# APPLICATION OF THE COMPRESSED SENSE IN THE STUDY OF FEMALE PELVI IN MAGNETIC RESONANCE 3 TESLA FOR THE DIAGNOSIS OF INFERTILITY IN WOMEN

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**KEYWORDS**: Parallel Imaging Technique, Incoherent Subsampling, Transform Sparsity, Non-Linear Iterative Reconstruction, Aliasing Artifact, Phased Array Coil.

## ABSTRACT

*Compressed Sense (CS) is a technological innovation in the field of Parallel Imaging (PI) that allows to reduce up to 50% the acquisition time per single sequence, reducing the whole duration of the MRI examination, and is based on the application of 3 principles: Incoherent k-space subsampling, sparsification transform and nonlinear iterative reconstruction. The purpose of our work was to evaluate the application of CS to the MRI protocol of the female pelvis performed for infertility, evaluating its Temporal Resolution and Signal/Noise Ratio (SNR) compared to the classic PI technique SENSE. MRI exams were performed with RM 3T scanners (Philips Ingenia, Philips Healthcare, Netherlands Eindhoven). The female pelvis MRI protocol included the following sequences: 3D PelvisView T2, 3D PelvisView T1, DWI (b0 and b1000), mDixon 3D THRIVE with ev. contrast media. The parameters of each sequence, with the exception of DWI in which the CS is not applicable, are shown in comparison between the application of Sense and Compressed Sense. The CS allows to obtain at the same spatial resolution, a protocol with faster acquisition times, correcting the effect of aliasing from data subsampling compared to conventional SENSE. In conclusion, the application of CS could bring multiple advantages in the field of MR imaging in the diagnosis of infertility in women, optimizing the image quality and the duration of each individual examination.*



## INTRODUCTION

The condition of infertility affects about 15-20% of Italian couples. According to the data provided by the Istituto Superiore di Sanità, the cause is male-related (in 35% of cases), female-related (in 35% of cases), a couple factor (in 15% cases), and sine causa (idiopathic infertility) in remaining 15%. In recent years, MRI of the female pelvis has become the gold-standard in the study of infertility in women, thanks to the progressive diffusion of increasingly high-performance and very high-field equipment that allows, compared to hysterosalpingography and transvaginal pelvic ultrasound, an evaluation of the most associated pathologies (congenital anomalies, fibroids, adenomyosis, endometriosis). The application of MRI, a multiplanar and multiparametric method, with high spatial resolution, to research the causes of infertility could represent the turning point for obtaining a more complete study in terms of information and without the use of ionizing radiation in women of childbearing age. In recent years, the birth of Parallel Imaging (PI) has paved the way for overcoming the greatest limitation of MRI, acquisition times, through the use of phased array coils. Compressed SENSE is a modern PI technique that collects only the "essential" components of the MR signal rather than all the K-space data, minimizing the error that derives from having an insufficient number of samples. The k-space is inconsistently subsampled with priority of central data (more useful data); subsequently the sparsification transform is applied and finally a "non-linear" Iterative reconstruction method, with the final goal of achieving a balance between "data consistency" and "sparsification data", allows to keep all useful data by removing, as much as possible, those without information. In fact, mathematically it is difficult to separate useful data from non-useful ones, but inevitably a part of them with the application of the Wavelet transform alone will be lost. The "non-linear iterative reconstruction" does exactly that: it behaves like a balance through the application of numerous algorithms that are repeated cyclically until the optimal data balance is achieved. Compressed Sense is therefore a PI technique which, by applying its 3 fundamental principles, which are inconsistent subsampling, sparsification transform and non-linear iterative reconstruction, manages to guarantee a reduction of acquisition times up to 50% without qualitative degradation of the images. A reduction in acquisition times of this level is able to balance the increased demand for MRI examinations in general and, more particularly, of the female pelvis, also for reasons related to infertility that cannot be resolved with other imaging methods.

## OBJECTIVES

The objective of this study was to evaluate the contribution of the new COMPRESSED-SENSE technique, comparing it with the conventional PI SENSE technique, when applied to the study of the female pelvis with 3T MRI, to the resolution of the diagnos-

tic question of female infertility, with optimization of acquisition times and image quality.

## MATERIALS AND METHODS

MRI examinations of the female pelvis were performed at the Department of Diagnostic Imaging of the University hospital Policlinico "Paolo Giaccone" (Palermo, Italy), with a Philips Ingenia 3T MRI scanner, equipped with combined gradients with Amplitude of 45 mT / m and Slew-Rate of 200 T / m / s. The receiving coil used is a Philips Healthcare surface coil, the 32-channel d-Stream SENSE Torso, positioned directly on the area of interest in order to obtain the maximum possible signal amplitude. The standard 3T MRI protocol of the female pelvis, performed at our Institute, includes the acquisition of 3DPelvisView T2, 3DPelvisView T1, DWI (b0 and b1000), mDixon 3D THRIVE sequences with MdCev. For each of the sequences listed above, except for the DWI, we acquired the images first with the "SENSE" PI technique and then with the "COMPRESSED SENSE" technique, thus comparing the following parameters: spatial resolution (mm x mm), FOV , matrix, thickness, NSA, acceleration factor R and temporal resolution.

## RESULTS

For all 3D TSE sequences (T1, T2 and SPAIR) the time saving with the CS is greater than 50% per sequence, while with mDixon 3D THRIVE the reduction of acquisition time is about 30%. Overall, including the DWI sequence (b0-b1000) which in our protocol lasts about 3 minutes, the total duration of the MRI Pelvis protocol with application of the SENSE is 30 minutes, while with the application of the COMPRESSED SENSE it is about 16 minutes, with a reduction of acquisition time of about 50%, and in particular about 15 minutes.

Tables 1-4 show in detail, for each sequence of the female pelvis MRI protocol analyzed in this study, the acquisition parameters compared with the use of the PI SENSE technique and with the COMPRESSED SENSE technique, and in particular: in plane resolution (mm x mm), FOV, matrix, NSA, acceleration factor R and time resolution.

| Sequence | Ax 3D View T2 (TSE Variable Flip Angle) | |
|---|---|---|
| PI Method | SENSE | COMPRESSED SENSE |
| FOV (mm x mm x mm) | 280 x 400 x 180 | 280 x 400 x 180 |
| Voxel (mm x mm x mm) | 1.00 x 1.00 x 1.00 | 1.00 x 1.00 x 1.00 |
| Recost. Voxel (mm x mm x mm) | 0.50 x 0.50 x 0.50 | 0.50 x 0.50 x 0.50 |
| NSA | 2 | 2 |
| Parallel Imaging Factor R | 4 | 10 |
| Temporal resolution (min:s) | 10.08 | 4.28 |

**Tab. 1** - *Acquisition parameters for the Ax 3D View T2 (TSE Variable Flip Angle) sequence of the MRI study of the female pelvis with 3T MRI scanner, with the PI SENSE technique and with the COMPRESSED SENSE technique.*

| Sequence | Ax 3D View T1 (TSE Variable Flip Angle) | |
|---|---|---|
| PI Method | SENSE | COMPRESSED SENSE |
| FOV (mm x mm x mm) | 280 x 400 x 180 | 280 x 400 x 180 |
| Voxel (mm x mm x mm) | 1.00 x 1.00 x 1.00 | 1.00 x 1.00 x 1.00 |
| Recost. Voxel (mm x mm x mm) | 0.50 x 0.50 x 0.50 | 0.50 x 0.50 x 0.50 |
| NSA | 2 | 2 |
| Parallel Imaging Factor R | 4 | 10 |
| Temporal resolution (min:s) | 6.52 | 3.02 |

**Tab. 2** - *Acquisition parameters for the Ax 3D View T1 (TSE Variable Flip Angle) sequence of the MRI study of the female pelvis with 3T MRI scanner, with the PI SENSE technique and with the COMPRESSED SENSE technique.*

| Sequence | Ax 3D TSE T2 SPAIR | |
|---|---|---|
| PI Method | SENSE | COMPRESSED SENSE |
| FOV (mm x mm x mm) | 280 x 400 x 180 | 280 x 400 x 180 |
| Voxel (mm x mm x mm) | 1.00 x 1.00 x 1.00 | 1.00 x 1.00 x 1.00 |
| Recost. Voxel (mm x mm x mm) | 0.50 x 0.50 x 0.50 | 0.50 x 0.50 x 0.50 |
| NSA | 2 | 2 |
| Parallel Imaging Factor R | 4 | 9 |
| Temporal resolution (min:s) | 6.48 | 3.10 |

**Tab. 3** - *Acquisition parameters for the Ax 3D TSE T2 SPAIR sequence of the MRI study of the female pelvis with 3T MRI scanner, with the PI SENSE technique and with the COMPRESSED SENSE technique.*

| Sequence | m-DIXON THRIVE | |
|---|---|---|
| PI Method | SENSE | COMPRESSED SENSE |
| FOV (mm x mm x mm) | 280 x 400 x 180 | 280 x 400 x 180 |
| Voxel (mm x mm x mm) | 1.00 x 1.00 x 1.00 | 1.00 x 1.00 x 1.00 |
| Recost. Voxel (mm x mm x mm) | 0.50 x 0.50 x 0.50 | 0.50 x 0.50 x 0.50 |
| NSA | 1 | 1 |
| Parallel Imaging Factor R | 2.5 | 4 |
| Temporal resolution (min:s) | 3.12 | 2.10 |

**Tab. 4** - *Acquisition parameters for the m-DIXON THRIVE sequence of the MRI study of the female pelvis with 3T MRI scanner, with the PI SENSE technique and with the COMPRESSED SENSE technique*

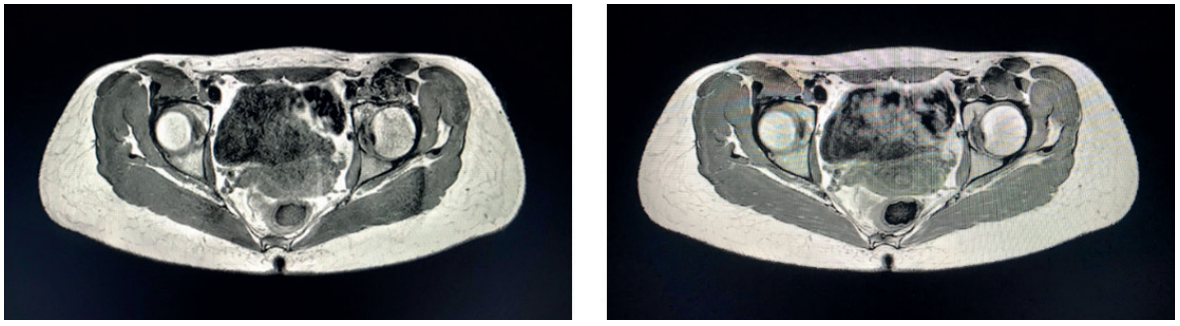

**Fig. 1** - *Comparison of the images obtained respectively with the SENSE and with the COMPRESSED-SENSE from the sequence AX 3D View T1 (TSE Variable Flip Angle).*

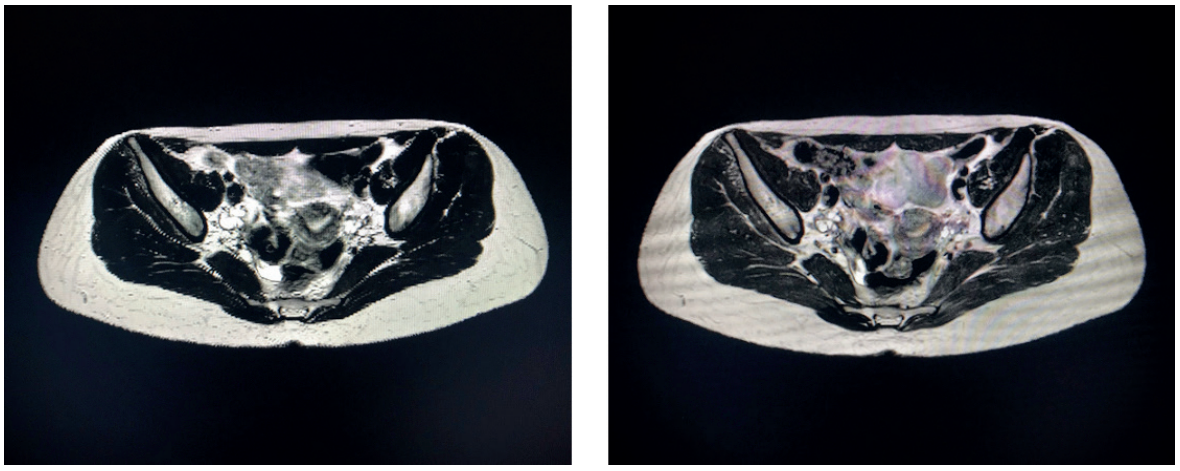

**Fig. 2** - *Comparison of the images obtained respectively with the SENSE and with the COMPRESSED-SENSE from the sequence AX 3D View T2 (TSE Variable Flip Angle).*

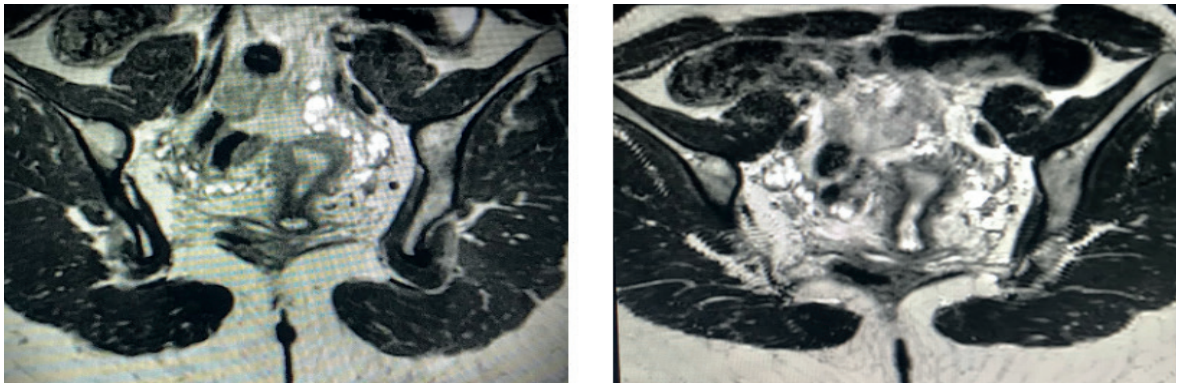

**Fig. 3** - *Comparison of the images (obtained with reconstruction) MPR CORONAL of the sequence AX 3D View T2 (TSE Variable Flip Angle) acquired with the SENSE and with the COMPRESSED-SENSE.*

## DISCUSSION AND CONCLUSIONS

Our data demonstrated that the application of the COMPRESSED SENSE can led to a considerable reduction of the average scan time of the sequences considered by 30-50%: in particular, about 50% is gained on the 3D TSE T1 sequences, T2 and T2SPAIR, 30% on the m-DIXON THRIVE post-contrast sequence. The images obtained were therefore acquired in a shorter time and were even of better quality than the conventional PI SENSE technique.

The ever increasing technological advances in the field of Magnetic Resonance, and including the development of scanners more and more performing in terms of Amplitude and Slew-Rate, the introduction of ever faster sequences, the development of increasingly efficient Parallel Imaging techniques and robust to allow ever higher acceleration factors R without incurring typical artifacts from K-space data subsampling, up to the introduction of Artificial Intelligence software, have led to exponential improvements and optimizations of Magnetic Resonance imaging. If one of the limits, until recently present in Magnetic Resonance, was the acquisition time, now with the advent of subsampling applied with Compressed Sense this limit is also exceeded, allowing the increase of the number of female pelvis MRI and therefore its use on a wider scale also in the diagnostic study of infertility in women.

Thanks to the COMPRESSED SENSE it is therefore possible to use of 3D T2 sequences for the morphological study of the pelvis in just 4 minutes, instead of 10 minutes with the SENSE in which the risk is to obtain inevitable movement artifacts that can affect the quality of the images. With the CS applied to the 3D sequences it is possible to obtain high resolution images on the axial, sagittal and coronal planes, with image quality comparable to the 2D sequences performed on a single plane which would require much longer acquisition times (about 12 minutes) than the 3D TSE T2 sequences obtainable with the CS in just 4 minutes, therefore with a scan time reduction of up to 67%.

With a total temporal gain of about 50% it is possible to double the number of exams per day. In addition, the acceleration guaranteed by the CS reduces movement artifacts and decreases the degree of fear of patients related to claustrophobia as the time in which they are forced to remain motionless in the context of the MRI scanner is reduced. We can conclude that the COMPRESSED SENSE represents a significant improvement in terms of accuracy and speed of reconstruction, constituting the future of Parallel Imaging.

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