Setting the pace in MRI acceleration

Whitepaper

In an environment of dropping reimbursements, high daily volume and quality of MRI exams are key to the financial viability of healthcare providers. Over the last decade, Siemens Healthineers has focused on increasing productivity and standardization in MRI with innovations ranging from improved coil and hardware design and intuitive user interfaces to the deployment of artificial intelligence to help better plan and execute exams.

In this general context, quick, and robust scans are essential. Furthermore, performing exams rapidly is one of the main ways to increase patient satisfaction. However, in MRI, faster scans traditionally come at the expense of quality and spatial resolution, as well as an increased number of artifacts.

With the advent of disruptive innovations in speed such as Compressed Sensing (CS), Simultaneous Multi-Slice (SMS), and CAIPIRINHA, pioneered by Siemens Healthineers, this is no longer the case. These innovative acceleration techniques, in combination with our portfolio of coils with the highest coil element density, enable accelerated and high-quality imaging throughout the body for a range of sequence types and contrasts. Just as importantly, our acceleration techniques can be seamlessly applied in everyday clinical practice thanks to our high-performance image reconstruction architecture: Images and results are readily available quickly at the scanner, with no need to upload and process data in the cloud or on a separate post-processing server.

At this point, it is worth emphasizing that not all acquisition techniques benefit equally from Compressed Sensing acceleration and iterative reconstruction: In particular, dynamic scans (2D dynamic or 3D dynamic imaging) have a high sparsity of the whole dataset. The Compressed Sensing regularization with iterative reconstruction can be applied through time and not only in space. Applying Compressed Sensing to 2D dynamic or 3D dynamic data is the most demanding and sophisticated implementation and enables very high acceleration factors of up to 40 in clinical practice. Conventional 'static' acquisitions, on the other hand, typically have a lower sparsity, and the clinically applicable Compressed Sensing acceleration is lower. Therefore, using CAIPIRINHA or SMS can achieve results similar to or better than acceleration with CS. For a standard 2D scan, for example, the maximum applicable CS factor is limited to 3 or 4, while SMS + PAT can easily enable total acceleration factors of 6 (3 x 2) or 8 (4 x 2) – see also Figure 1.

With the most comprehensive portfolio of acceleration techniques in the industry, every clinical application on Siemens Healthineers' MRI scanners can be accelerated using the appropriate technique. The result: substantial time savings for the entire exam and high quality. However, shorter scan times are not the only benefit of MRI acceleration. Acceleration can also be a lever for higher spatial resolution, capturing more information

SIEMENS Healthineers

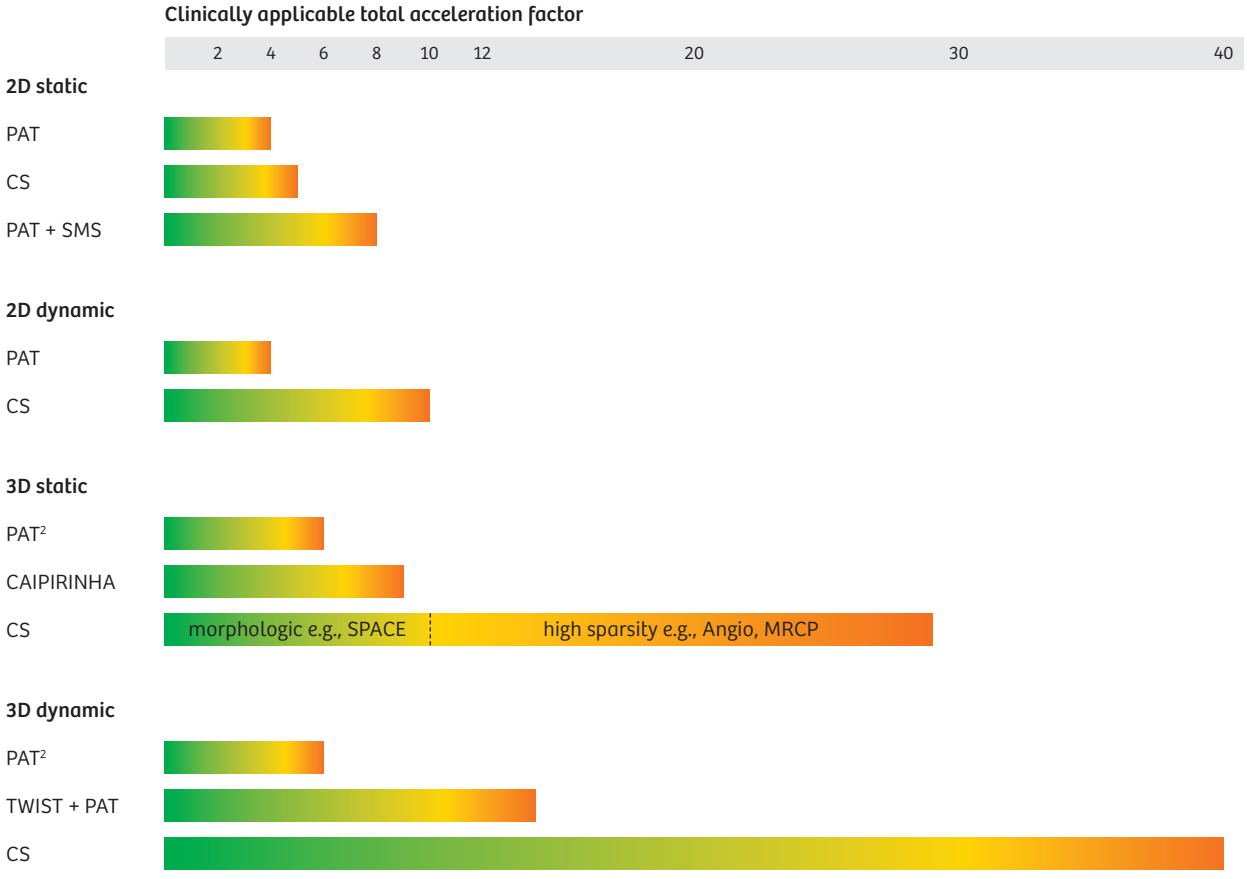


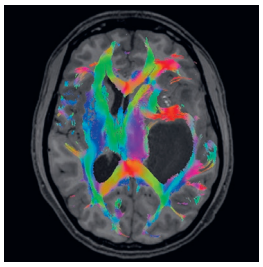
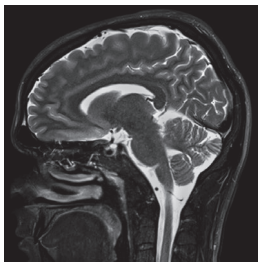
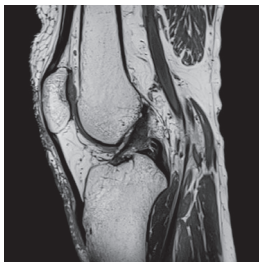
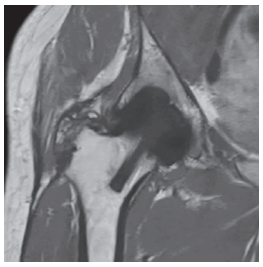
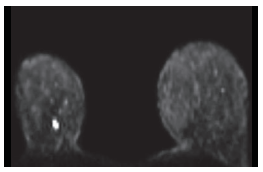
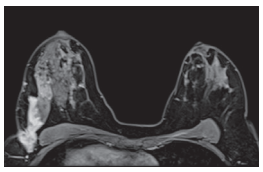
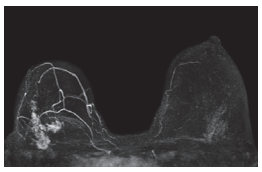
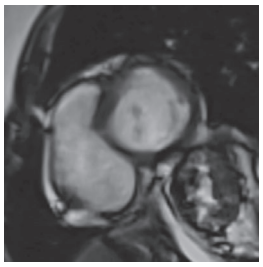
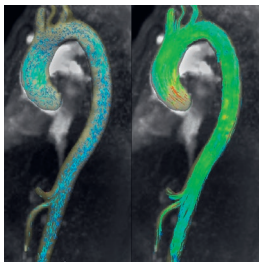
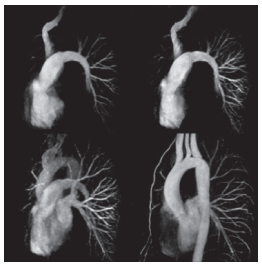
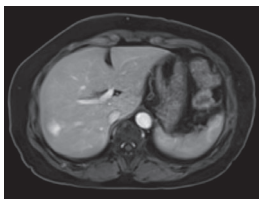
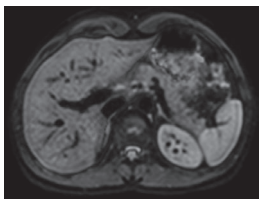
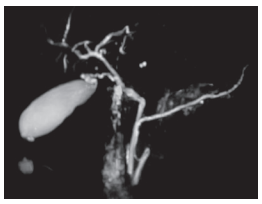
Figure 1:
Total acceleration factors for different types of sequences (2D, 3D, and dynamic acquisitions) and acceleration techniques (Parallel Acquisition Techniques, CAIPIRINHA, SMS, and CS) which are typically achievable and applied in clinical practice. For static 2D imaging, for example, commonly used acceleration factors are 2 or 3 with parallel imaging. Here, the gain of applying Compressed Sensing is limited, and SMS + PAT can enable higher acceleration factors. For static 3D acquisitions, the value of CS largely differs with the sparsity of the acquired images: 'morphological' scans like SPACE have a rather low sparsity and accordingly a lower acceleration potential with CS, while in particular angiographic exams or MRCP scans have a high intrinsic sparsity (= many black voxels and a relatively small number of bright voxels) and allow higher acceleration factors. Dynamic scans have in general a much higher sparsity than static scans, with much higher possible acceleration factors. With TWIST, the acceleration factor could be increased up to 100 (keyhole approach), but this would be accompanied by the disadvantage of substantial temporal blurring.

without adding to the scan time. What is more, short acquisition times can help capture dynamic processes such as the beating heart or the passage of a contrast bolus, or reduce artifacts caused by physiological motion. In other words, faster scans ultimately help expand the patient population eligible for MRI, and can have a positive impact on patient care.

We have a long list of 'industry firsts' and are committed to continuing to deliver and to set the pace in MRI acceleration by expanding our portfolio of accelerated routine and advanced scans. The following pages illustrate innovative techniques that can be applied to all major clinical fields. The methods are designed to improve clinical utility, patient satisfaction, and productivity.

1st price ISMRM challenge SRT reconstruction and R&D100 award
Siemens Healthineers' Compressed Sensing Cardiac Cine algorithm was awarded first price among 23 submissions of different vendors at the ISMRM SRT reconstruction challenge in 2014. In 2017 we have been awarded the prestigious R&D100 award, for the technologically most significant product. In addition CS Cardiac Cine has won the 2017 Gold award in the category "Market Disruptor Product".

Besides standard acceleration, we offer a comprehensive portfolio of tailored acceleration solutions for every major clinical field

Neuro	SMS BOLD / DWI / DTI  up to x8 6:42 min	3D CS TOF*  up to x6.8 3:30 min	SMS TSE*  up to x4 1:14 min
MSK	3D CAIPIRINHA SPACE  up to x4 4:41 min	CS SEMAC*  up to x8 4:01 min	SMS TSE*  up to x6 2:11 min
Breast	SMS DWI  up to x4 2:12 min	4D TWIST-VIBE  up to x8 7 s per 3D volume	4D CS cartesian VIBE*  up to x20 4 s per 3D volume
Cardio-vascular	2D dynamic CS Cardiac Cine  up to x10 Left ventricular function in 7–15 s	4D CS Flow*  up to x7.7 3:36 min	4D CS TWIST*  up to x22 2 s per 3D volume
Body	4D CS GRASP-VIBE  up to x40 3 s per 3D volume	SMS DWI  up to x4 2:36 min	3D CS SPACE MRCP*  up to x28 16 s

Legend: ■ Total acceleration factor** ■ Acquisition time / temporal resolution

* This product is currently under development; is not for sale in the U.S and other countries. Its future availability cannot be guaranteed.
** The total acceleration factor can be the result of a combination of parallel imaging and SMS, e.g., SMS 3 x PAT 2 = 6.

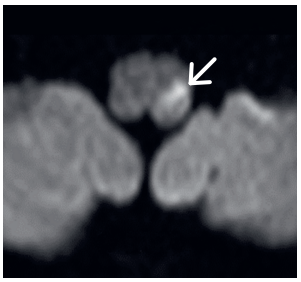
Images courtesy of: Centre Hospitalier Universitaire de Québec, Université Laval, Québec, Canada (SMS DSI). Prof. B. Wintersperger, Toronto General Hospital, Toronto, Canada (CS TOF). CMRR, Minnesota, USA (SMS TSE). Prof. Jan Fritz, Johns Hopkins, Baltimore, USA (CS SEMAC). CHRU Brest, Brest, France (SMS DWI, Breast). Dr. Evelyn Wenkel, University Hospital Erlangen, Erlangen, Germany (TWIST). Dr. Kanao, Kyoto University, Kyoto, Japan (CS VIBE). Prof. J. M. Lee, SNUH, Seoul, Rep. of Korea (CS SPACE MRCP).

Acceleration with Simultaneous Multi-Slice

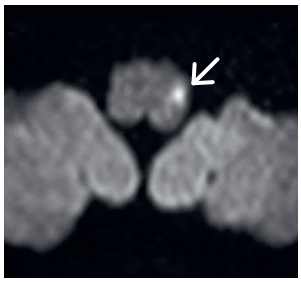
Neuro

Challenge: Unclear finding in DWI: Susceptibility artifact or small medullary infarction?

Conventional DWI, b1000, SL 4 mm



SMS-accelerated DWI, b1000, SL 2 mm



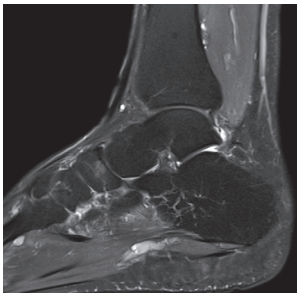
Doubled resolution

Solution: Clearly circumscribed lesion visible in multiple 2 mm slices, improving diagnostic confidence without increasing the scan time.

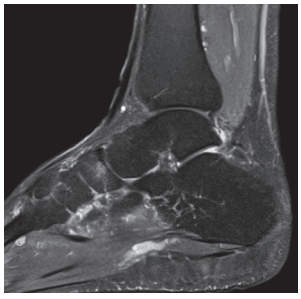
MSK

Challenge: Knee and foot/ankle exams are among the most common routine MR examinations. High-resolution 2D scans typically add up to 15–20 minutes total exam time.

Conventional TSE, TA 3:32 min



SMS-accelerated TSE*, TA 1:51 min



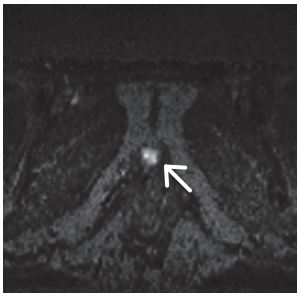
48% faster

Solution: By saving up to an additional 50% per scan compared to conventional parallel imaging. SMS-accelerated TSE reduces the exam time for a knee or foot/ankle scan by almost half. This can help to significantly increase the number of patients examined per day.

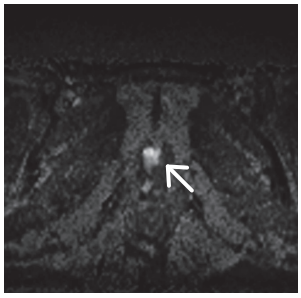
Prostate

Challenge: DWI with high b-values and thin slices is essential for prostate imaging. However, achieving good SNR in the pelvis involves long acquisition times, in particular at 1.5T.

Conventional DWI (calculated b2000), TA 4:58 min



SMS-accelerated DWI (calculated b2000), TA 2:55 min



41% faster

Solution: With SMS-accelerated DWI, acquisition times for DWI of the prostate can be significantly shortened for efficient routine imaging.

Simultaneous Multi-Slice (SMS) significantly speeds up imaging thanks to the simultaneous excitation and readout of multiple slices with acceleration factors of up to 8. SMS Diffusion, DTI and BOLD bring advanced neuro applications into clinical routine while also offering significant time savings for diffusion-weighted imaging in the body. By applying an SMS factor of 2 SMS-accelerated TSE has the potential to significantly accelerate routine MSK examinations.

Learn more about Simultaneous Multi-Slice at **siemens.com/magnetom-world > Hot Topics**

* This product is currently under development; is not for sale in the U.S and other countries. Its future availability cannot be guaranteed.

Neuro images courtesy of Prof. Val M. Runge, et al. Simultaneous Multi-Slice (slice accelerated) diffusion EPI: Early experience for brain ischemia and cervical lymphadenopathy. MAGNETOM Flash 2015; 63 (Special SMS Supplement): 92–95. Prostate images courtesy of CHRU Brest, Brest, France.

Acceleration with 3D CAIPIRINHA SPACE and 3D CAIPIRINHA VIBE

MSK

Challenge: High-resolution 3D scans involve unacceptably long scan times. However, 3D scans enable highly desirable, flexible reconstruction capabilities, e.g., cruciate ligament views or meniscus views.

PAT 2, 0.5 mm isotropic, TA 9:58 min

CAIPIRINHA 4, 0.5 mm isotropic, TA 4:41 min

50% faster

Solution: The unique Siemens CAIPIRINHA SPACE technology brings high-resolution, isotropic 3D MSK imaging into clinical practice. GOKnee3D employs CAIPIRINHA SPACE to achieve a high-resolution diagnostic knee exam including PD and T2 FatSat in 10 minutes.

Abdomen

Challenge: Many patients are unable to hold their breath for more than 15 seconds. As a result, the quality of abdominal MRI scans is often compromised by blurring or severe motion artifacts, impairing assessment.

PAT 2, TA 22 s

CAIPIRINHA 4, TA 10 s

Significantly shorter breath-hold

Solution: The unique Siemens CAIPIRINHA VIBE technology can be used to significantly shorten breath-holds, resulting in increased edge sharpness, better delineation of structures and less blurring, leading to higher diagnostic confidence and greater predictability of abdominal MR image quality.

Abdomen

Challenge: To keep breath-hold times at an acceptable level, spatial resolution often has to be compromised in abdominal scans, leading to uncertainty in the assessment.

GRAPPA 3, matrix 256, SL 3 mm, TA 19.2 s

CAIPIRINHA 6, matrix 320, SL 1.5 mm, TA 18.1 s

3 times higher resolution

Solution: Higher spatial resolution with CAIPIRINHA VIBE helps increase the conspicuity of abdominal lesions*.

CAIPIRINHA (Controlled Aliasing in Parallel Imaging Results in Higher Acceleration) for SPACE and VIBE is a unique *k*-space acquisition scheme for parallel imaging techniques (PAT) that improves the SNR by up to 18% compared to conventional acceleration with SENSE or GRAPPA**. This enables higher PAT factors in clinical routine, resulting in significantly faster acquisitions for MSK, or shorter breath-holds.

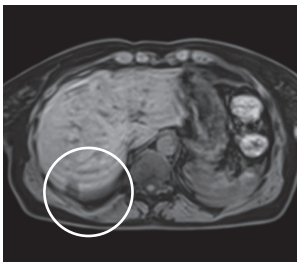
* AlObaidy M, et al. Eur Radiol. 2015 Apr 28. PMID: 25916391
** Breuer FA et al, Magn Reson Med 2006; 55 (3): 549-56

Acceleration with Compressed Sensing

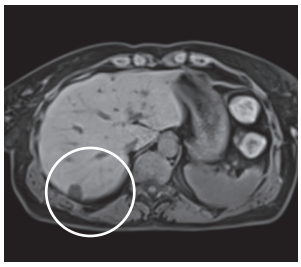
Abdomen

Challenge: Non-diagnostic image quality is an issue in patients with limited or no breath-hold capability, such as those suffering from dementia or hearing impairment, or children* and multi-morbid patients.

Conventional 3D VIBE, 14 s breath-hold



4D Compressed Sensing GRASP-VIBE, free-breathing acquisition



Free breathing

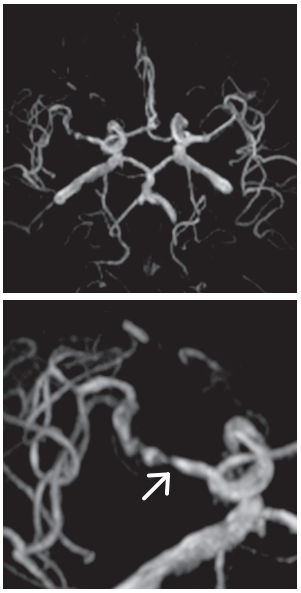
7 s per 3D volume

Solution: By enabling push-button, free-breathing liver dynamics, Compressed Sensing GRASP-VIBE overcomes timing challenges in dynamic imaging and eliminates respiratory artifacts. This makes it possible to expand the patient population eligible for liver MRI.

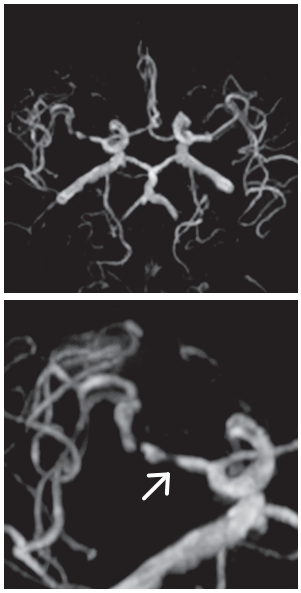
Neuro

Challenge: ToF is decisive in the detection of vessel occlusions, malformations or aneurysms. However, acquisition times are typically in the order of 5 minutes.

Conventional 3D ToF, 0.6 x 0.6 x 0.6 mm^3, TA 5:54 min



Compressed Sensing 3D ToF**, 0.6 x 0.6 x 0.6 mm^3, TA 3:15 min



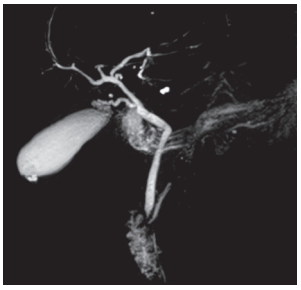
45% faster

Solution: Compressed Sensing Time of Flight (ToF)** allows scan time savings of up to 50% without compromising image quality. In time-critical cases such as stroke patients, scan times can be reduced to around 2 minutes.

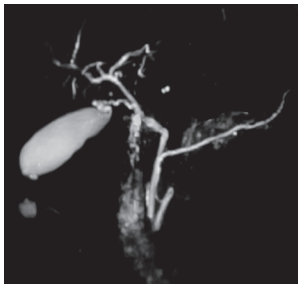
Abdomen

Challenge: 3D SPACE MRCP typically requires respiratory-gated acquisition times of 4 to 6 minutes, resulting in a high risk of motion artifacts compromising image quality.

PACE-triggered 3D SPACE, PAT 6, TA 5:48 min



3D CS SPACE, 28-fold acceleration, TA 16 s breath-hold



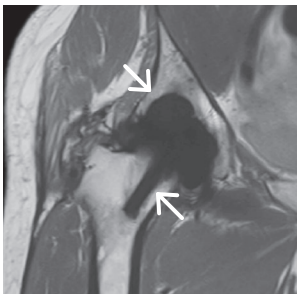
Only 16 s

Solution: With Compressed Sensing, 3D SPACE MRCP can either be performed in a triggered fashion with significantly shortened acquisition time or even within one short breath-hold.

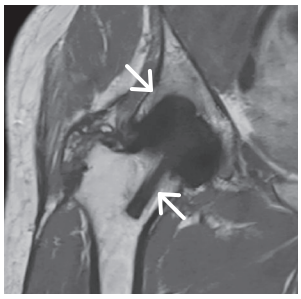
MSK

Challenge: Conventional SEMAC provides substantial metal artifact*** reduction, but clinical adoption suffers from long scan times.

SEMAC T1 TSE, PAT 3,
0.8 x 0.8 x 3.5 mm³, TA 10:06 min



Compressed Sensing
T1 SEMAC TSE **,
acceleration factor 8,
0.8 x 0.8 x 3.5 mm³, TA 4:01 min



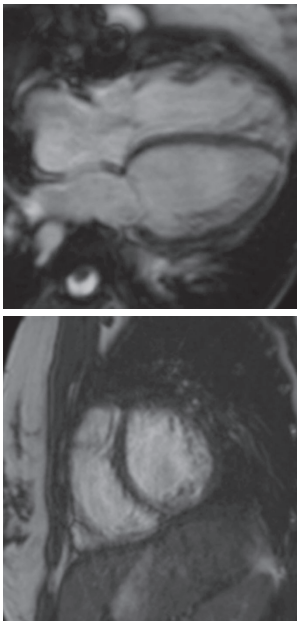
> 60% faster

Solution: Significantly shorter acquisition times with Compressed Sensing SEMAC make advanced metal artifact*** reduction clinically viable.

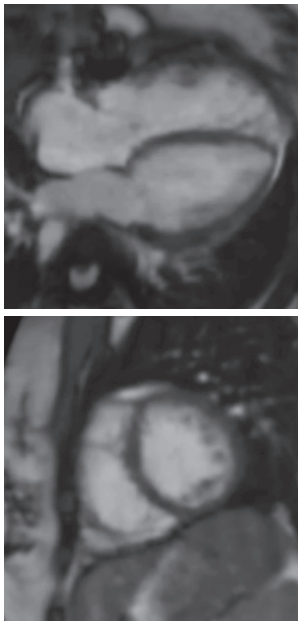
Cardiac

Challenge: Cardiac MR patients often present with irregular heart rate and limited breath-hold capabilities resulting in non-diagnostic images.

Conventional Cardiac Cine,
TA ~ 4–6 min,
~ 7–12 breath-holds



CS Cardiac Cine,
TA ~ 23 s, Free-breathing
or only one breath-hold



Highly robust

Solution: Compressed Sensing Cardiac Cine images acquired in the same patient provide diagnostic image quality in only 23 seconds. By acquiring one image per heartbeat this provides robustness for patients with dyspnea, irregular heart rate and complex anatomy.

Compressed Sensing speeds up data acquisition with sparse subsampling by a factor of up to 40. Excellent, artifact-free image quality is achieved by applying iterative reconstruction to the raw data. The acceleration makes it possible to either cut acquisition time or increase spatial and/or temporal resolution. Real-time imaging featuring Compressed Sensing helps reduce the need for breath-holding or ECG triggering.

Learn more about Compressed Sensing at **siemens.com/magnetom-world > Hot Topics**

* The safety of imaging infants under two years of age has not been established. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures.

** The product is currently under development and is not for sale in the US and in other countries. Its future availability cannot be ensured.

*** The MRI restrictions (if any) of the metal implant must be considered prior to the patient undergoing an MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the above warning may not be applicable. Please contact the implant manufacturer for specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.

Images courtesy of: Prof. K. Togashi , Kyoto University, Kyoto, Japan (ToF). Prof. J. M. Lee, SNUH, Seoul, Rep. of Korea (MRCP). Prof. J. Fritz, Johns Hopkins, Baltimore, USA (SEMAC). Prof. Pontana, Dep. of Cardiovascular Radiology, Lille University, Lille, France (Cardiac Cine).

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Further Reading:

M. Lustig, D. Donoho, and J. M. Pauly. "Sparse MRI: The Application of Compressed Sensing for Rapid MR Imaging". Magnetic Resonance in Medicine, Vol. 58, No. 6, pp. 1182–1195, Dec 2007.

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Published by Siemens Healthcare GmbH · Order No. A91MR-1100-96C-7600 · Printed in Germany · 5695 02181.5 ·