Compressed SENSE
Speed done right. Every time.

Liesbeth Geerts-Ossevoort, PhD; Elwin de Weerdt, PhD; Adri Duijndam, PhD; Gert van IJperen, PhD; Hans Peeters, PhD; Mariya Doneva, PhD; Marco Nijenhuis; Alan Huang, PhD

Since its introduction, MR has been challenged by matters of speed. Today, the imperative to shorten MR exams without impeding image quality has become even more urgent, because an increase in chronic conditions has led to a growing use of MR, which when combined with declining reimbursements has created a need for a paradigm shift in productivity[1,2]. This white paper explains the main principles of Compressed SENSE and how it introduces a paradigm shift in productivity, how Compressed SENSE was designed around image quality, and how it advances productivity for clinical MR imaging.

All authors are Philips employees

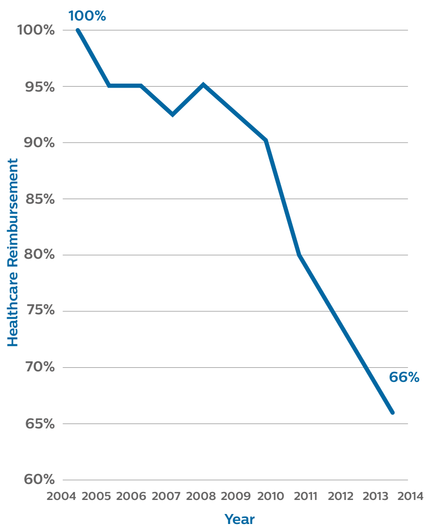
Why is it important to increase productivity?

Healthcare spending across the globe is increasing at a shockingly high rate. In the United States, healthcare costs are expected to reach 20% of its gross domestic product (GDP) by 2025, and in China, healthcare costs have grown at a compound annual growth rate of 15% between 2010-2015 and are expected to reach $1 trillion by 2020-2021[3, 4].
This trend has led to the emergence of value-based healthcare reimbursements, in which reimbursements are based on patient outcomes rather than procedures.
A recently conducted survey shows that healthcare providers and payers in the United States expect value-based reimbursement to surpass volume-based reimbursements by 2020[5]. This shift requires better care at lower costs.

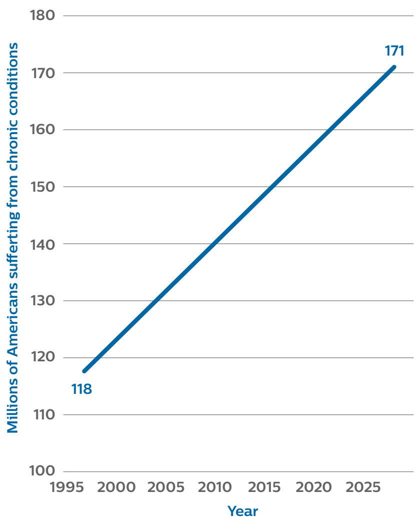
One way of addressing this is by accelerating scans. The parallel imaging technique SENSE, which later evolved to dS SENSE after the dStream platform was introduced, greatly accelerated MR image acquisition by under-sampling the data and using coil sensitivity information to restore the full image. Yet despite these and other advances, more acceleration is needed.

Recent advances in compressed sensing technology make it possible to reduce scan time beyond that of conventional parallel imaging accelerated scans. Building on principles of compressed sensing and the best of SENSE, Philips introduces Compressed SENSE.

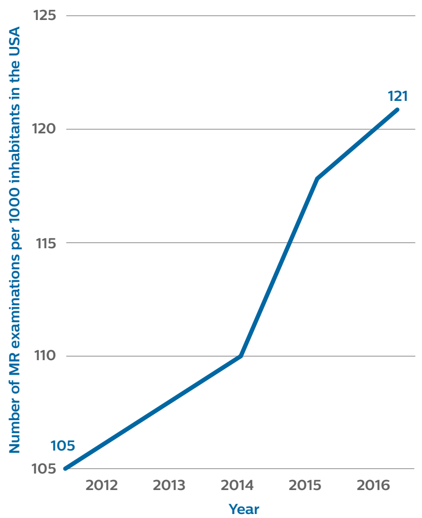
> “We can reduce the time needed per patient. By adding Compressed SENSE to multiple sequences in an exam, we can accelerate our examinations by up to 20-40%, and that’s very good for the patients.”
>
> Dr. Sabine Sartoretti
> Kantonsspital Hospital, Switzerland



Decrease in healthcare reimbursement[3]



Increase in chronic conditions[1]



Increase in number of MR procedures[2]

How can Philips’ Compressed SENSE produce a paradigm shift in productivity?

Compressed SENSE is built on compressed sensing, a breakthrough approach to accelerating imaging. By also incorporating components of Philips’ SENSE, it delivers images for all 2D and 3D scans in all anatomies with all anatomical contrasts.

What is the technique compressed sensing?

Compressed sensing is a signal processing technique built on the fact that signals contain redundant information. Compressed sensing was developed by David Donoho[6], while in the same period Emmanuel Candès, Terence Tao et al.[7, 8] showed the same principles. The initial evidence that image data can be compressed comes from digital photography. To address the issue of storage of large digital image files, several image compression techniques, such as jpeg, were developed. The realization that image compression was possible without loss of detail led to the intriguing question of whether this could be turned around: If all the data is not needed to store the relevant information, why should it be acquired?

In MR, in which acquisition times are determined by the relaxation properties and proton densities of tissues, the relevant question about compressed sensing is this: Can a full image be reconstructed from severely under-sampled data in k-space? The answer to this question was provided by Lustig et al[9] and soon after by several research groups for very specific applications. While these studies were all specific to a single type of acquisition and contrast, they showed that acquisition times could be reduced, while maintaining virtually equivalent image quality.

Conditions required for compressed sensing in clinical practice

Compressed sensing is concerned with the whole chain of acquisition strategy, signal processing and reconstruction.

In general, compressed sensing can be exploited in clinical practice under the following four conditions:

- The under-sampling pattern needs to promote noise-like incoherent artifacts.
- The data needs to be sparse either directly or in a transform domain.
- Combination with current parallel imaging technology to leverage further acceleration on phased array coils.
- An iterative reconstruction implementation that balances data consistency and sparsity needs to be present.

How does compressed sensing benefit from a sampling pattern that promotes incoherent artifacts?

When data is completely sampled, all of the information is available to reconstruct the image (Figure 1A). Under-sampling the data is one way to accelerate scanning. The way that the data is under-sampled dictates the kind of artifacts that can occur in the images. If the data is uniformly under-sampled (as it is for SENSE and other parallel imaging techniques), the result is regular, back folding artifacts (Figure 1B).
For compressed sensing, these structured artifacts are difficult, if not impossible, to separate from the signal (Figure 1C). Therefore, compressed sensing benefits from a sampling scheme in which artifacts are distributed incoherently over the image. This can be achieved by a variable density incoherent under-sampling (Figure 1D). Because most of the energy of the MR signal is in the center of k-space, the sampling pattern is adjusted so that the center is more densely sampled than the periphery to achieve the typical non-uniform sampling patterns that are usually used for compressed sensing.

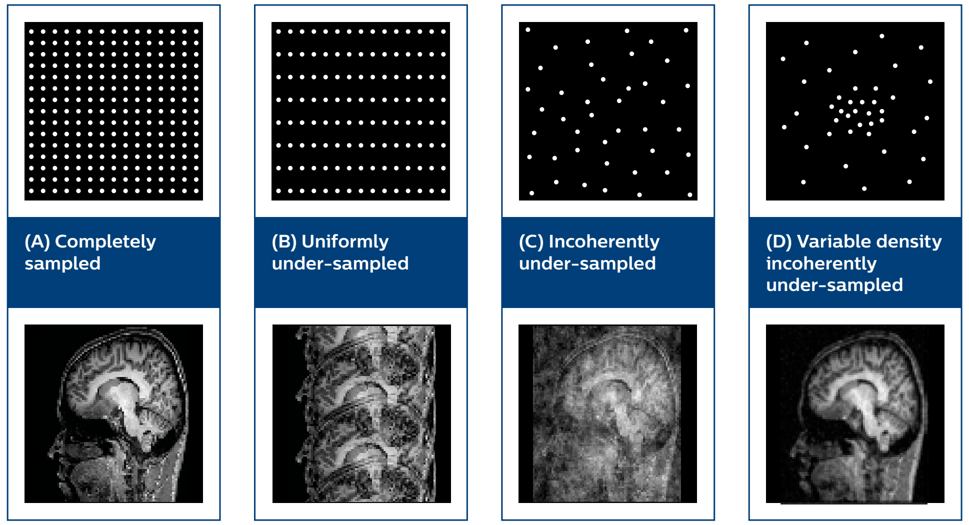


Figure 1. Various sampling patterns and the resulting images.

How does compressed sensing benefit from sparse data?

Sparsity in general means "very little of anything;" for example, trees in the desert are sparse. In imaging, sparsity refers to images with many black (zero) pixels, and few grey or white pixels (such as a magnetic resonance angiography (MRA)). In compressed sensing, sparsity is important because in a sparse environment, it is relatively easy to recognize the relevant information, and ignore the rest. Using the desert example: it is relatively easy to spot a particular tree in the desert, whereas it would be challenging to spot that tree in the jungle.

In general, MR images are not naturally sparse – most of the pixels in an MR image are not black, but they contain many levels of black-grey-white. In compressed sensing technology, transforming an image to a different domain – for example, the wavelet domain – forces the image to become sparse. It is important to realize that all information going back and forth from one domain to the other is preserved. In the wavelet domain, image information is represented at different spatial scales, much like an image can be bandpass-filtered with different filter widths. As the information in this domain is sparse, the image information is captured much more efficiently, hence more time can be saved. Figure 2 shows a histogram resulting after the image has gone through a wavelet transformation where it becomes easier to see the pixels that do or do not contribute to essential information in the image.

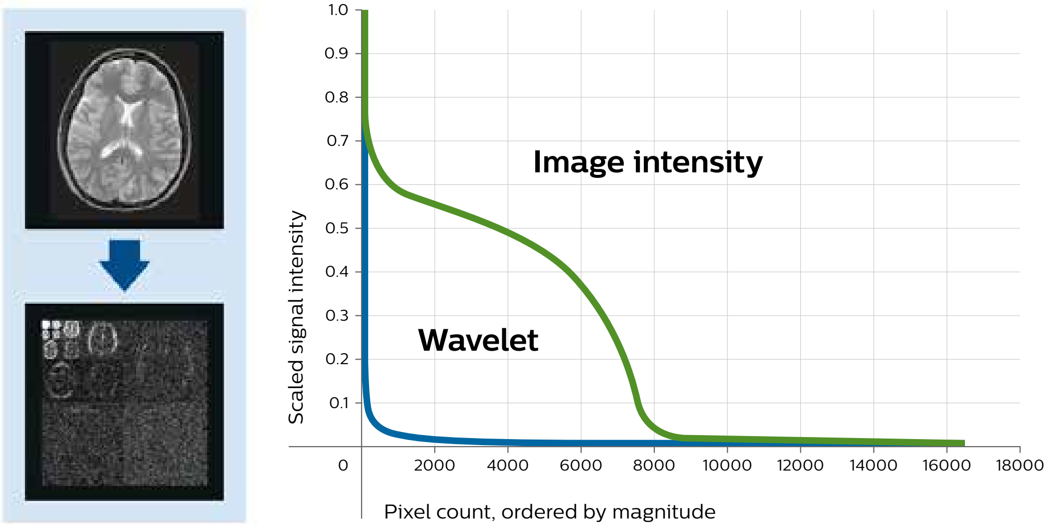


Figure 2. Representation of the amount of pixels that contain relevant/non-zeros information. [10]

How can phased array coils be leveraged for further acceleration?

The development of phased array coils in the early 1990s enabled the first wave of parallel imaging techniques (SENSE, GRAPPA, ARC), of which SENSE was able to enable scan time reductions up to 6× for 2D sequences and 9× for 3D sequences[11]. However, these techniques still had their limitations. Parallel imaging techniques based on the acquisition of auto-calibration lines are limited in acceleration when the extra reference lines acquired begin to dominate the acquisition time at high accelerations. Additionally, all parallel imaging techniques are limited by the g-factor. To create a paradigm shift in productivity, new compressed sensing technology needs to be compatible with current hardware and parallel imaging techniques.

How does compressed sensing benefit from iterative reconstruction?

In conventional MR reconstruction, a set of linear equations is solved, in which the number of measurements is greater than the number of unknowns. When using SENSE (or any other parallel imaging technique) the set of linear equations contains information about the coil sensitivities, but in essence, still a linear set of equations is solved. This is very straightforward and fast.

In compressed sensing, the k-space is vastly and irregularly under-sampled. In this case, it is more efficient to use an iterative reconstruction algorithm. Also, there are not enough measurements to solve for all the unknowns. In mathematical terms this implies that we have many solutions that could fit the data. Thus, the challenge is to find the right solution from the many that fit the measured data.

This is where the sparsity constraint comes into play: the main assumption in compressed sensing is that from all the possible solutions, the optimal solution is the sparsest one. This assumption makes sense, because noise is very non-sparse. Therefore, searching for the sparsest solution means searching for a solution in which all the (pseudo-) noise components are absent.

The search for the sparsest solution is not a single step approach. After a candidate for (or initial estimation of) the sparsest solution has been selected, it must be checked to determine if it still matches with the measurement data (data consistency check). Typically, a number of iterations are required to find the optimal solution in terms of the balance between a sparse solution (low noise-like appearance) and a solution that matches the measurement data (data consistency).

How does Philips' Compressed SENSE deliver image quality?

Philips' Compressed SENSE delivers speed without sacrificing image quality. Combining the strengths of SENSE and compressed sensing results in a robust technique that can accelerate all routine 2D and 3D clinical MR applications by up to 50%[1] with virtually equivalent image quality.

How is Philips' Compressed SENSE unique?

The value of Philips' Compressed SENSE lies in its versatility, combination with phased array coils and current parallel imaging technology, automation, and reconstruction speed optimization.

Versatility

Many compressed sensing solutions focus on sparsity in the time domain. In contrast, Philips' Compressed SENSE focuses on sparsity in the spatial domain. As a result, it is suitable for all anatomies and all anatomical image contrasts, making it a solution for routine clinical exams. It can be applied to commonly used contrast sequences including T1, T2, PCA, MRA, and others, as well as quantitative techniques including mDIXON-Quant and T2-mapping. It supports different acquisition techniques such as mDIXON-XD and FFE, TFE, SE, TSE (in combination with pre-pulses like fat suppression and REST slabs), as well as both 2D and 3D acquisition slabs. Compressed SENSE can be used to shorten dynamic scans for 4D acquisitions as well.

Because native SNR, contrast and acquisition strategy (2D vs 3D) all impact acceleration, all sequences do not achieve the same acceleration factors. In particular, a 3D, high SNR, high contrast scan can be accelerated more than a 2D, low SNR, low contrast scan. Philips' Compressed SENSE starts from image quality, which enabled the development of this technology for all anatomies and all anatomical contrasts.

Combination with phased array coils and parallel imaging

Some compressed sensing solutions in the MR industry often require acquisition of auto-calibration lines, which makes the sampling scheme less flexible. To reach acceleration levels that are equivalent to those of techniques (such as SENSE) that do not require the acquisition of auto-calibration lines, non-SENSE-based compressed sensing methods must compromise the sampling scheme, introducing a discontinuous sampling density and leading to a low sampling density of peripheral k-space lines. If this happens, these images will either be blurry, contain structured noise that degrades image quality (Figure 3), or be unsuitable for some anatomies, contrasts and sequences.

> "With Compressed SENSE, our patients benefit from much shorter breath hold times."
>
> Masakazu Iwamoto, RT
> Hakodate Neurosurgical Hospital, Japan

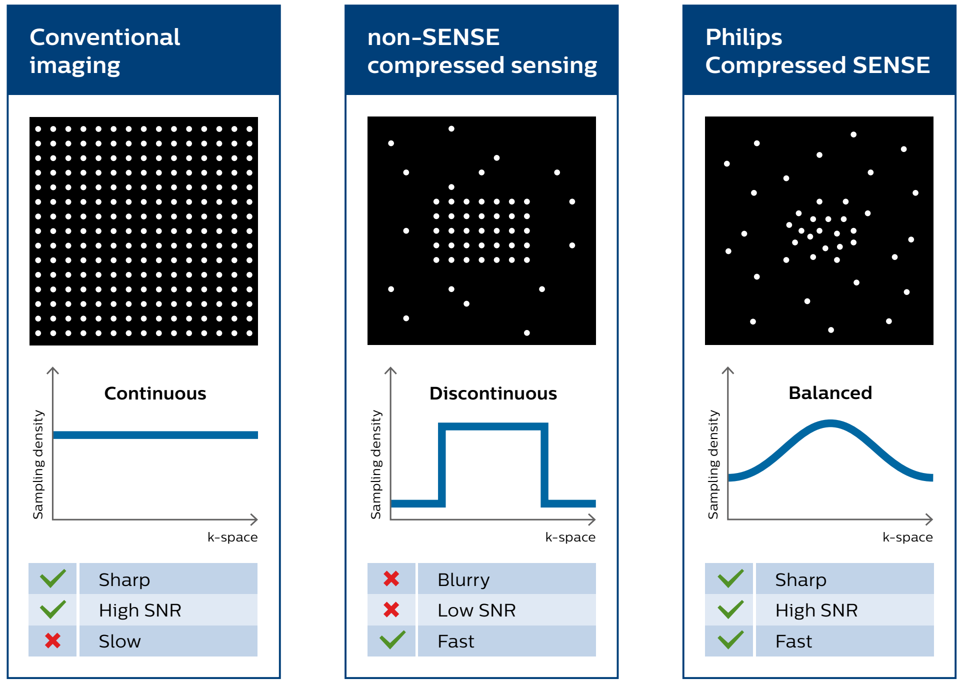


Figure 3. Various acquisition strategies, their sampling density in k-space, and their resulting image quality and scan time characteristics.

1 Compared to scans without Compressed SENSE

Automation

In addition, the Compressed SENSE implementation is fully automated, both in generating the sampling pattern, and in balancing between consistency and sparsity constraints. The SENSE-based balanced sampling pattern is automatically optimized using a variable density incoherently under-sampled scheme that samples the center of k-space more densely than the periphery. The sampling schemes also automatically minimize other sources of artifacts, such as eddy currents and patient motion.

Fully automated balancing between data consistency and data sparsity is independent of anatomy, image contrast, acceleration factor, and the receiver coils that are used.

Reconstruction speed optimization

Reconstruction time can significantly impact productivity and depends on a number of different factors such as number of coil elements, resolution and coverage, Compressed SENSE factor, and use of reconstruction compression. For example, a 3D-T1W-TFE brain scan acquired on the dS Head 32 coil with 1 mm isotropic resolution and Compressed SENSE factor 4.5 has a reconstruction time of 37 seconds, and a 2D-PDW-TSE sequence acquired on the dS Knee 8 coil with 0.3×0.3×3.0 mm resolution (reconstructed to 0.16×0.16×3.0 mm) and Compressed SENSE factor 5 has a reconstruction time of 72 seconds on all our systems delivered with dSync from 2014. To accomplish clinically relevant reconstruction times with Compressed SENSE, every step of the reconstruction process was optimized:

1. The automatic derivation of the wavelet threshold leads to faster convergence and is the main reason for Compressed SENSE 's reconstruction speed and robustness. The algorithm was also optimized to reduce the number of iterations, significantly decreasing reconstruction time.
2. The Compressed SENSE reconstruction takes advantage of all the benefits of the dSync reconstruction platform with optimized parallel computing and integrated optimization down to the lowest level computing functions.
3. Reconstruction compression was optimized for Compressed SENSE, particularly for 3D imaging, to allow shorter reconstruction and lower memory imprint while maintaining image quality.

How easy is it to use Philips' Compressed SENSE?

Philips' Compressed SENSE is very easy to use. Only three parameters are required to use Compressed SENSE (Figure 4). The adoption of new clinical MR techniques can often times be challenging. In a radiology department, the radiologist must be confident that this technique does not affect their ability to read the images. The MR operator must be confident enough to apply it to protocols. By designing Compressed SENSE with the radiologist and the MR operator in mind, it is extremely easy to use:

1. Enable Compressed SENSE.
2. Select the desired Compressed SENSE acceleration (time reduction) factor, on a scale of 1-32.
3. Select the preferred denoising level (no, weak, medium, strong, or system default).

SENSE	no
C-SENSE	yes
reduction	10
denoising	system default

Figure 4. Easy, user-intuitive Philips' Compressed SENSE user interface

The acceleration factor is the ratio between the number of k-space lines of a fully acquired image and an image acquired with Compressed SENSE. The optimal sampling strategy is designed based on the sequence input parameters and the acceleration factor.

The denoising level sets the regularization parameter (see λ_2 in the technical note) that balances data consistency and sparsity constraining. This option allows users to select the image appearance that they prefer: images reconstructed with a weak denoising setting will appear noisier than images reconstructed with medium or strong settings.

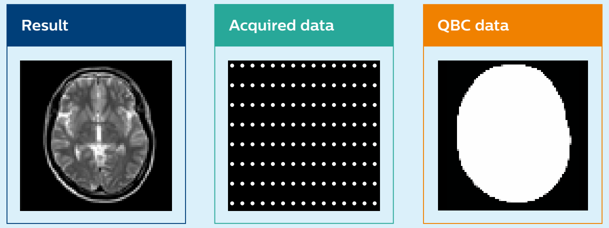
To make Compressed SENSE even easier to use, there are Examcards that come out-of-the-box ready-to-use for all routine scans, including brain, head/neck, spine, MSK (shoulder, elbow, wrist, hip, knee, and foot), cardiac, breast, body (including liver, prostate, and uterus) and MRA.

> “Compressed SENSE increases the examination efficiency thanks to a shorter scan time with no change in image quality.”
>
> Sachi Fukushima, RT
> Kurashiki Central Hospital, Japan

What are the basics of SENSE technology?

Figure 5 visualizes how SENSE technology works[11]. SENSE is a parallel imaging technique used in the imaging domain. From the equation, the following input elements can be deduced:

- [p] – the image to be reconstructed.
- [$m_{d,i}$] – the measured data for a given coil element after noise decorrelation.
- [E] – the under-sampled Fourier operator as defined by the sampling pattern.
- [$S_{d,i}$] – the coil sensitivity for a given coil element, after noise decorrelation, obtained with the SENSE reference scan.
- [λ_1] – regularization factor for balancing between data consistency and prior knowledge of image content.
- [R] – coarse resolution image from the integrated body coil obtained with the SENSE reference scan. It is used to constrain the solution during the regularization process.



$$p = \min_p \left(\sum_{i=1}^{\#coils} \left\| m_{d,i} - ES_{d,i}p \right\|_2^2 + \lambda_1 \left\| R^{-1/2} p \right\|_2^2 \right)$$

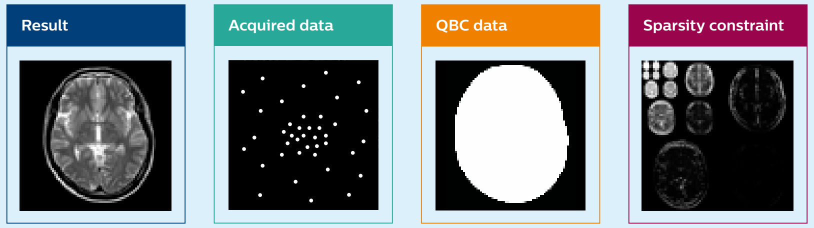
Figure 5. Visualization of the Philips' SENSE technology (for 1 slice).

How does Philips' Compressed SENSE build upon SENSE?

Figure 6 visualizes how Compressed SENSE technology works. As outlined in the main text, Compressed SENSE technology is built on compressed sensing theory and SENSE technology by leveraging a balanced variable density incoherent under-sampling acquisition scheme and iterative reconstruction to solve an inverse problem with a sparsity constraint. From the equation, the following input elements can be deduced:

- [p] – the image to be reconstructed.
- [$m_{d,i}$] – the measured data for a given coil element after noise decorrelation.
- [E] – the under-sampled Fourier operator as defined by the sampling pattern.
- [$S_{d,i}$] – the coil sensitivity for a given coil element, after noise decorrelation, obtained with the SENSE reference scan.
- [λ_1] – regularization factor for balancing between data consistency and prior knowledge of image content.
- [R] – coarse resolution data from the integrated body coil obtained with the SENSE reference scan. It is used to constrain the solution during the regularization process.
- [λ_2] – regularization factor to balance the sparsity constraining and data consistency in the iterative solution.
- [Ψ] – sparsity transform into the wavelet domain.

In case the sparsity constraining (red box) is omitted from the Compressed SENSE equation, it boils down to the SENSE solution. This indicates that the prior knowledge of noise decorrelation, regularization and coil sensitivities is used to provide the optimal SNR as starting point providing additional acceleration capabilities via sparsity constraining.



$$p = \min_p \left(\sum_{i=1}^{\#coils} \left\| m_{d,i} - ES_{d,i}p \right\|_2^2 + \lambda_1 \left\| R^{-1/2} p \right\|_2^2 + \lambda_2 \left\| \Psi p \right\|_1 \right)$$

Figure 6. Visualization of the Philips' Compressed SENSE technology (for 1 slice).

What are the clinical benefits of Compressed SENSE?

Philips' Compressed SENSE creates opportunities to increase productivity, to increase precision, and to enhance patient experience.

Increased productivity
Philips' Compressed SENSE enables acceleration by up to 50% with the same resolution and virtually equivalent image quality as dS SENSE scanning. The time saved can boost productivity by enabling more patients per day. Furthermore, by shortening breath hold scans, it enables patients who have compromised vascular compliance to more easily complete their examinations.

Increased precision
Compressed SENSE can be used to create images with higher resolution in the same scan time that is currently allotted for exams to increase diagnostic confidence. This can benefit a broad range of clinical areas. Compressed SENSE enables higher resolution with similar scan time in breast imaging, enables higher resolution for 3D PelvisVIEW T2 and eTHRIVE in similar scan time and with virtually equivalent image quality, and provides fast 3D submillimeter (0.7 mm or less) isotropic images in less than 5 minutes, using PD, T1, T2, and SPAIR acquisition techniques with virtually equivalent image quality to diagnose challenging patients and anatomies.

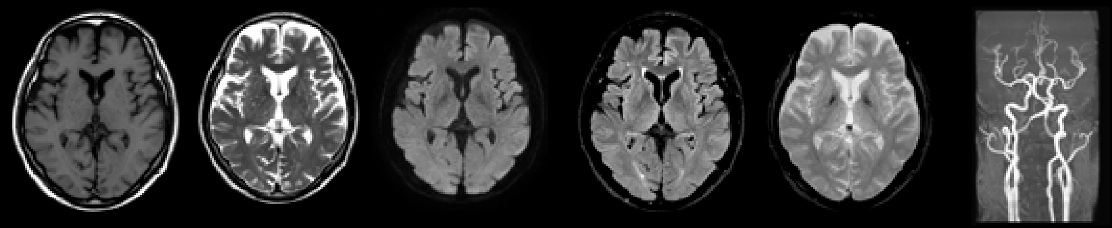
Enhanced patient experience
Philips' Compressed SENSE was designed with the patient in mind. Enabling shorter exams[13–17], particularly for the 35% of patients who experience claustrophobia or have considerable apprehension about entering an MR[18]. Philips' Compressed SENSE reduces the time spent in the MR for the patient. Furthermore, an internal multi-center trial showed that over 50% of patients found it difficult to hold their breath. Compressed SENSE enables the reduction of breath hold times[1]. In addition, it reduces SAR, which is better for the patient. The true test of any imaging technology is how it impacts diagnosis, and the excellent image quality achieved using Compressed SENSE enables confident diagnosis, which supports positive patient care.

> "Compressed SENSE enables increased resolution in 3D PelvisVIEW (by reducing slice thickness by 2). With the MPR, we could see detailed anatomical structures and lesions."
>
> Dr. Tomohiro Namimoto, abdominal diagnosis specialty
> Kumamoto University Hospital, Japan

1 Results from case studies are not predictive of results in other cases. Results in other cases may vary.

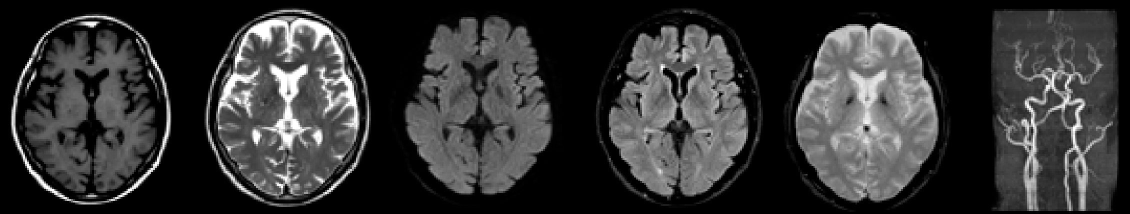
Complete brain exams up to 50% faster with virtually equal image quality

Without Compressed SENSE



T1W SE	T2W TSE	DWI (b1000)	T2W FLAIR	T2W FFE	3D MRA
0.9 × 1.3 × 5.0 mm	0.6 × 0.7 × 5.0 mm	1.8 × 1.4 × 5.0 mm	1.0 × 1.2 × 5.0 mm	0.9 × 1.1 × 5.0 mm	0.7 × 1.3 × 1.4 mm
2:35 min	2:04 min	0:45 min	2:12 min	1:15 min	7:11 min

With Compressed SENSE

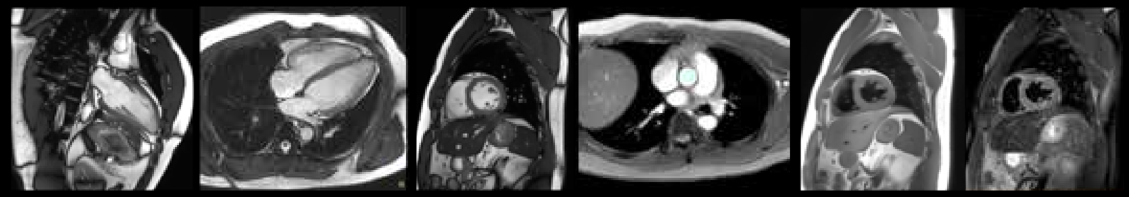


T1W SE	T2W TSE	DWI (b1000)	T2W FLAIR	T2W FFE	3D MRA
0.9 × 1.3 × 5.0 mm	0.6 × 0.7 × 5.0 mm	1.8 × 1.4 × 5.0 mm	1.0 × 1.2 × 5.0 mm	0.9 × 1.1 × 5.0 mm	0.7 × 1.3 × 1.4 mm
1:14 min	1:30 min	0:45 min	1:30 min	0:49 min	3:06 min

All images are acquired on an Ingenia 1.5T CX

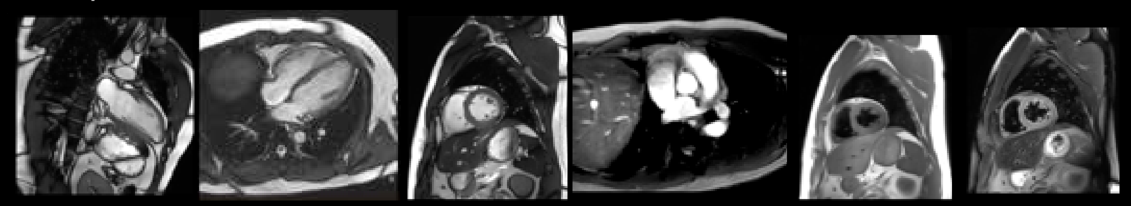
Complete cardiac exams up to 50% faster with virtually equal image quality

Without Compressed SENSE



bTFE 2 chamber	bTFE 4 chamber	bTFE Short axis	QFlow	T1 TSE BB	T2 TSE SPIR BB
1.97 × 1.71 × 8.0 mm	1.97 × 1.71 × 8.0 mm	1.97 × 1.71 × 8.0 mm	2.5 × 2.5 × 8.0 mm	1.29 × 1.85 × 8.0 mm	1.29 × 1.65 × 8.0 mm
8.3 sec	8.3 sec	8.3 sec	19.4 sec	12.0 sec	12.9 sec

With Compressed SENSE

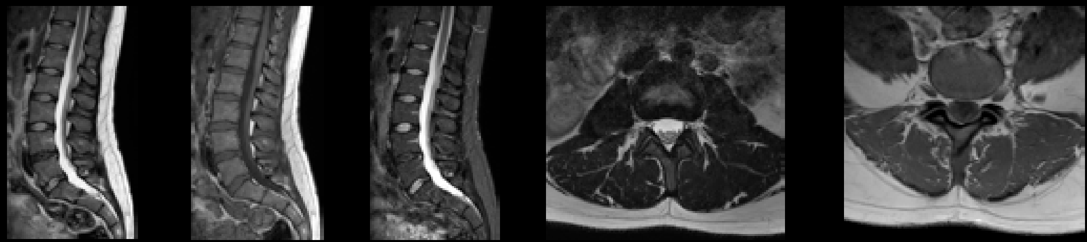


bTFE 2 chamber	bTFE 4 chamber	bTFE Short axis	QFlow	T1 TSE BB	T2 TSE SPIR BB
1.97 × 1.71 × 8.0 mm	1.97 × 1.71 × 8.0 mm	1.97 × 1.71 × 8.0 mm	2.5 × 2.5 × 8.0 mm	1.29 × 1.85 × 8.0 mm	1.29 × 1.65 × 8.0 mm
4.5 sec	4.5 sec	4.5 sec	9.1 sec	8.4 sec	7.3 sec

All images are acquired on an Ingenia 3.0T

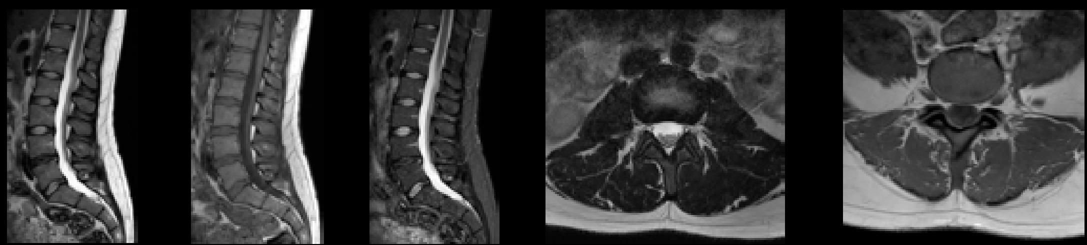
Complete spine exams up to 25% faster with virtually equal image quality

Without Compressed SENSE



T1W TSE	T2W TSE	STIR TSE	T2W TSE	T1W TSE
0.9 × 0.8 × 4.0 mm	0.8 × 0.9 × 4.0 mm	1.0 × 1.0 × 4.0 mm	0.6 × 0.8 × 4.0 mm	0.7 × 0.9 × 4.0 mm
4:16 min	4:12 min	5:16 min	3:35 min	5:30 min

With Compressed SENSE



T1W TSE	T2W TSE	STIR TSE	T2W TSE	T1W TSE
0.9 × 0.8 × 4.0 mm	0.8 × 0.9 × 4.0 mm	1.0 × 1.0 × 4.0 mm	0.6 × 0.8 × 4.0 mm	0.7 × 0.9 × 4.0 mm
3:34 min	3:00 min	3:38 min	2:23 min	4:37 min

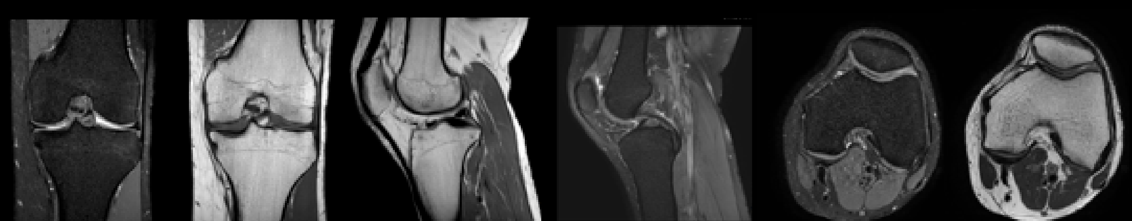
All images are acquired on an Ingenia 3.0T

Complete MSK exams up to 25% faster with virtually equal image quality

Without Compressed SENSE

PDW SPAIR	T1W TSE	PDW TSE	PDW SPAIR	T2W SPAIR	T2W TSE
0.4 × 0.5 × 2.5 mm	0.3 × 0.4 × 2.5 mm	0.3 × 0.4 × 2.5 mm	0.4 × 0.4 × 2.5 mm	0.4 × 0.5 × 1.5 mm	0.4 × 0.5 × 1.5 mm
3:25 min	2:23 min	3:55 min	4:25 min	4:59 min	4:29 min

With Compressed SENSE

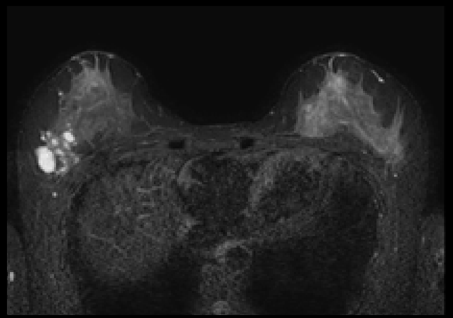


PDW SPAIR	T1W TSE	PDW TSE	PDW SPAIR	T2W SPAIR	T2W TSE
0.4 × 0.5 × 2.5 mm	0.3 × 0.4 × 2.5 mm	0.3 × 0.4 × 2.5 mm	0.4 × 0.4 × 2.5 mm	0.4 × 0.5 × 1.5 mm	0.4 × 0.5 × 1.5 mm
1:42 min	1:56 min	3:25 min	3:42 min	4:11 min	2:59 min

All images are acquired on an Ingenia 3.0T

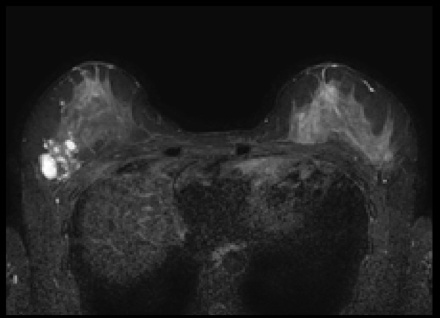
Accelerate in 2D scans. Every time.

Without Compressed SENSE



2D STIR TSE
Ingenia 1.5T
0.99 × 1.46 × 3.00 mm
3:39 min

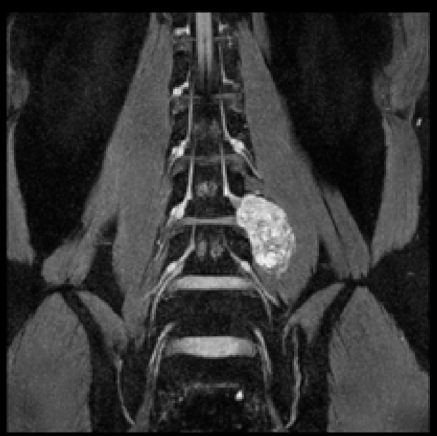
With Compressed SENSE



2D STIR TSE
Ingenia 1.5T
0.99 × 1.26 × 3.0 mm
2:52 min

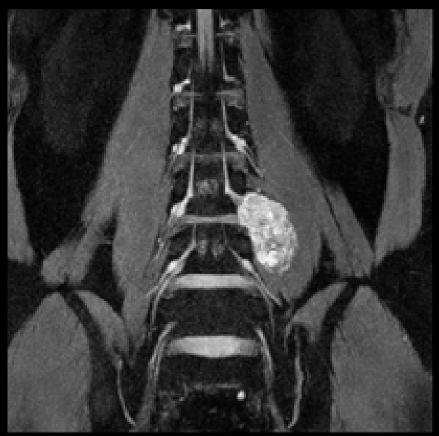
Accelerate in 3D scans. Every time.

Without Compressed SENSE



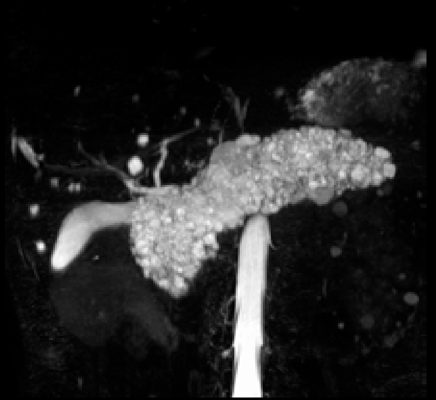
3D T2 TFE
Ingenia 1.5T
0.98 × 0.98 × 1.0 mm
3:52 min

With Compressed SENSE



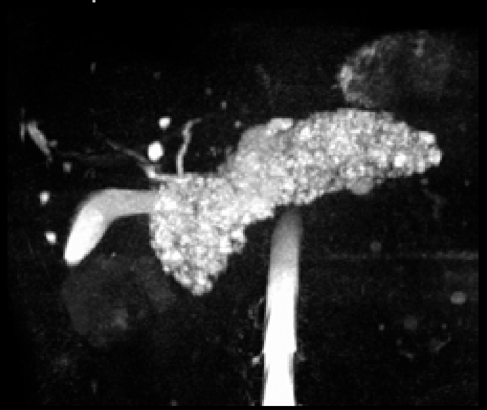
3D T2 TFE
Ingenia 1.5T
0.98 × 0.98 × 1.0 mm
2:53 min

Without Compressed SENSE



3D MRCP
Ingenia 3.0T CX
0. 97 × 0.67 × 2.00 mm
3:21 min

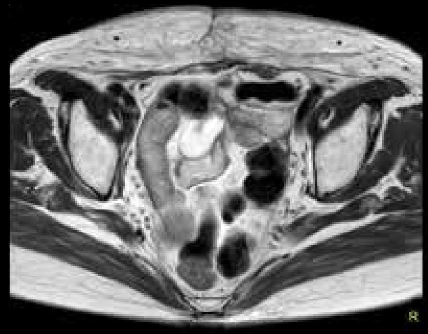
With Compressed SENSE



3D MRCP
Ingenia 3.0T CX
0.97 × 0.76 × 2.0 mm
0:45 min

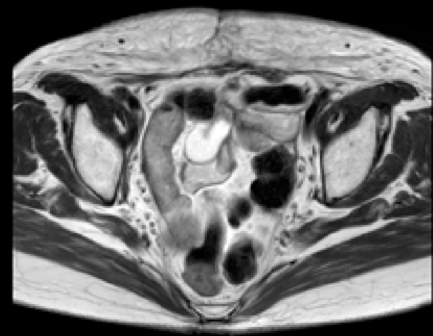
Accelerate in 2D scans. Every time.

Without Compressed SENSE



T2W TSE
Ingenia 3.0T CX
0.6 × 0.8 × 5.0 mm
1:44 min

With Compressed SENSE



T2W TSE
Ingenia 3.0T CX
0. 63 × 0.72 × 5.0 mm
1:07 min

Accelerate in 3D scans. Every time.

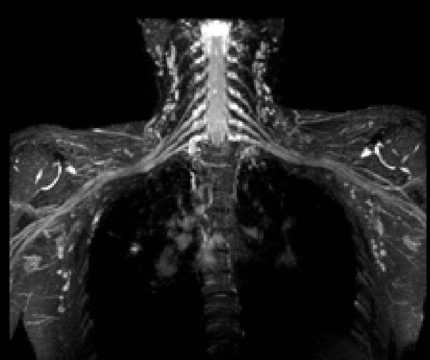
Without Compressed SENSE

mDIXON XD FFE WB
Ingenia 1.5T
4.27 × 4.27 × 4.4 mm
32 sec (16 sec/station)

With Compressed SENSE

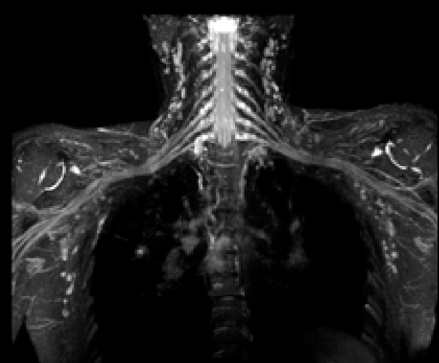
mDIXON XD FFE WB
Ingenia 1.5T
4.27 × 4.27 × 4.4 mm
16 sec (8 sec/station)

Without Compressed SENSE



3D NerveVIEW
Ingenia 3.0T
1.2 × 1.2 × 2.0 mm
6:16 min

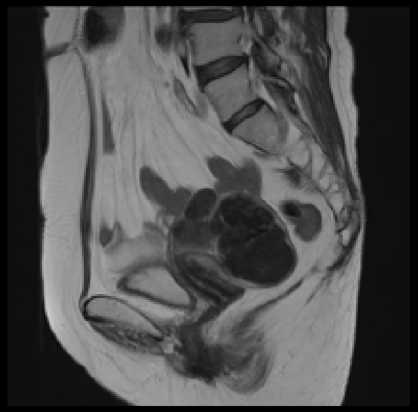
With Compressed SENSE



3D NerveVIEW
Ingenia 3.0T
1.2 × 1.2 × 2.0 mm
4:22 min

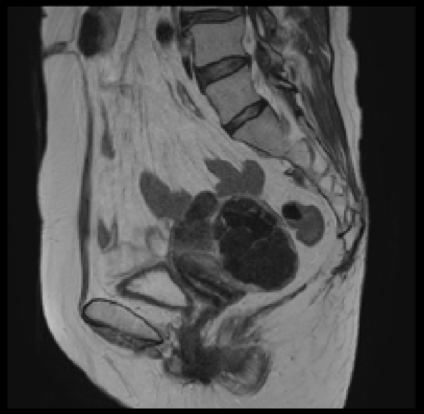
Precision in 2D scans. Every time.

Without Compressed SENSE



2D T2W TSE
Ingenia 1.5T
0.82 × 0.86 × 5.0 mm
3:42 min

With Compressed SENSE



2D T2W TSE
Ingenia 1.5T
0.82 × 0.82 × 2.5 mm
3:23 min

Precision in 3D scans. Every time.

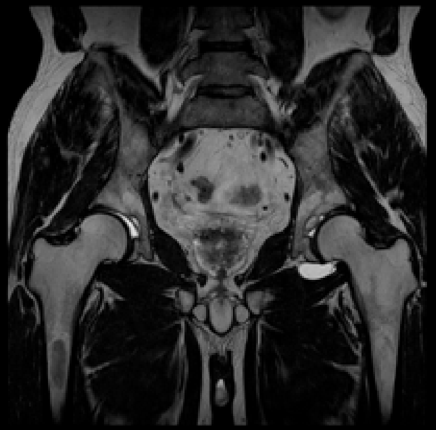
Without Compressed SENSE

3D PDW MSK VIEW
Ingenia 1.5T
0.58 × 0.58 × 0.58 mm
4:49 min

With Compressed SENSE

3D PDW MSK VIEW
Ingenia 1.5T
0.5 × 0.5 × 0.5 mm
4:46 min

Without Compressed SENSE



3D T2W PelvisVIEW
Ingenia 1.5T
0.98 × 0.98 × 2.0 mm
4:12 min

With Compressed SENSE

3D T2W PelvisVIEW
Ingenia 1.5T
0.98 × 1.03 × 1.0 mm
4:16 min

Conclusion

Appropriate for all anatomies and anatomical contrasts, 2D and 3D sequences, multiple scan techniques, and 1.5T and 3.0T field strengths, Philips' Compressed SENSE, enabled by SENSE-based balanced sampling, creates a productivity paradigm shift that bolsters MR departments' ability to address the challenges of decreasing reimbursements and the growing use of MR. With the possibility to create images with higher resolution in the same scan time, it can help increase diagnostic confidence. Compressed SENSE enhances patient experience and gives the opportunity for clinicians and staff to focus on the patient.

References

1. Wu, Shin-Yi and Anthony Green. Projection of Chronic Illness Prevalence and Cost Inflation. RAND Corporation; October 2000.
2. OECD, Magnetic resonance imaging (MRI) exams (indicator). https://data.oecd.org/healthcare/magnetic-resonance-imaging-mri-exams.htm. Accessed October 31, 2017.
3. NHE Fact Sheet. Centers for Medicare & Medicaid Services. https://www.cms.gov/research-statistics-data-and-systems/statistics-trends-and-reports/nationalhealthexpenddata/nhe-fact-sheet.html. Published month June 14, 2017. Accessed October 31, 2017.
4. Frost & Sullivan. 2016 China Hospital Outlook: Rapid growth, reforms, and privatization transforming China's hospital sector. September 2016.
5. https://revcycleintelligence.com/news/survey-value-based-reimbursement-to-eclipse-ffs-by-2020. Published June 14, 2016. Accessed October 31, 2017.
6. Donoho D. Compressed sensing. IEEE Trans Inf Theory 2006; 52: 1289–1306.
7. Candès EJ, Romberg JK, Tao T. Stable signal recovery from incomplete and inaccurate measurements. Commun Pur Appl Math 2006; 59:1207–1223.
8. Candès, Emmanuel J.; Romberg, Justin K.; Tao, Terence (2006). "Robust Uncertainty Principles: Exact Signal Reconstruction from Highly Incomplete Fourier Information" . IEEE Trans. Inf. Theory. 52 (8): 489–509.
9. Lustig M, Donoho D, Pauly JM. Sparse MRI: The application of compressed sensing for rapid MR imaging. Magnetic Resonance in Medicine. 2007;58(6):1182-95.
10. Hollingsworth, K.G. Reducing acquisition time in clinical MRI by data undersampling and compressed sensing reconstruction. Physics in Medicine & Biology. 2015; 60:R297-322.
11. Peeters H, et al. Next generation parallel imaging with dS SENSE technology. The Netherlands: Philips Healthcare; 2017 Mar. Report No: 4522 991 13591.
12. Pruessmann KP, Weiger M, Scheidegger MR, Boesiger P. SENSE: Sensitivity encoding for fast MRI. Magn. Reson Med.1999;42(5):952-962.
13. Enhancing the patient experience of imaging. The Netherlands: Philips Healthcare; 2017 Oct. Report No: 4522 991 31021.
14. Quirk ME et al. Anxiety in patients undergoing MR imaging. Radiology. 1989;170(2):463–6.
15. Katz RC, Wilson L, Frazer N. Anxiety and its determinants in patients undergoing magnetic resonance imaging. J Behav Ther Exp Psychiatry. 1994;25(2):131–4.
16. McIsaac HK et al. Claustrophobia and the magnetic resonance imaging procedure. J Behav Med. 1998;21(3):255–68.
17. Brennan SC et al. Anxiety and panic during magnetic resonance scans. Lancet. 1988;2(8609):512.
18. Meléndez, J. Carlos, and Ernest McCrank. "Anxiety-related reactions associated with magnetic resonance imaging examinations." Jama 270.6 (1993): 745-747.

4522 991 35411 * APR 2018

How to reach us
Please visit www.philips.com
healthcare@philips.com