White paper

Deep Resolve[1] – Mobilizing the power of networks

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Digitalizing Healthcare

The digitalization of healthcare is an ongoing process that is also affecting diagnostic imaging and MRI in particular. This starts with streamlined operation management, including patient scheduling, and goes all the way to support for clinical decision making, such as image interpretation, quantification, and report generation. Digitalization has impacted the way patients and providers approach diagnostic imaging. Especially the use of AI has proven to be a valuable tool for a range of steps along the image acquisition and processing chain, such as exam planning or image processing and decision support.

This results in improved productivity for the providers and ultimately improved patient experience, due to shorter scan times and a reduced risk of repeated measurements. But AI also has great potential when it comes to the generation of the image itself, helping to tackle some of the core limitations of MRI, including acquisition speed, image noise, and artifacts.

The limitations of conventional image reconstruction

MRI is established as one of the key modalities in diagnostic imaging. The absence of ionizing radiation and the unmatched soft tissue contrast distinguish MRI from other imaging modalities. While these features have helped to establish MRI as the method of choice for the diagnosis of many pathologies, the main limitation of MRI is the acquisition time.

With conventional reconstruction methods, the acceleration of an acquisition can only be achieved by accepting compromises with respect to image resolution or signal-to-noise ratio (SNR). In general, acquisition speed, image resolution and SNR are tightly linked and increasing one of the three automatically has a negative effect on at least one of the two others (see Figure 1).
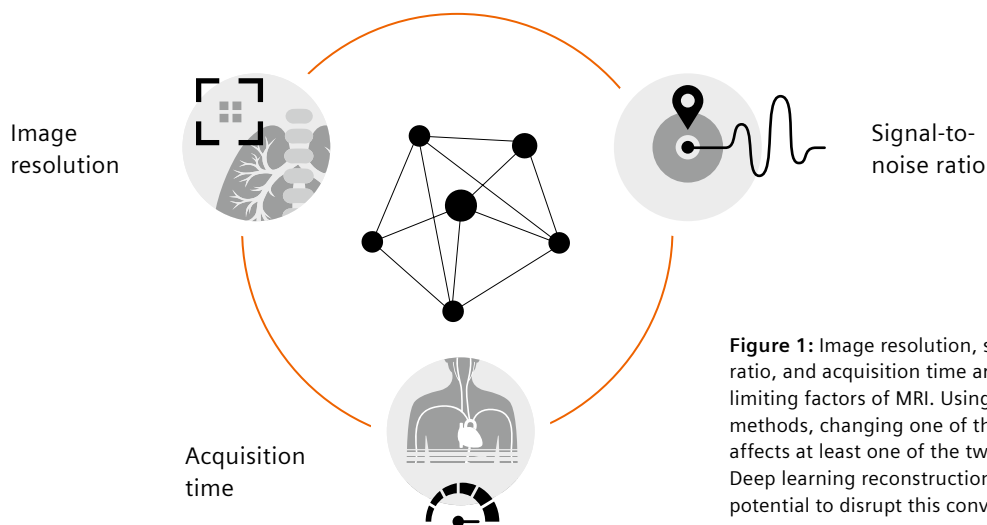

Image resolution

Signal-to-noise ratio

Acquisition time

Figure 1: Image resolution, signal-to-noise ratio, and acquisition time are the three limiting factors of MRI. Using conventional methods, changing one of them directly affects at least one of the two others. Deep learning reconstruction has the potential to disrupt this convention.

The use of receive arrays and parallel imaging has been an important breakthrough in MR image reconstruction and is an essential part of clinical routine in MRI [1,2].

Parallel imaging, however, usually comes at the price of higher image noise, especially in regions further away from the receive coils. This results in inhomogeneous noise distribution, especially if high acceleration factors are used. Compressed Sensing was another major development when it comes to image acceleration [3]. It benefits especially dynamic and non-cartesian 3D imaging but comes at the cost of a higher computational burden. Also, 2D cartesian imaging, which still is building the backbone of routine MR imaging, benefits less from Compressed Sensing.

Over the last years, AI technologies have made their appearance in a various research publications [4,5]. Especially the use of deep neural networks has proven to be helpful when trying to address the limitations of conventional MR image reconstruction, especially also for routine 2D imaging. Deep learning image reconstruction has the potential to tackle all three limiting factors of MR imaging simultaneously: image resolution, signal-to-noise ratio and acquisition speed.

Deep Resolve Gain & Deep Resolve Sharp

With Deep Resolve, we bring deep learning and AI to the MR image reconstruction process. Deep Resolve is our advanced reconstruction technology, which in its first step brings intelligent denoising and deep-learning-based image reconstruction directly to the core of the imaging chain.

Deep Resolve Gain is our solution for intelligent denoising. As mentioned above, in MRI, image noise is not uniformly distributed across the image. This can be due to coil array geometries since the SNR is usually higher close to the receive coils. Also the use of parallel imaging reconstruction techniques can lead to varying noise levels in the reconstructed image. These local variations in image noise can't be addressed by conventional noise filters, as these operate globally on the entire reconstructed image. Deep Resolve Gain incorporates specific noise maps, which are acquired together with the original raw data, directly into the image reconstruction [6].

These noise maps are generated without needing to spend additional scan time and can be extracted from the raw data. The reconstruction algorithm takes local noise variations into account and enables stronger denoising where noise would be most dominant when reconstructing with conventional methods.
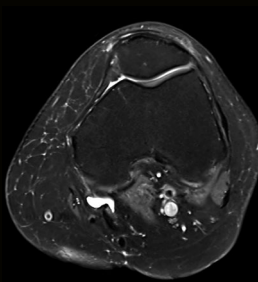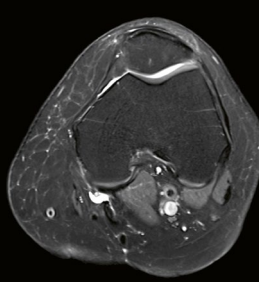
Deep Resolve Gain helps to mitigate noise that is introduced when accelerating the acquisition e.g. by reducing the number of averages or by increasing the acceleration factor in parallel imaging.

As the noise maps can be generated from the originally acquired raw data, no additional acquisition time is needed, and the results are available in real-time. Figure 2 shows how Deep Resolve Gain can be employed to accelerate an entire knee exam. Images acquired with increased acceleration and reconstructed with Deep Resolve Gain are similar in quality to the standard protocols which are conventionally reconstructed. In this example it results in an acceleration by 28% over the entire exam.

Deep Resolve Sharp is a novel image reconstruction technology to generate images with increased sharpness. The deep neural network at the core of Deep Resolve Sharp generates a high-resolution image from low resolution input data. The network was trained on a large number of pairs of low-resolution and high-resolution data.

As the training data for Deep Resolve Gain covered a wide range of anatomies, the reconstruction network can be applied to all body regions. Deep Resolve Sharp can increase the matrix size by a factor of up to two along both in-plane axis, resulting in substantially increased image sharpness.
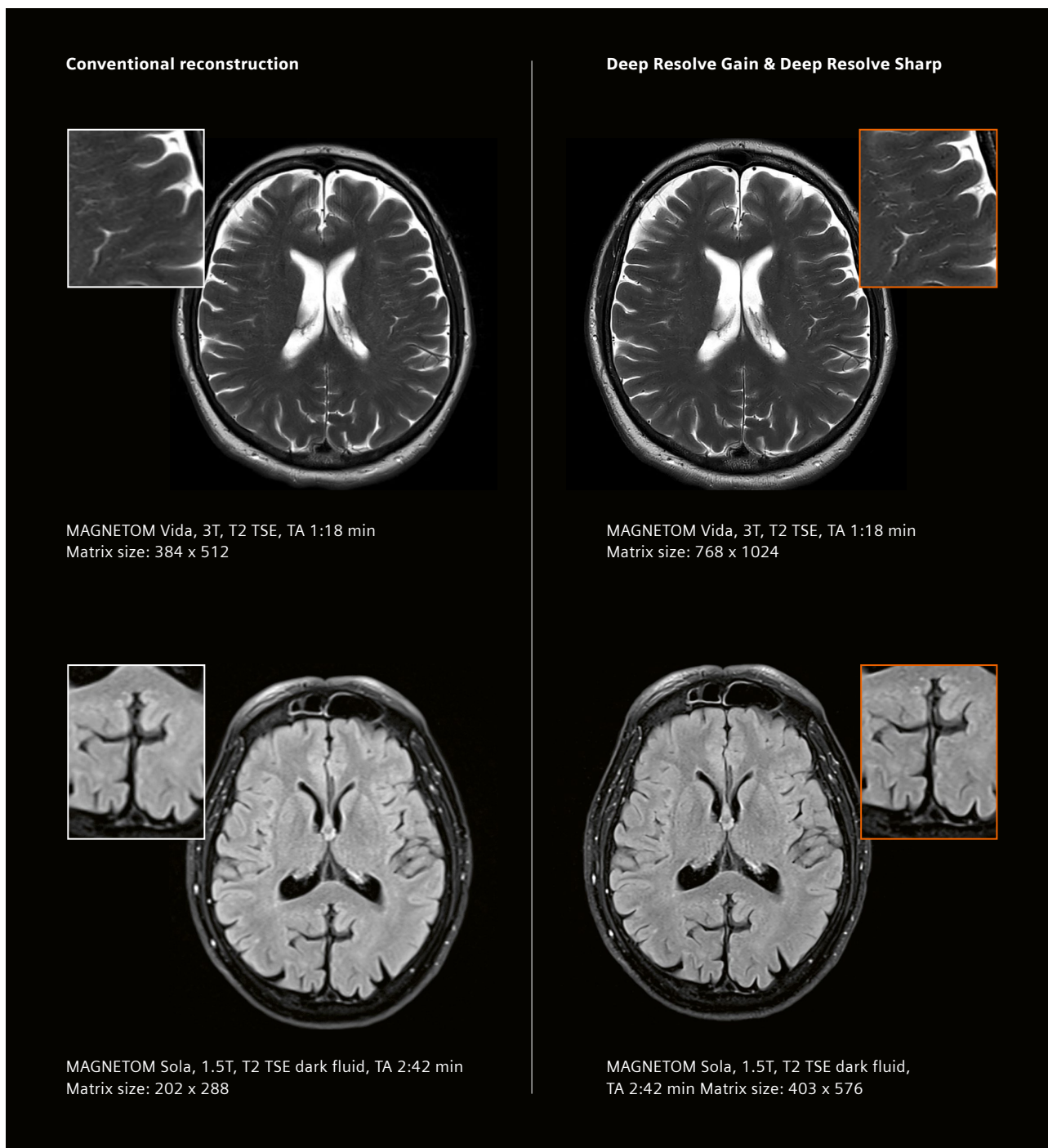
Conventional reconstruction

Deep Resolve Gain

pD tse fs p2
TA 3:12 min
0.4 x 0.3 x 3 mm³

PD tse fs p3
TA 2:20 min
0.4 x 0.3 x 3 mm³

T1 tse p2
TA 3:38 min
0.5 x 0.3 x 2.5 mm³

T1 tse p3
TA 2:38 min
0.5 x 0.3 x 2.5 mm³

pD tse p2
TA 3:52 min
0.4 x 0.2 x 3 mm³

PD tse p3
TA 2:50 min
0.4 x 0.2 x 3 mm³

T2 tse fs p2
TA 3:10 min
0.6 x 0.3 x 3 mm³

PD tse fs p3
TA 2:10 min
0.6 x 0.3 x 3 mm³

PD tse fs p2
TA 3:45 min
0.5 x 0.3 x 3 mm³

PD tse fs p3
TA 2:46 min
0.5 x 0.3 x 3 mm³

17:37

12:44
With Deep
Resolve Gain

28% reduction

2   The increase in SNR achievable with Deep Resolve enables you to accelerate entire knee exams. The targeted reduction of image noise allows for the use of higher acceleration factors, without having to pay with increased image noise. Images are acquired on a MAGNETOM Vida 3T scanner.

To ensure robust results, the acquired raw data is directly incorporated into the reconstruction and ensures consistency with the data from the scanner. The inclusion of the cross-check with the acquired raw data is essential for the robustness of the reconstruction and to ensure that contrasts are correctly represented in the final output. Figure 3 shows how Deep Resolve Sharp can be used to increase the sharpness of reconstructed images, without having to extend the acquisition time.

Conventional reconstruction

MAGNETOM Vida, 3T, T2 TSE, TA 1:18 min
Matrix size: 384 x 512

MAGNETOM Sola, 1.5T, T2 TSE dark fluid, TA 2:42 min
Matrix size: 202 x 288

Deep Resolve Gain & Deep Resolve Sharp

MAGNETOM Vida, 3T, T2 TSE, TA 1:18 min
Matrix size: 768 x 1024

MAGNETOM Sola, 1.5T, T2 TSE dark fluid,
TA 2:42 min Matrix size: 403 x 576

3A

Conventional reconstruction

Deep Resolve Gain & Deep Resolve Sharp
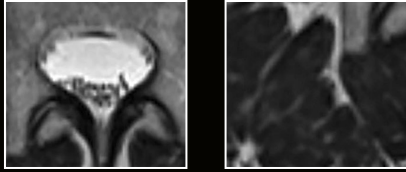
MAGNETOM Sola, 1.5T, T2 TSE, TA 3:45 min
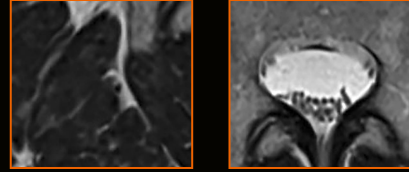Matrix size: 256 x 320

MAGNETOM Sola, 1.5T, T2 TSE, TA 3:45 min
Matrix size: 512 x 640

MAGNETOM Sola, 1.5T, T2 TSE, TA 2:24 min
Matrix size 307 x 384
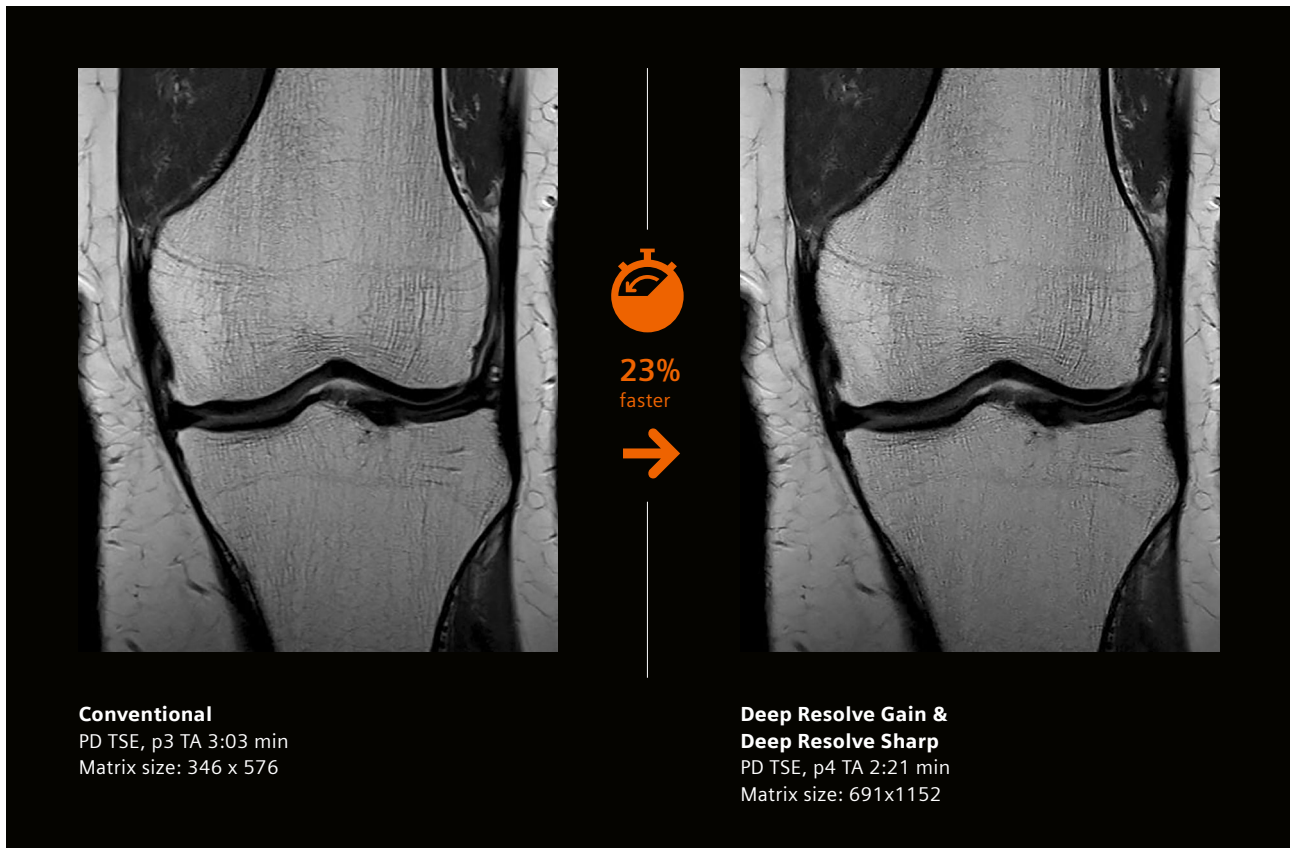
MAGNETOM Sola, 1.5T, T2 TSE, TA 2:24 min
Matrix size 614 x 768

3B Deep Resolve Sharp uses a deep neural network to generate sharper images than ever before, enabling a clear depiction of fine structures and sharp edges. The use of raw data within the reconstruction process ensures robust results.

In Figure 4 you can see how Deep Resolve enables accelerated acquisition while simultaneously increasing image quality and sharpness.

23%
faster

Conventional
PD TSE, p3 TA 3:03 min
Matrix size: 346 x 576

**Deep Resolve Gain &
Deep Resolve Sharp**
PD TSE, p4 TA 2:21 min
Matrix size: 691x1152

3aaaa1597

4 Together, the Deep Resolve technologies enable faster acquisitions, while increasing the image sharpness simultaneously. The targeted denoising achieved with Deep Resolve Gain allows for the use of higher acceleration, while Deep Resolve Sharp increases the sharpness of the image by increasing the matrix size. Images are acquired on a MAGNETOM Vida scanner.

Open innovation platform[2]

Deep learning reconstruction is a very active field for researchers, demonstrating great potential for the future of MR image reconstruction, including denoising, artifact reduction, and possibly even the reconstruction of multiple contrasts from one single acquisition [7]. With Deep Resolve, we want to give users access to the plentitude of deep learning applications being developed in the field. Via an open innovation interface, Deep Resolve is planned to enable our partners to position their solutions in the Digital Marketplace, powered by the teamplay Digital Health Platform.

Currently, prototyping for image reconstruction algorithms is usually done offline, which means that the raw data has to be transferred from the scanner to a workstation, where they are finally reconstructed using a prototype developed e.g. in Matlab or Python. These reconstructions then have to be converted to DICOM again if a clinician wants to evaluate them for a clinical study. Deep Resolve is planned to facilitate clinical transition for image reconstruction prototypes by enabling online reconstruction, directly at the scanner. The open innovation protocol is designed to support open community standards, such as the ISMRM raw data format and Gadgetron (see Figure 5).
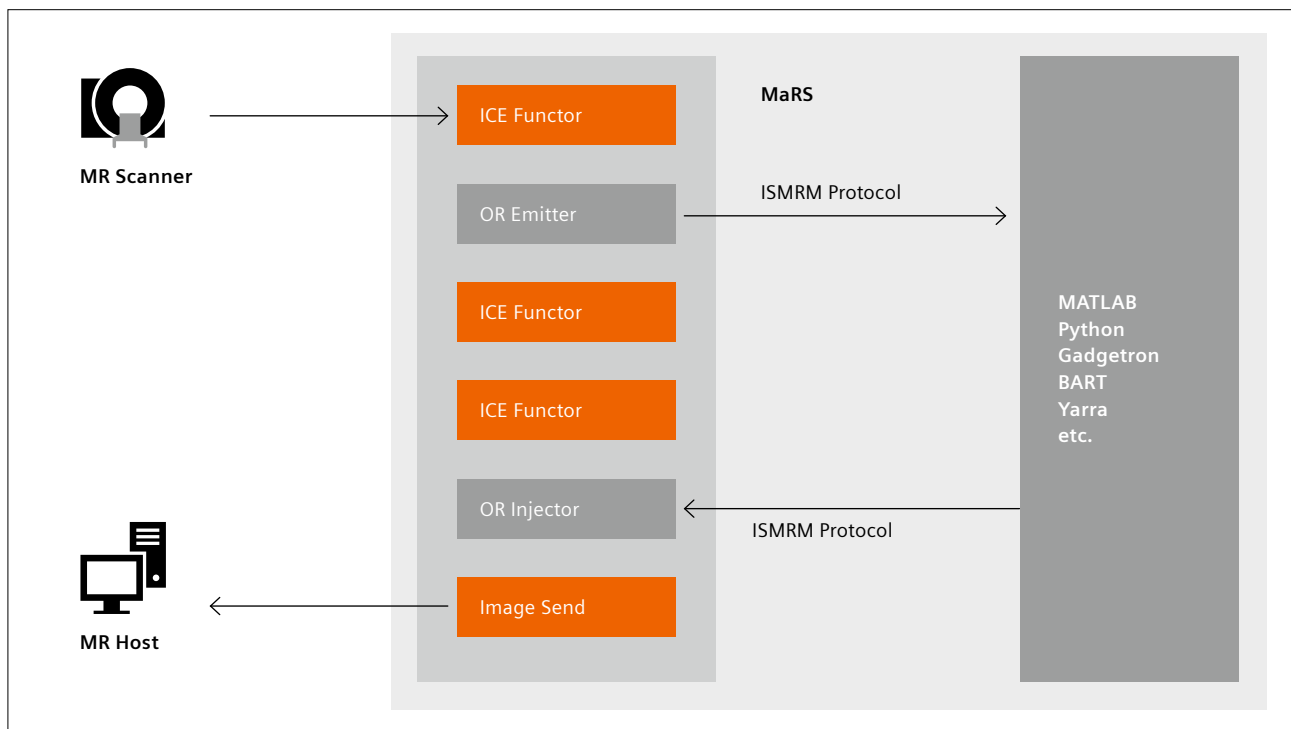
5 With an open innovation protocol, Deep Resolve is planned to facilitate translational research by enabling researchers to run their image reconstruction prototypes directly on the scanner.

Let's open a new chapter in image reconstruction!

With Deep Resolve, we are taking the next step to shape the future of AI in image reconstruction. Deep Resolve Gain and Deep Resolve Sharp are our technologies for intelligent denoising and deep learning reconstruction. Together, they deliver sharper images, faster, thus enabling shorter scan times and increased throughput.

The potential of deep learning image reconstruction is immense, and current research is indicating a multitude of fascinating applications to come. Collaboration is key in MRI, so let us join our efforts in driving this exciting technology forward!

References

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[3] Lustig, Michael, David Donoho, and John M. Pauly. "Sparse MRI: The application of compressed sensing for rapid MR imaging." Magnetic Resonance in Medicine: An Official Journal of the International Society for Magnetic Resonance in Medicine 58.6 (2007): 1182–1195.

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[5] Hammernik, Kerstin, et al. „Deep Learning for Parallel MRI Reconstruction." MAGNETOM Flash 75 (4/2019): 10:23.

[6] Kannengiesser, Stephan A.R., et al. „Universal iterative denoising of complex-valued volumetric MR image data using supplementary information." Proceedings of the ISMRM, Abstract 1776, 2016

[7] Knoll, Florian, et al. "Deep-learning methods for parallel magnetic resonance imaging reconstruction: A survey of the current approaches, trends, and issues." IEEE Signal Processing Magazine 37.1 (2020): 128–140.

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[1] *Deep Resolve is pending 510(k) clearance, and is not yet commercially available in the United States. Its future availability cannot be guaranteed.*

[2] *The product is still under development and not commercially available yet. Its future availability cannot be ensured.*