D-F) acquired with total scan time 2:57 min.

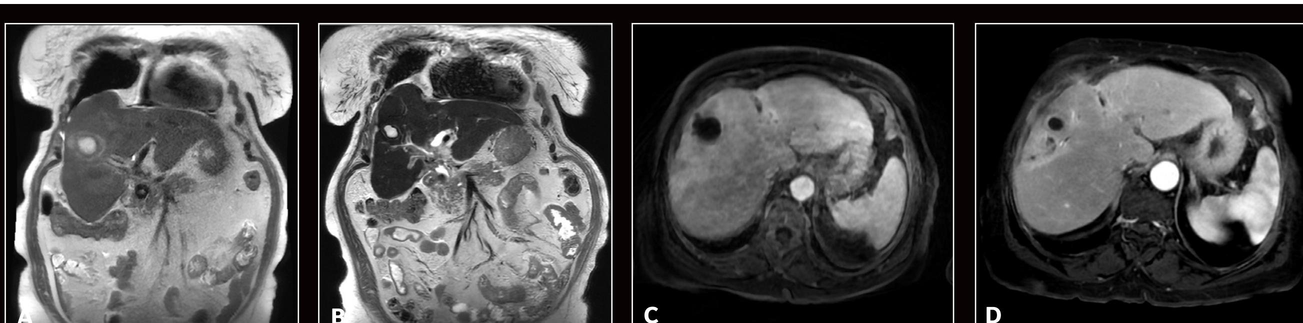

Figure 4. Case 1. (A) Conventional reconstruction (June 2020) and (B) with AIR™ Recon DL (Nov. 2020); same patient with (C) DISCO with Auto Navigator (June 2020) and (D) DISCO Star after software upgrade (Nov. 2020).

Technique

In this case, we utilized dynamic contrast-enhanced DISCO and LAVA acquisitions, post-gadolinium delayed phase LAVA Flex with HyperSense, AIR™ Recon DL for SnapShot SSFSE and 2D FSPGR image reconstruction for high SNR and image sharpness (Figure 5). The combination of DISCO, LAVA and HyperSense provides high temporal and spatial resolution to help detect small metastases.

Results

Patient has progressive liver metastasis. Multiple hypervascular metastases are clearly seen on the early DISCO arterial phases and become isointense with portal phases (Figure 5).

Discussion

MR system performance and patient compliance typically make abdominal imaging more difficult to obtain standard diagnostic image quality. Dynamic imaging is a critical sequence for identifying lesion characterization; however, it often comes with a trade-off between high temporal or high spatial resolution. Making the best choice between these two trade-offs requires an experienced operator and/or clinician. Additionally, patient compliance for breath-hold imaging can lead to significant respiratory motion artifacts.

Now, with highly robust, free-breathing techniques such as DISCO Star and LAVA Star, it is easier for the technologist to acquire quality exams and standardize image quality across all patients.

Also, with the noticeable improvement of AIR™ Recon DL on both SNR and image resolution, our radiologists now prefer to review AIR™ Recon DL images over images with conventional reconstruction. They comment that there is less eye fatigue due to the increased image sharpness and reduced noise.

Operationally, we can now increase the number of patients, scans and exams performed each day. After the upgrade, we have reduced scan times for abdominal exams by an average of 29%, and simultaneously reduced voxel volume by 30% (Figure 6). Overall, 23% of our MR exam volume now consists of abdominal and/or pelvic imaging. After the upgrade with AIR™ Recon DL helping to reduce scan times, we have seen a 33% increase in the number of abdominal exams we can perform each day.

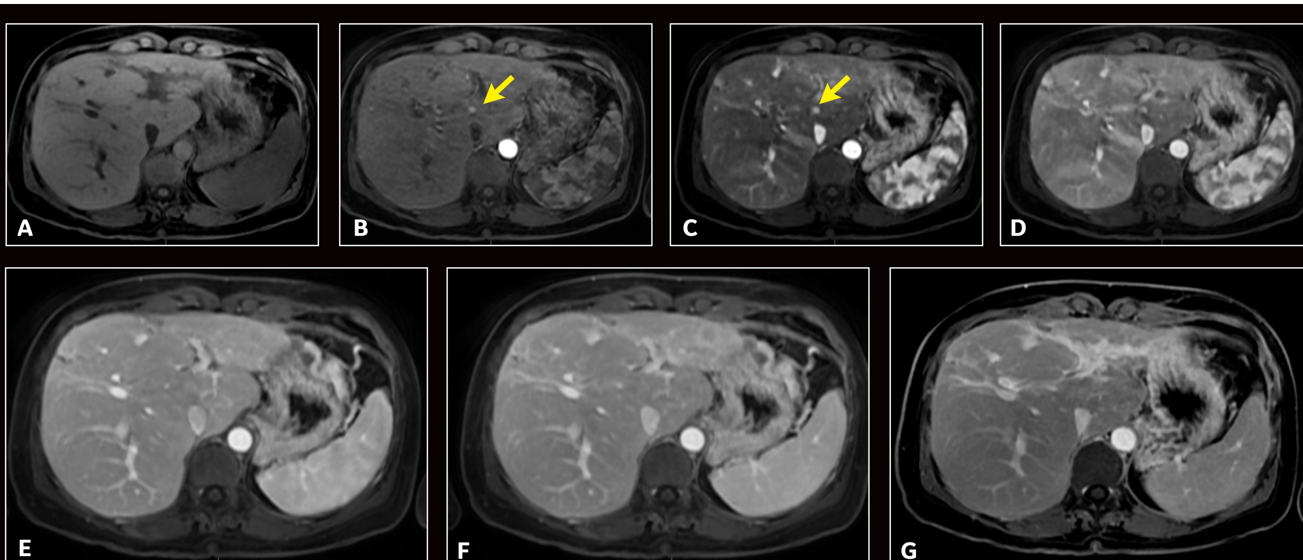

Figure 5. Case 2. (A-D) DISCO-LAVA with HyperSense, 1.2 x 1.8 x 1.8 mm, temporal resolution ~5 sec/phase, (A) pre-contrast, (B-D) multi-arterial. (E-G) LAVA Flex with HyperSense, 1.1 x 1.5 x 2 mm, 12 sec., (E) portal phase, (F) equilibrium and (G) delayed.

	August 17, 2020 — 62 days — November 12, 2020 — 74 days — February 15, 2021		
	Before upgrade	**After upgrade**	
Abdomen FSE average scan time	2:32 min.	1:48 min.	↘ 29%
Abdomen FSE average voxel volume	4.92 mm³	3.43 mm³	↘ 30%

Figure 6. Scan time and voxel volume.

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Dark-blood, phase-sensitive myocardial late enhancement for assessing myocardial viability

by Alexander Hirsch, MD, PhD, Assistant Professor and Principal Investigator of Cardiovascular Magnetic Resonance Imaging, Department of Cardiology/Radiology and Nuclear Medicine, Erasmus MC, University Medical Center Rotterdam, Rotterdam, The Netherlands

For the last two decades, bright-blood late gadolinium enhancement (LGE) cardiovascular magnetic resonance (CMR) has been the standard non-invasive assessment of myocardial viability in patients with suspected and known ischemia[1]. A key clinical question is whether the myocardium is still viable. Based on an inversion recovery (IR) pulse sequence performed after gadolinium contrast administration, late gadolinium enhancement can help distinguish ischemic heart disease by nulling the magnetization level of viable myocardium so that its dark appearance is distinguished from scar tissue, which appears bright. However, the adjacent blood pool can have a similar bright signal, making the border between scar and blood difficult to distinguish and in some cases obscured. This limitation is heightened in cases of thin subendocardial infarction and scarring. Pathology obscured or undistinguishable from the blood pool can result in under reporting of the volume of scar tissue, as well as false negative observations.

To overcome these problems, several dark-blood LGE sequences have been developed to improve the contrast between blood and scar, including a novel sequence from GE Healthcare[2]. However, Holtackers et. al.,[3] proposed a simple, elegant dark-blood approach using a standard phase-sensitive (PS) LGE sequence that can easily be implemented in routine clinical care. This dark-blood approach was found to improve detection of ischemic scar and significantly increased total scar burden compared to bright-blood LGE. The authors also reported significant improvement in image quality and significantly higher observer confidence[4]. The only difference between the regular bright-blood PS LGE and dark-blood approach is the setting of the inversion time. For conventional bright-blood PS LGE, the inversion time is set to null viable myocardium, while for dark-blood PS LGE the inversion time is set to null the left ventricular blood pool. Whichever blood pool contrast is desired, the nulling point can be determined by the Cine IR.

In this article, different examples are shown using a single-shot PS LGE (myocardial delayed enhancement, or MDE, on GE MR systems) sequence and Cine IR on the SIGNA™ Artist 1.5T. The inversion time was shortened from nulling remote myocardium to nulling blood pool signal based on the Cine IR images, so that the blood pool appears as black as possible against the infarct that appears bright. The inversion time is set differently for each patient,

SIGNA™ Artist 1.5T

	Bright-blood PS MDE	*Dark-blood PS MDE*
Inversion preparation time (ms):	250-350 null viable myocardium	150-250 null the LV blood pool

depending on the amount of contrast, the post-contrast acquisition time and the dynamic of the contrast. Other PS LGE parameters remain unchanged. A prototype of AIR™ Recon DL, a deep-learning-based reconstruction algorithm that improves signal-to-noise ratio (SNR) and image sharpness by making use of the raw data to remove image noise and ringing, was also utilized.

Case 1

Patient history

A 60-year-old male without cardiac history presented with out-of-hospital cardiac arrest. An invasive coronary angiogram showed extensive three-vessel disease. CMR was performed to assess viability and showed a dilated left ventricle with poor systolic function.

Results

Images depict extensive subendocardial infarction in both the right coronary artery and the left anterior descending artery territory. The dark-blood PS MDE image (Figure 1C) shows much better delineation between the blood and subendocardial infarction than the bright-blood images (Figures 1A, 1B).

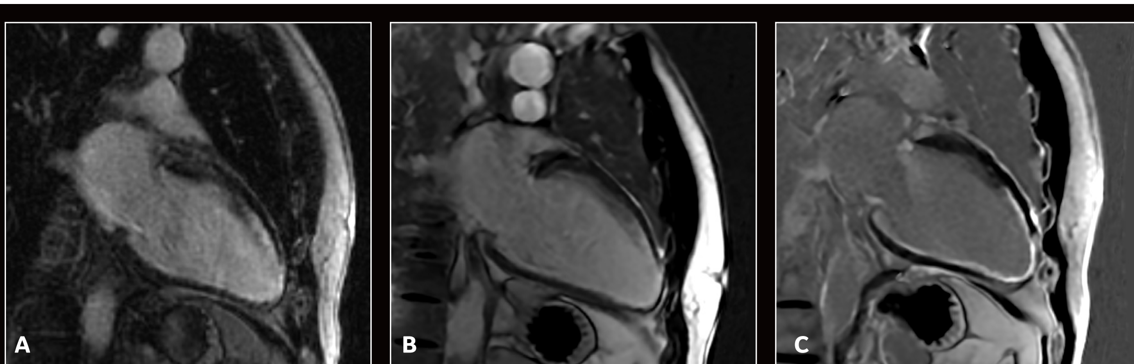

Figure 1. Depicted are two-chamber LGE images with different techniques. (A) Multi-shot bright-blood MDE, (B) single-shot, bright-blood PS MDE with a prototype AIR™ Recon DL (high) and (C) single-shot, dark-blood PS MDE with a prototype AIR™ Recon DL (high).

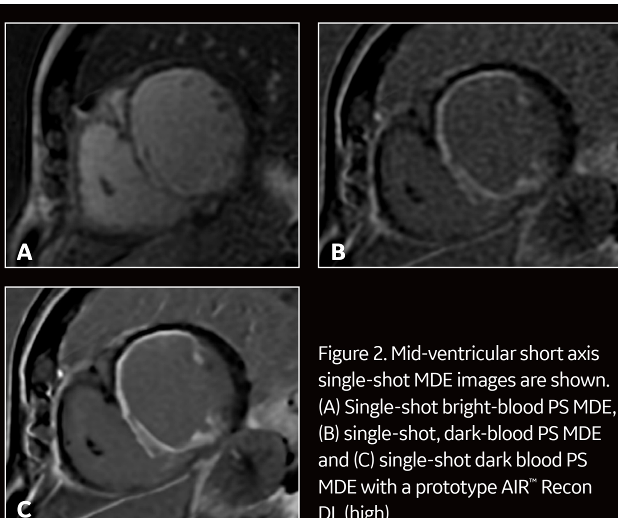

Figure 2. Mid-ventricular short axis single-shot MDE images are shown. (A) Single-shot bright-blood PS MDE, (B) single-shot, dark-blood PS MDE and (C) single-shot dark blood PS MDE with a prototype AIR™ Recon DL (high).

Case 2

Patient history

A 65-year-old male with a history of inferior myocardial infarction was admitted because of heart failure with poor systolic left ventricular function. MR was performed to assess viability after invasive coronary angiogram and helped determine three-vessel disease, including significant left main disease and chronic total occlusion of the right coronary artery and left anterior descending artery. The 2D MDE images were of poor quality because of difficulties with breath-holds (images not shown).

Results

The extensive myocardial infarction is much better visualized with dark-blood PS MDE as shown in Figure 2B, 2C. Also late gadolinium enhancement of the papillary muscle is observed in the dark-blood PS MDE and further enhanced by the prototype AIR™ Recon DL (Figure 2C).

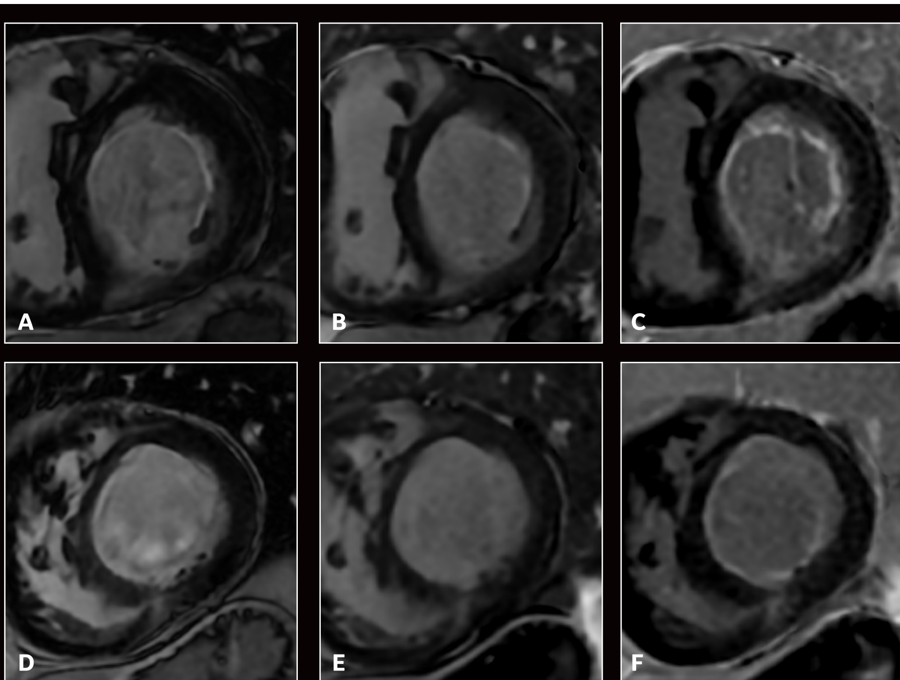

Figure 3. Comparison of (A, D) 2D bright-blood MDE, (B, E) single-shot bright-blood PS MDE and (C, F) single-shot, dark-blood PS MDE. All images were aquired with a prototype AIR™ Recon DL (high). (A-C) Basal short axis MDE images and (D-F) mid-ventricular short axis images.

Case 3

Patient history

This is a rare case of restrictive cardiomyopathy with pulmonary hypertension due to endocardial fibroelastosis in a 20-year-old patient with history of congenital subvalvular and valvular aortic stenosis[5].

Results

There is a thin layer of endocardial late enhancement visible in the left ventricle that is almost circular. This is best recognized in the dark-blood PS MDE images (Figure 3C). In addition to the endocardial late enhancement, there is also focal late enhancement in the inferior right ventricular insertion point.

Discussion

The dark-blood technique with PS MDE and Cine IR facilitates evaluation of myocardial scarring and viability, especially in cases of subendocardial infarction. It is easy to implement and currently available on most MR scanners and, therefore, can be implemented in clinical practice. As demonstrated by Holtackers et. al., the dark-blood PS MDE is more sensitive for detecting ischemic scar, yet it did not impede the ability to detect thrombus.

A single-shot PS MDE typically results in less SNR and more noise compared to segmented breath-hold techniques. However, the addition of AIR™ Recon DL increases overall image quality by neutralizing the increase in noise and boosting SNR[6]. While the addition of AIR™ Recon DL is not a requirement for dark-blood PS MDE, it improves a rapidly acquired scan with high image quality. Further, this reconstruction technique helped highlight the infarct in cases of ischemic heart disease with good contrast between the infarct, the blood and the blood pool.

The combination of single-shot PS MDE for dark-blood imaging and AIR™ Recon DL also enhanced our clinical confidence, although diagnoses were unchanged. Understanding how this technique may impact quantification of the infarct is an area that remains to be studied. Therefore, dark-blood, single-shot PS MDE could be used as a rapid tool in addition to standard PS MDE. S

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1. Kramer CM, Barkhausen J, Bucciarelli-Ducci C, Flamm SD, Kim RJ, Eike Nagel. Standardized cardiovascular magnetic resonance imaging (CMR) protocols: 2020 update. J Cardiovasc Magn Reson. 2020 Feb 24;22(1):17.
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3. Holtackers RJ, Chiribiri A, Schneider T, Higgins DM, Botnar RM. Dark-blood late gadolinium enhancement without additional magnetization preparation. J Cardiovasc Magn Reson. 2017; 19(1):64.
4. Holtackers RJ, Van De Heyning CM, Nazir MS, et al. Clinical value of dark-blood late gadolinium enhancement cardiovascular magnetic resonance without additional magnetization preparation. J Cardiovasc Magn Reson. 2019; 21(1):44.
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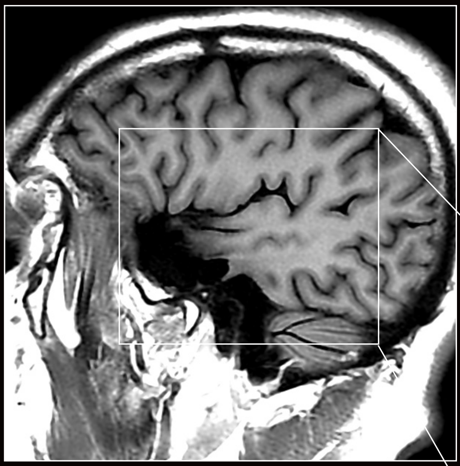
6. van der Velde N, Hassing HC, Bakker BJ, et al. Improvement of late gadolinium enhancement image quality using a deep learning-based reconstruction algorithm and its influence on myocardial scar quantification. Eur Radiol. 2020; in press.

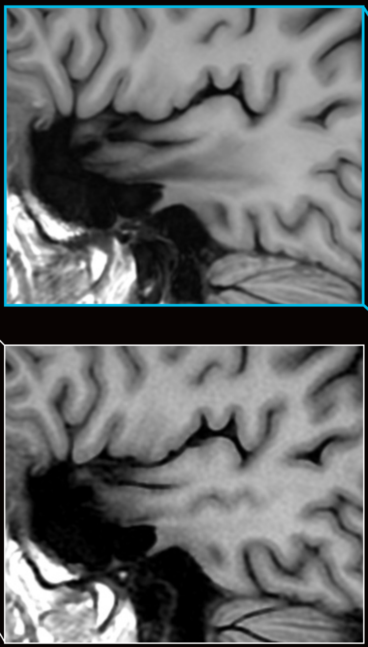
AIR™ Recon DL image gallery

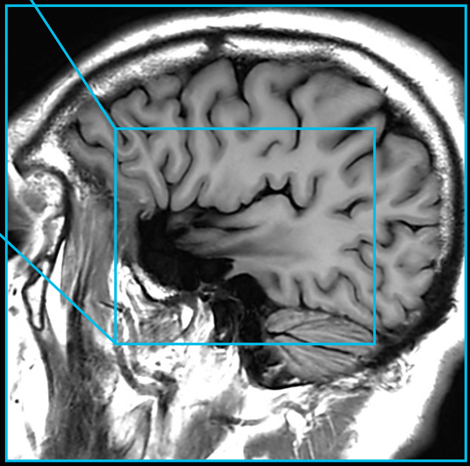
Neuro with AIR x™

Follow up exam on a brain tumor patient demonstrating an improvement in image quality compared to previous scans performed two months prior, both acquired using AIR x™.



Conventional reconstruction





AIR™ Recon DL

Sagittal T1w images using AIR™ Recon DL enabled a 23% reduction in scan time (2:21 min. vs. 1:48 min.) and 24% improvement in acquired spatial resolution (0.7 x 0.8 x 4.5 mm vs. 0.5 x 0.7 x 4.5 mm).

Images acquired on SIGNA™ Architect 3.0T, courtesy of Hacettepe University, Ankara, Turkey.

Pituitary

Conventional reconstruction

AIR™ Recon DL

Comparison of conventional MR scan acquired two months prior to the AIR™ Recon DL scan, demonstrating a Rathke's cleft cyst. Sagittal T1 FSE +C, 0.4 x 0.4 x 2 mm, 2:53 min.

Images acquired on SIGNA™ Architect 3.0T, courtesy of Queen Silvia Children's Hospital, Göteborg, Sweden.

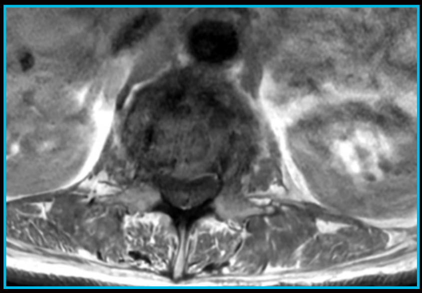
AIR™ Recon DL image gallery

Lumbar spine

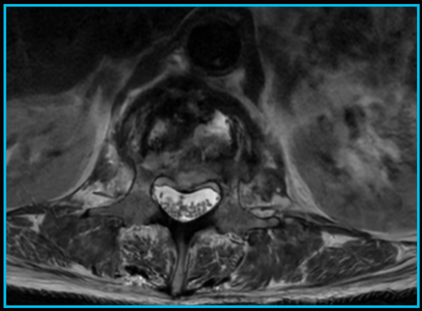
High-resolution lumbar spine exam with traumatic injury, performed in 10 min.

Sagittal T2 FSE
0.5 x 0.6 x 3 mm, 21 slices
2:04 min.

Sagittal T1 FSE
0.6 x 0.9 x 3 mm, 21 slices
2:10 min.



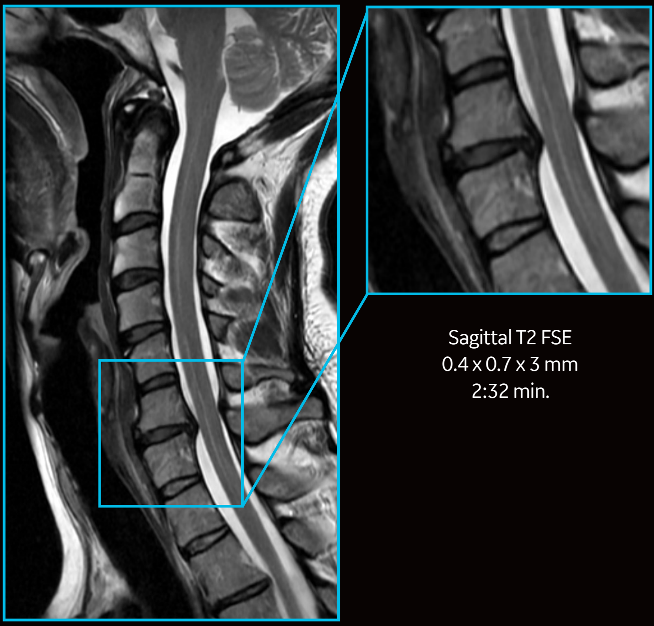
Axial T1 FSE
0.6 x 0.7 x 3 mm, 48 slices
2:40 min.



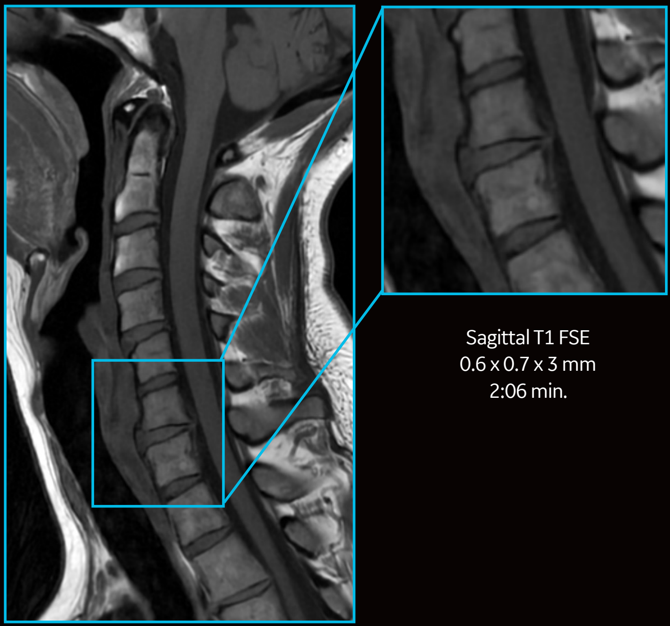
Axial T2 FSE
0.5 x 0.6 x 3 mm, 48 slices
1:46 min.

Images acquired on SIGNA™ Premier 3.0T, courtesy of Acibadem Maslak Hospital, Istanbul, Turkey.

Cervical spine



Sagittal T2 FSE
0.4 x 0.7 x 3 mm
2:32 min.



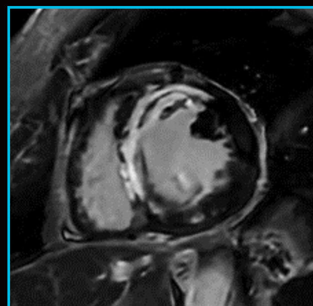
Sagittal T1 FSE
0.6 x 0.7 x 3 mm
2:06 min.

Images acquired on SIGNA™ Artist 1.5T.

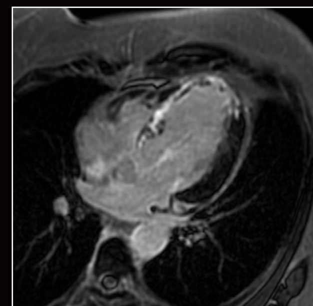
AIR™ Recon DL image gallery

Cardiac

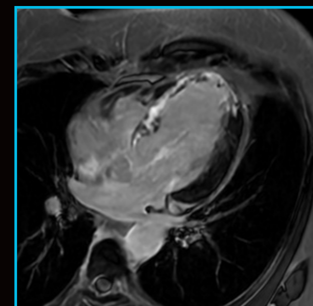
Conventional reconstruction



AIR™ Recon DL



Conventional reconstruction



AIR™ Recon DL

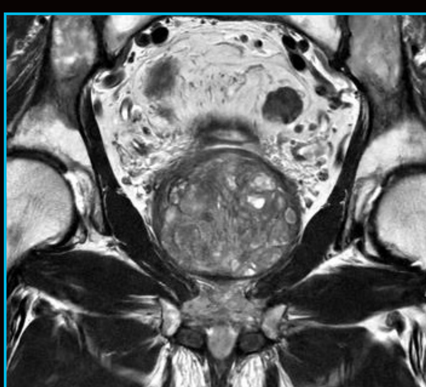
Short Axis MDE
1.6 x 1.9 x 8.0 mm

4ch MDE
1.7 x 2.0 x 8.0 mm

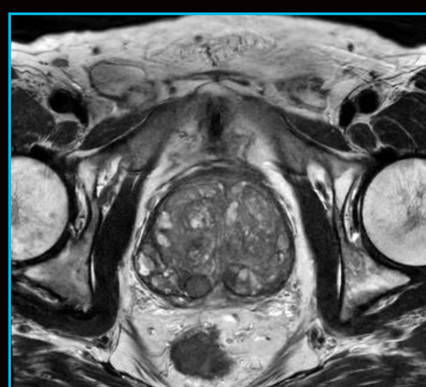
Images acquired on SIGNA™ Pioneer 3.0T, courtesy of radiomed, Weisbaden, Germany.

Body

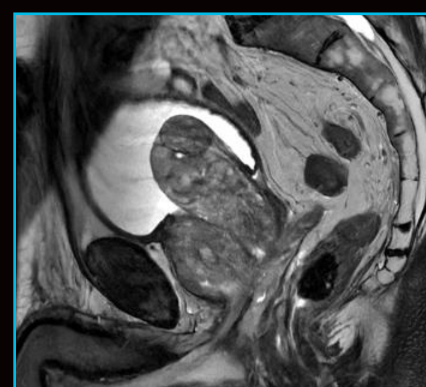
Male pelvis (prostate) using AIR™ Anterior Array Coil. PI-RADS®-compliant protocols can be achieved in much shorter acquisition times with AIR™ Recon DL.



Axial T2 frFSE
0.4 x 0.7 x 3 mm, 37 slices
2:10 min.



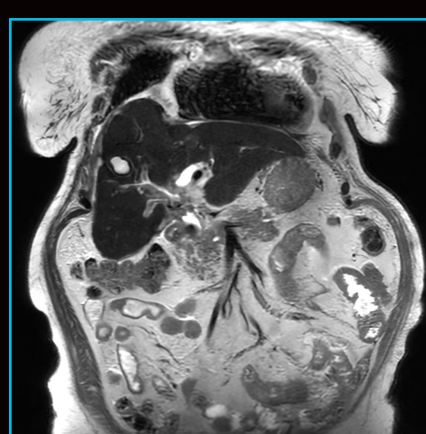
Coronal T2 frFSE
0.4 x 0.7 x 3 mm, 30 slices
1:31 min.



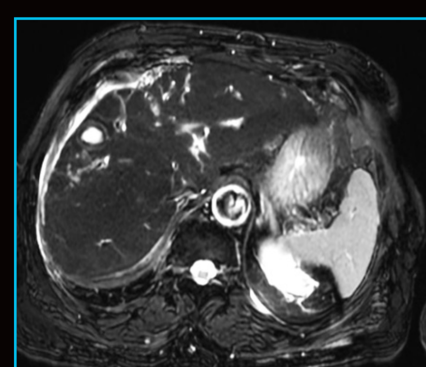
Sagittal T2 frFSE
0.4 x 0.7 x 3 mm, 24 slices
2:51 min.

Images acquired on SIGNA™ Pioneer 3.0T, courtesy of radiomed, Weisbaden, Germany.

Sagittal T2 FSE
0.6 x 0.8 x 3 mm, 40 slices
2:00 min.



Coronal T2
1.1 x 1.7 x 4 mm, 42 slices
1:31 min.

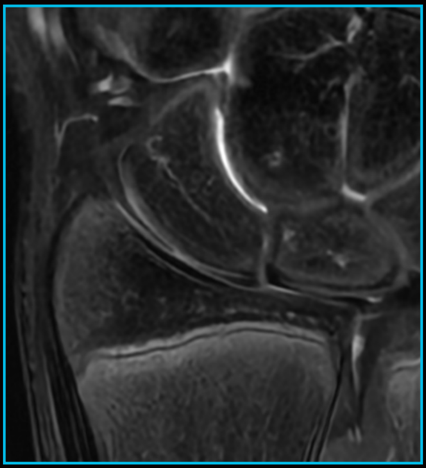


Axial TX FatSat
1.2 x 1.9 x 5 mm, 42 slices
1:39 min.

(Left) Image acquired on SIGNA™ Premier 3.0T, courtesy of Centre Cardiologique du Nord (CCN), Paris, France.
(Middle & right) Images acquired on SIGNA™ Premier 3.0T, courtesy of Acibadem Maslak Hospital, Istanbul, Turkey.

AIR™ Recon DL image gallery

Musculoskeletal



Coronal T2 FatSat
0.4 x 0.4 x 2 mm
1:58 min.

Coronal T1
0.3 x 0.3 x 2 mm
1:47 min.

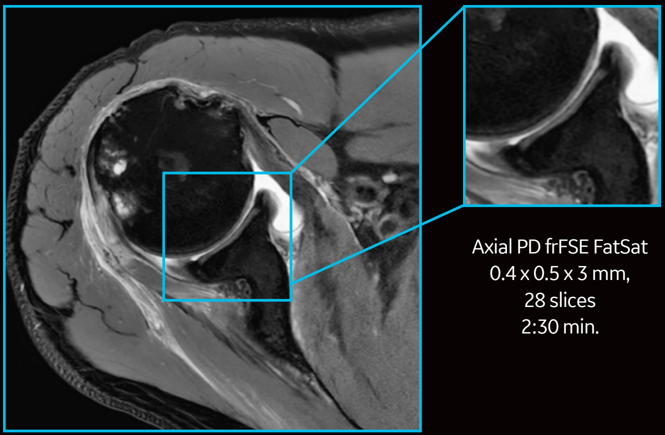
Images acquired on SIGNA™ Architect 3.0T, courtesy of American Hospital of Paris, France.

Coronal PD FatSat
0.35 x 0.35 x 2.5 mm, 22 slices
1:03 min.

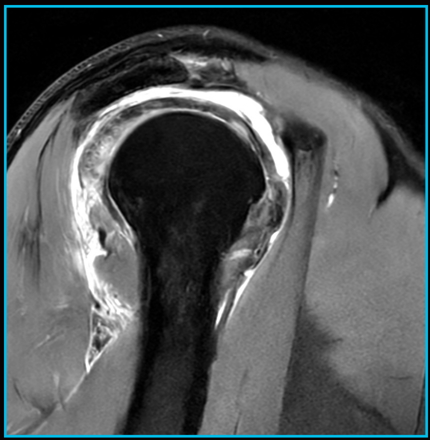
Sagittal PD FatSat
0.35 x 0.35 x 2.5 mm, 32 slices
2:13 min.

Axial PD FatSat
0.4 x 0.4 x 3 mm, 32 slices
1:18 min.

Images acquired on SIGNA™ Pioneer 3.0T, courtesy of Clinic Charcot, Lyon, France.



Axial PD frFSE FatSat
0.4 x 0.5 x 3 mm,
28 slices
2:30 min.



Sagittal PD frFSE FatSat
0.4 x 0.5 x 3 mm,
24 slices
2:14 min.

Images acquired on SIGNA™ Pioneer 3.0T, courtesy of Shields MRI, Framingham, MA.

The clinical benefits of AIR Recon DL for MR image reconstruction

By Robert D. Peters, PhD, Global Product Marketing Director, MR Applications & Visualization, Heide Harris, RT(R)(MR), Global Product Marketing Director, MR Applications & Visualization, and Steve Lawson, RT(R)(MR), Global MR Clinical Marketing Manager, GE Healthcare

The advantages of MR as a medical imaging modality are well documented, including the lack of ionizing radiation, volumetric capabilities, superior soft tissue contrast and the potential for quantitative imaging. Unfortunately, long imaging times and a lack of high spatial resolution remain as common clinical complaints and represent a major focus of present-day technical development activities.

To this end, the MR industry has addressed these needs with innovations such as parallel imaging, compressed sensing and simultaneous multi-slice for scan time acceleration.

Artificial intelligence, particularly deep-learning (DL) techniques such as AIR™ Recon DL, have recently been introduced to improve image quality (SNR and sharpness) as well as enable scan time reductions.

In MR imaging, raw data is collected in the form of so-called k-space, which represents the Fourier transform of the object being imaged. Due to the finite amount of k-space that is collected in MR imaging, certain artifacts result, such as Gibbs ringing, which is also known as a truncation artifact, and occur irrespective of the pulse sequence. Gibbs ringing manifests as duplication or ringing of sharp edge structures, like cerebrospinal fluid (CSF). To reduce Gibbs ringing artifacts, raw data is routinely filtered or apodized, effectively suppressing the peripheral regions and consequently attenuating high-resolution structures.
However, suppression of Gibbs ringing through raw data filtering comes at a cost in image sharpness or spatial resolution. This delicate balance of Gibbs ringing suppression and spatial resolution is a well-known tradeoff in MR imaging.

One image quality metric that is often used to describe image quality is SNR. In MR, there are multiple sources of noise, such as thermal and electrical noise, which impacts the raw data that is collected. Noise in raw data translates into noise in the final image. The typical approach to improving SNR is to perform multiple averaging, which comes at the expense of prolonged scan time, or to increase the voxel volume at the expense of lower spatial resolution. Other hardware-related solutions to improve SNR include using a higher field strength, quality surface coils and low-noise receiver components, which add to overall system cost.

MR users have become familiar with managing the tradeoff and compromise with respect to spatial resolution, SNR and scan time with conventional MR image reconstruction. In some facilities, this tradeoff has led to multiple imaging protocols. Compounding this is the increased pressure to meet ever-demanding schedules and the need to manage variables such as patient shape, size and level of cooperation. Re-scans and patient callbacks are no longer options for managing unexpected results.

To read the complete whitepaper, visit:
tinyurl.com/AIR-Recon-DL-whitepaper

Enter AIR™ Recon DL

What if there was an alternative to conventional MR image reconstruction where the user did not have to choose between spatial resolution, SNR or scan time? Well, now there is. In 2020, GE Healthcare introduced AIR™ Recon DL, an algorithm that is embedded in the MR image reconstruction pipeline[1], where a neural network model is applied to remove noise and Gibbs ringing artifacts prior to final image formation. The network employs a cascade of over 100,000 unique pattern recognitions for noise and low resolution to reconstruct only the ideal object image.

AIR™ Recon DL performs two separate functions within the MR image reconstruction pipeline: ringing suppression and SNR improvement. These provide for clinical benefits such as scan time reduction, sharper images, greater tolerance of protocol variations and images that are easier and faster to read.

With AIR™ Recon DL's Intelligent Ringing Suppression, part of the reconstruction-embedded deep neural network, the tradeoff of ringing suppression for spatial resolution is avoided by making images sharper and having higher spatial resolution. As such, the clinically acceptable voxel volumes for AIR™ Recon DL are larger than for conventional reconstructed images.

Based on a phantom study for equivalent spatial resolution, it is estimated that the AIR™ Recon DL in-plane voxel dimension can be approximately 1.4 times larger than that of the conventional image. This 1.4 factor is consistent with an independent study that found a factor of 1.6, based on edge gradient analysis[1]. Results from this phantom study suggest that a lower in-plane matrix setting can be used with AIR™ Recon DL to obtain equivalent spatial resolution and image sharpness as a conventional image, independent of the SNR improvement.

Addressing the tradeoff

AIR™ Recon DL provides a solution to the tradeoff with SNR, spatial resolution and scan time. To begin, SNR is usually thought of as an output metric of the image, which depends on various input protocol settings of the MR scan such as voxel volume (e.g., spatial resolution) and number of averages (e.g., scan time). There generally is no direct SNR parameter; SNR simply results from the selected MR parameters.

SNR is directly dependent on voxel volume, which is the product of the in-plane pixel dimensions with slice thickness. Voxel volume is typically used to characterize the prescribed spatial resolution. It is generally intuitive to most MR users that the larger the signal-bearing voxel volume, the greater the SNR and that this dependence is linear, i.e., if the voxel volume doubles then the SNR doubles.

In MR imaging, the most common way to increase SNR is to acquire additional signal averages or excitations, effectively collecting more raw data. Unfortunately, due to the nature of MR noise statistics, a doubling of the number of excitations (NEX) only results in a square root 2 increase in the resultant SNR. The well-known relationship is that SNR varies as the square root of the total scan time.

Acceptable clinical protocols are those that simultaneously meet three criteria: SNR, spatial resolution and scan time. Figure 2A is an example of conventional reconstruction. Given a clinically acceptable SNR level, as indicated by the red contour line, any protocol with a larger voxel volume or longer scan time will result in higher SNR. However, the acceptable clinical protocol is also bounded by the clinical spatial resolution threshold (vertical dotted line) and clinical scan time threshold (horizontal dotted line), leaving the only clinical acceptable protocols as being those in the red triangular shaped region in Figure 2A.

We can redraw the protocol space for AIR™ Recon DL to see how the SNR gain and improved image sharpness manifest in the protocol space. As shown in Figure 2B, the SNR contour with AIR™ Recon DL is shifted lower for scan time and voxel volume due to the SNR advantage over conventional reconstruction. To clarify, the red contour in Figure 2A and the blue contour in Figure 2B represent the same clinically acceptable SNR, however, AIR™ Recon DL delivers this with shorter scan times and smaller voxel volumes. Also note the positioning of the clinical resolution threshold (vertical dotted line) as being further to the right on Figure 2B compared to Figure 2A. This reflects AIR™ Recon DL's Intelligent Ringing Suppression that can deliver equivalently sharp images with larger voxel volumes.

AIR™ Recon DL reconstruction allows for an expanded protocol space, or more protocol combinations of voxel

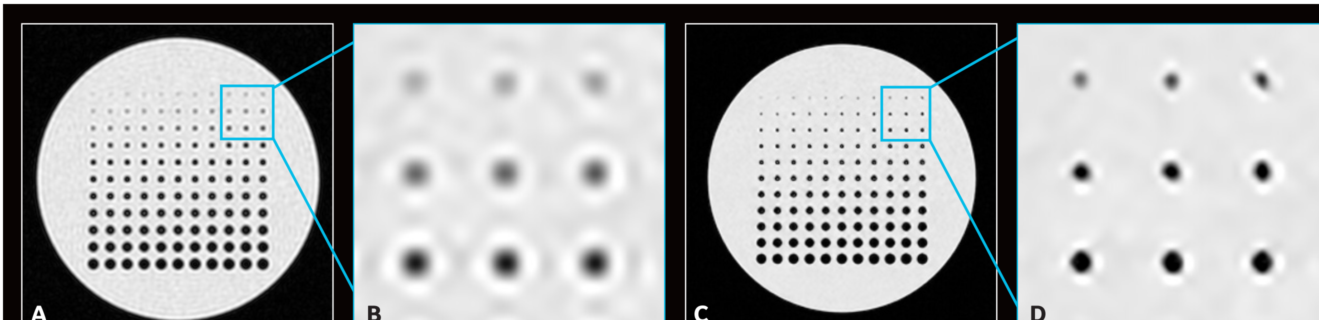


Figure 1. AIR™ Recon DL Intelligent Ringing Suppression for sharper images as demonstrated in an imaging phantom. (A) Conventional image reconstruction with apodization still results in significant Gibbs ringing. (B) Magnified A showing ringing and a loss of fine detail in the circular structures. (C) The same raw data as reconstructed using AIR™ Recon DL shows elimination of Gibbs ringing artifacts and (D) considerably sharper images. Note that the AIR™ Recon DL images also show the added benefit of noise reduction, however, this is considered unrelated to the improved sharpness of the images.

volumes and scan times that are clinically acceptable for SNR, scan time and spatial resolution.

Users have the freedom to select their own level of SNR improvement through a user interface that provides a low, medium or high setting. It is anticipated that, once familiar with the product, users will choose to use the AIR™ Recon DL high setting.

Benefits and early adopter feedback

There are many benefits to AIR™ Recon DL which extend to clinical, operational and financial aspects of MR imaging. Clinical benefits are best demonstrated with images that span multiple anatomies, which compare AIR™ Recon DL to conventional image reconstruction and are shown in Figures 3-6.

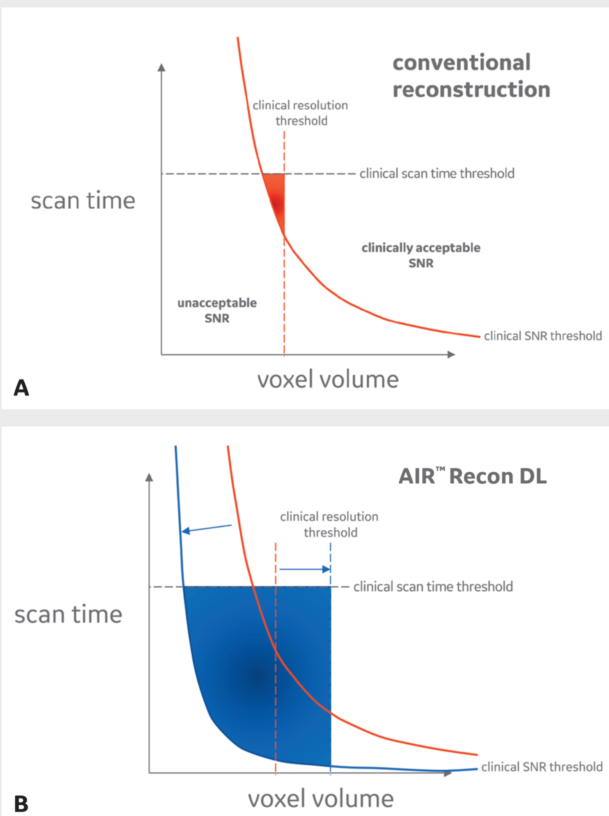


Figure 2. Expanded clinical protocol space with AIR™ Recon DL. (A) Conventional reconstruction with the clinically acceptable SNR contour, as indicated in red, the only protocol combinations of voxel volume and scan time that are simultaneously clinically acceptable for SNR, scan time and spatial resolution is the triangular area in red. (B) An expanded protocol space with AIR™ Recon DL reconstruction showing the clinically acceptable SNR contour to be shifted lower and the clinically acceptable resolution threshold is further to the right, compared to conventional reconstruction in (A, red solid and dotted lines). The area in blue represents more protocol combinations of voxel volumes and scan times that are clinically acceptable for SNR, scan time and spatial resolution with AIR™ Recon DL.

Operationally, it is expected that AIR™ Recon DL will lead to more predictable patient scheduling as a result of fewer repeat scans and shorter scan times. This may also allow for disinfection time between patients during the COVID-19 pandemic. The scan time savings and more consistent image quality may help reduce stress among the MR technologists and radiographers.

Of the thousands of cases collected with both conventional and AIR™ Recon DL reconstructions, no pathologies were reported to have been missed compared to the conventional reconstructed images§. In addition, no instances were identified where structures were hallucinated with AIR™ Recon DL.

Anatomical coverage is also a key consideration and can sometimes be dependent on the training of the DL algorithm. AIR™ Recon DL is compatible with all anatomies.

GE provides users the capability to generate the conventional reconstruction images for comparison with AIR™ Recon DL images, which can be useful for establishing clinical confidence during the initial phase of familiarity.

As AIR™ Recon DL makes use of raw data and is integrated in the reconstruction pipeline, it delivers images to the MR

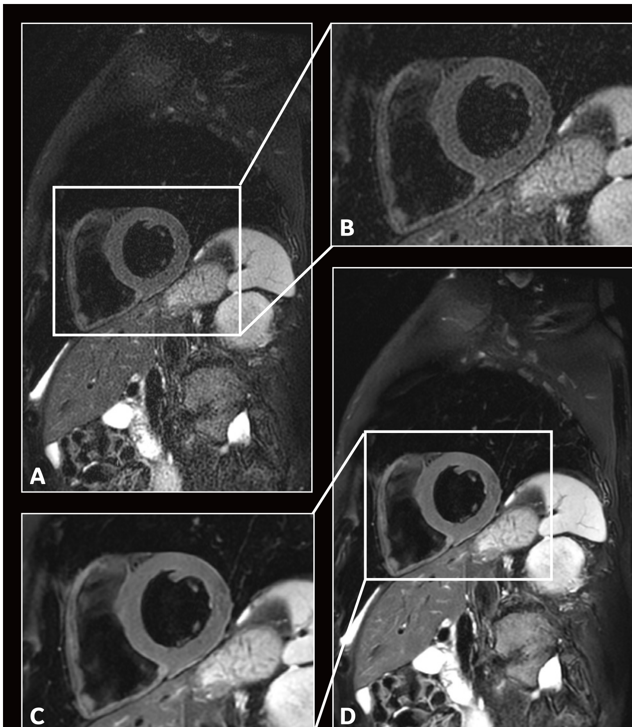


Figure 3. SNR improvement with AIR™ Recon DL. Shown is a short axis T2 Double IR black-blood FatSat breath-hold scan, 1.3 x 1.4 x 6 mm, 2:13 min. scan time with 11 sec. breath hold. (A, B) Conventional image reconstruction and (C, D) AIR™ Recon DL high setting of the same raw data showing considerable SNR improvement.

§These cases were not part of the US FDA submission for AIR™ Recon DL.

console in real-time, allowing the MR technologist to assess the image quality while the patient is still on the table.

In summary, AIR™ Recon DL offers many clinical benefits over conventional image reconstruction, including increased SNR and sharper images due to the Intelligent Ringing Suppression, as demonstrated on both phantom and in vivo. Functioning on raw data, AIR™ Recon DL can help users manage the delicate balance between spatial resolution, SNR and scan time. With an understanding of the relationship between SNR, voxel volume and scan time, AIR™ Recon DL can significantly expand the clinically useable protocol space, allowing users more freedom and flexibility in prescribing MR scans to suit their needs. S

References

1. Lebel, R.M. Performance characterization of a novel deep learning-based MR image reconstruction pipeline. August 2020. http://arxiv.org/abs/2008.06559.

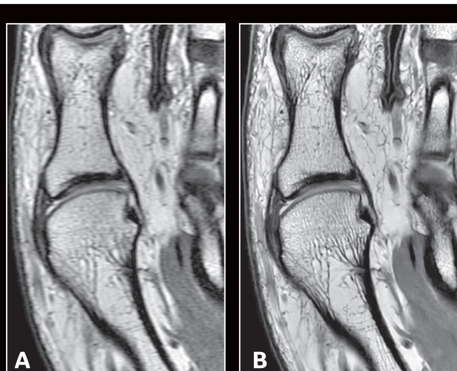


Figure 4. Sharper images with AIR™ Recon DL. Shown is a coronal FSE PDw, 0.3 x 0.3 x 1.0 mm of the first metatarsal. (A) Conventional image reconstruction and (B) AIR™ Recon DL high setting of the same raw data (same matrix and scan time) showing sharper trabecular structure.

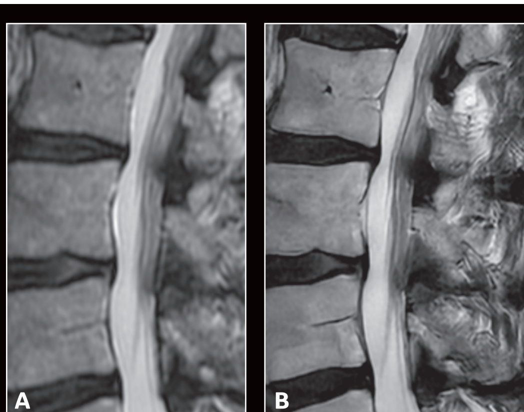


Figure 5. Lumbar spine exam demonstrating (A) conventional reconstructed image, 0.9 x 1.3 x 3 mm, BW 32.2 kHz, NEX 2, 2:47 min. and (B) AIR™ Recon DL reconstructed image, 0.7 x 0.9 x 3 mm, BW 41.7 kHz, NEX 1, 1:16 min.

What early users are saying

21 radiologists from 11 different sites and 6 different countries were asked about their experience using AIR™ Recon DL‡‡.

100% said:

- Images are sharper and more detailed
- Can enable prescription changes to shorten scan time
- Images display less noise

95% said:

- Improves lesion conspicuity
- Improves diagnostic confidence
- May help reduce the number of repeat series

90% said:

- May allow for prescription changes to increase spatial resolution
- Images are easier to read, can be read quicker and lead to reduced eye fatigue

4 out of 5 radiologists agree

that AIR™ Recon DL will reduce variability across different patients and technologists

‡‡Based on an early adopter survey of 21 radiologists from 11 different sites and 6 different countries.

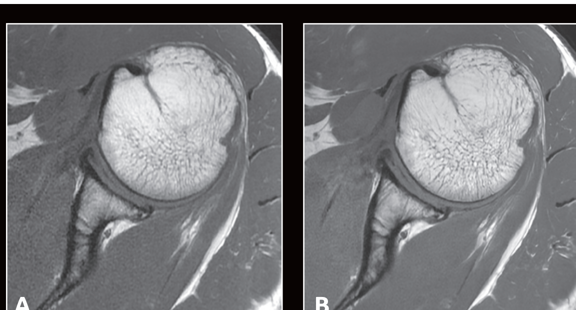


Figure 6. Shoulder exam demonstrating a 46 percent improvement in resolution and a 36 percent reduction in scan time with AIR™ Recon DL. (A) Conventional reconstructed image, 0.4 x 0.6 x 3 mm, BW 41.7 kHz, NEX 1, 2:14 min. and (B) AIR™ Recon DL reconstructed image, 0.3 x 0.5 x 3 mm, BW 62.5 kHz, NEX 1, 1:33 min.

Practical protocol conversion and optimization with AIR Recon DL

by Robert D. Peters, PhD, Global Product Marketing Director, MR Applications & Visualization, Holly Blahnik, RT(R)(MR), Lead Clinical Development Specialist, Heide Harris, RT(R)(MR), Global Product Marketing Director, MR Applications & Visualization and Steve Lawson, RT(R)(MR), Global MR Clinical Marketing Manager, GE Healthcare

There's a saying in MRI that, "there's no free lunch." That's because there are often tradeoffs when it comes to MR, especially with protocols. While there are many ways to optimize a protocol, there are certain parameters that can give sharper images or save scan time. However, these can contribute to more noise in the image, which impacts SNR. In order to obtain sufficient SNR in current MR protocols, adjustments to these parameters tend to be more conservative to achieve a good balance between scan time and image quality.

AIR™ Recon DL, a novel deep-learning-based reconstruction technique that uses a trained convolutional neural network, delivers enhanced clinical benefits[1] and technical performance[2] in clinical settings. The algorithm includes a means of both SNR improvement and image sharpening, which provides for multiple clinical benefits over conventional image reconstruction, helping users manage the delicate balance between spatial resolution, signal-to-noise ratio (SNR) and scan time.

By expanding the useable "protocol space," AIR™ Recon DL enables more choices that meet the clinical demands for higher spatial resolution and SNR, overall better image quality and sharpness, and lower scan times – all while avoiding the tradeoffs that can lead to inconsistent imaging results.

AIR™ Recon DL provides users with the capability of scanning at significantly higher spatial resolutions, higher SNR and greater speed, which were not attainable with conventional image reconstruction.

This article introduces an effective way to optimize current protocols to get the most out of AIR™ Recon DL. First, it's important to consider your overall scanning goals. Some users want to achieve an improvement in scan times to accommodate more time slots in their schedule each day or to open up the ability to add another patient into an already full schedule. Others prefer to drive the system to previously unattainable resolution, such as smaller FOVs or higher spatial resolution. In other cases, it can be a mix of both.

With AIR™ Recon DL, it is important to remember that increasing resolution will still allow for faster scan times. Figure 1 is a simple and easy chart to follow utilizing the three primary parameters when optimizing protocols for AIR™ Recon DL, based on your scanning goals. Early adopters of AIR™ Recon DL have found this process to be a simple and effective way to drive consistency and performance, and change the way they think about optimizing MR protocols.

Getting the most from AIR™ Recon DL

Resolution

Resolution provides the ability to resolve small structures and details within the image. In MR, the resolution is determined by the number of voxels in a specific FOV. The higher the image resolution, the better that small structures can be visualized[3]. Adjusting resolution typically includes a few basic parameters: in-plane (frequency and phase) matrix, slice thickness and FOV. These factors make up the voxel size and overall resolution. Adjusting any of these factors (i.e., decreasing slice thickness or increasing the matrix) will have an effect

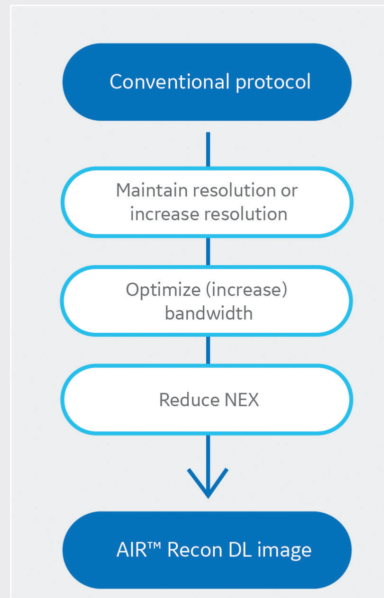


Figure 1. General guide for optimization.

on your overall voxel size and thus SNR and scan time. For example, a higher matrix costs more time and reduces SNR since the voxel is smaller. However, with AIR™ Recon DL these tradeoffs are removed.

Whether you're looking to maintain your resolution or level up your resolution, there's a few considerations to keep in mind:

- There is spatial resolution improvement with AIR™ Recon DL even if they don't reduce the voxel size.
- Increasing frequency matrix will improve resolution with minimal impact to scan time.

- Increasing phase matrix will improve resolution with a proportionate impact to scan time.
- Thinner slices improves spatial resolution and slice volume averaging, producing sharper images.
- Smaller FOV will increase spatial resolution without any scan time impact. For example, it's easy to decrease your FOV on a small part, such as a finger, in order improve resolution. If you do not change your phase or frequency matrix, a smaller FOV will increase spatial resolution.
- All of these techniques affect voxel size and they introduce more noise on an image. However, AIR™ Recon DL boosts the SNR, making thinner slices and higher resolution more feasible.

Bandwidth

Bandwidth (BW) can have an effect on many parameters such as SNR, minimum FOV, noise, chemical shift, TR/TE, susceptibility/distortion/metal artifacts and echo spacing. Most importantly, increasing bandwidth can reduce echo spacing (ESP). ESP is the space between the 180 degree refocusing pulses on FSE sequences, so decreasing ESP can help to decrease overall scan time while also reducing blurring. Increasing bandwidth adds more noise to an image. However, with AIR™ Recon DL, noise is reduced, allowing the user to get the best benefit from bandwidth.

Consider this:

- With FSE scans, BW should be increased to reduce the ESP, which will reduce T2-related blurring.
- ESP is also dependent on the frequency matrix, so determine the spatial resolution first and then increase the BW. Adjusting the BW will update the BW per pixel and the ESP directly on the user interface for easy selection.
- A good starting point on a 3.0T system is to increase your BW until your BW/pixel is above 300 Hz/pixel. This will balance your ESP and SNR. For 1.5T, that number will be lower.

NEX

NEX is the most commonly used parameter to reduce scan time. In fact, it's probably the most commonly used factor to go fast for the novice technologist. However, it comes at a detriment of signal loss. Technically, SNR is directly proportional to the square root of the NEX (√NEX). It directly impacts scan time, so the more NEX on a sequence, the more time is added. And some sequences such as STIR or FatSat need more signal because signal is suppressed.

Consider this:

- NEX is most commonly used to achieve sufficient signal at the expense of scan time. AIR™ Recon DL will boost the SNR and allows you to reduce NEX to save scan time. In many cases, it can be reduced to 1 NEX.
- Some believe that using more than 1 NEX may reduce physiologic motion (e.g., peristalsis, respiration, flow). Scanning with more than 1 NEX remains possible, when preferred.

What other parameters can be used to optimize protocols with AIR™ Recon DL?

1. Parallel imaging is another factor to continue decreasing scan time. Whether it's ASSET or ARC, it's important to remember the amount of acceleration will depend on the coil, the acceleration factor and the patient habitus. Generally, parallel imaging should only be used when NEX has been reduced. AIR™ Recon DL does not have a direct effect on artifacts related to acceleration. If you're already using acceleration, either keep the same acceleration factor or incrementally increase it until the desired scan time is achieved.
2. Echo Train Length (ETL) – FSE scans, the ETL can be increased to proportionately reduce scan time with minor reduction in SNR. When increasing ETL, the readout BW should also be increased to reduce the ESP to preserve ESP * ETL product. Note that if Auto TR is used, an increase in the ETL will lead to a longer TR and eliminate the scan time reduction benefit.

Choosing SNR improvement level

Users can select the level of SNR improvement – low, medium or high – on the user interface under Recon DL Strength. Users can also decide to save the conventional reconstruction and the AIR™ Recon DL images, saving both for comparison to help determine the best level for the facility and radiologists. This option is located in the system preferences toolbox.

Helpful Hints:

- Setting AIR™ Recon DL strength to "high" will allow the biggest improvement in noise reduction. Following the steps outlined above will help achieve this impact in overall image quality. All GE supplied AIR™ Recon DL protocols are set to "high".

Figure 2. Toe scanned with 100 μm resolution and reconstructed with (A) conventional and (B) AIR™ Recon DL.

Summary

To fully realize the clinical benefits of AIR™ Recon DL is to understand how it can provide more freedom to achieve higher spatial resolution, higher SNR and shorter scan times, separately or simultaneously. The concept of an expanded protocol space can be helpful, in particular, to realize what type of scans were simply not attainable with conventional image reconstruction. All users have some amount of preference when it comes to spatial resolution, SNR and scan time, and utilizing these step-by-step guidelines can help your facility make the most of AIR™ Recon DL. Ⓢ

References

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3. Zafar W, Masood A, Iqbal B, Murad S. Resolution, SNR, Signal Averaging and Scan Time in MRI for Metastatic lesion in spine. A case report. J Radiol Med Imaging. 2019; 2(1): 1014. https://meddocsonline.org/journal-of-radiology-and-medical-imaging/resolution-snr-signal-averaging-and-scan-time-in-mri-formetastatic-lesion-in-spine-a-case-report.pdf

Differentiators of AIR™ Recon DL:

- Use of raw data for the most effective result
- Compatible with all anatomies
- Sharpens images in addition to denoising
- User-selectable SNR improvement level
- Images that appear directly on the MR console
- Thoroughly tested in clinical settings with multiple peer-reviewed published studies

Key considerations when implementing:

- How to reduce scan time (keeping spatial resolution preserved)?
- How to increase spatial resolution (keeping scan time preserved)?
- How to reduce scan time and increase spatial resolution?
- What SNR improvement level is preferred?

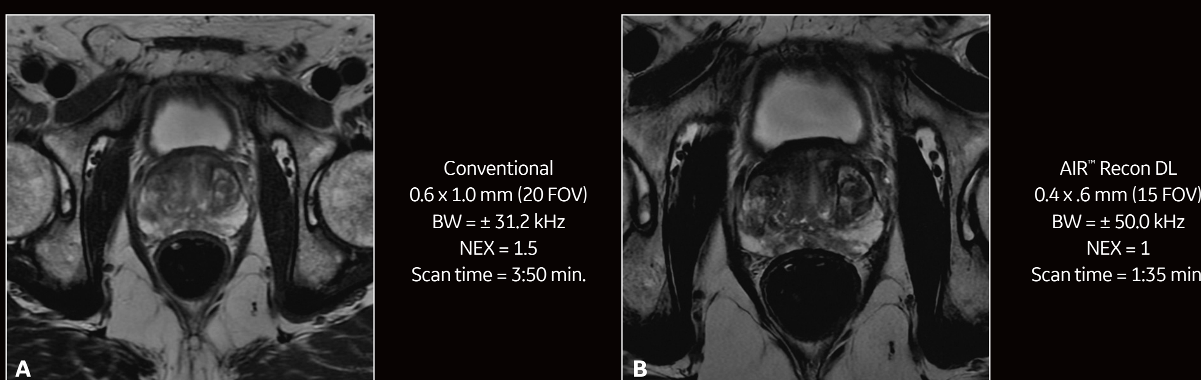

Figure 4. Comparison of (A) conventional reconstructed image and (B) AIR™ Recon DL reconstructed image.

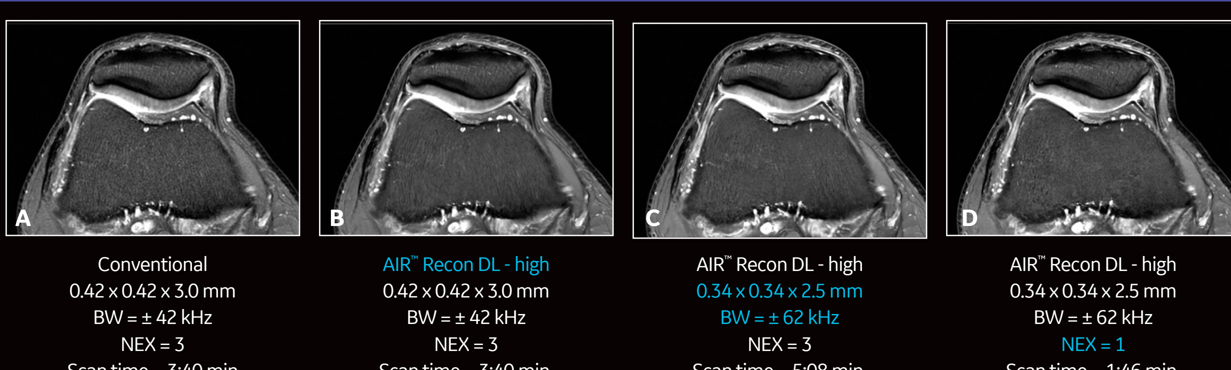

Figure 5. Representative images demonstrating AIR™ Recon DL for simultaneous scan time reduction and spatial resolution improvement. Shown are PDw FatSat knee images. (A) Conventional reconstruction image, (B) AIR™ Recon DL reconstruction of the same raw data as in (A), (C) AIR™ Recon DL protocol from (B) with higher in-plane pixel size, reduced slice thickness and increased BW, and (D) the final AIR™ Recon DL image, protocol from (C) with reduced NEX to attain a shorter scan time and higher resolution compared to the conventional image in (A).