

3D Compressed SPEEDER in daily practice: Total examination time reduction and additional benefits



Xavier Alomar, M.D.
Head of Radiology,
Clínica Creu Blanca, Barcelona, Spain

Introduction

The exponential increase of MRI examination requests these last decades led to the need to accelerate exam time. One approach is to replace multiple two-dimensional (2D) scans with a single three-dimensional (3D) sequence. Initially, this substitution was not possible because of the long scan time of the 3D sequences. However, thanks to the recent development of Compressed SPEEDER for 3D sequence (3D CS), fast 3D examinations are achievable without sacrificing diagnostic image quality.

The goal of this study was to evaluate multiple 2D scans versus a single 3D CS scan in MSK applications. The multi-2D and single-3D CS images are evaluated with regard to total examination time, diagnostic image quality, and additional benefits, such as flow artifact reduction and multi-planar reconstruction.

Compressed SPEEDER - General concept and 3D application

Compressed SPEEDER accelerates scan time by means of k-space undersampling. It is based on the compressed sensing theory¹ and the following conditions are required for proper performance:

- **Incoherent undersampling**

Acquisition time is reduced by k-space undersampling. To avoid aliasing, a random undersampling pattern is used. This pattern gives the aliasing artifacts an incoherent and noise-like appearance which enables them to be distinguished from the actual image signal.

- **Sparsity**

The Compressed SPEEDER method relies on sparsity to separate the image signal from the noise-like incoherent aliases. Thus, the image data are transformed into the wavelet domain so that the image signal can be easily distinguished from noise². In this way, a threshold operation within the wavelet domain can remove incoherent artifacts.

- **Non-linear iterative reconstruction**

In order to reach the optimal balance between noise reduction and consistency between reconstructed and acquired data, the Compressed SPEEDER algorithm employs iterative reconstruction. The estimate of the image is updated each iteration, balancing the data consistency with the thresholded wavelet representation of the image data.

The entire process for 3D CS acquisition is illustrated in Figure 1. First, an acquisition with k-space undersampling is performed. The scan acceleration is determined by the Compressed SPEEDER acceleration factor (CS factor), selectable by the user. The higher the factor, the more accelerated the scan. It is important to reach a balance between time reduction and image quality, because SNR is reduced as a consequence of decreasing the amount of acquired samples. The center of k-space is fully sampled to be used for the generation of sensitivity maps for each coil element. Next, an initial noisy image is obtained combining the inverse Fourier transform of the undersampled k-space with the sensitivity maps. Then, wavelet-based image denoising is achieved in an iterative process by setting a threshold, adjusted by the regularization factor, which determines the amount of noise to be removed from the image. Setting the regularization factor too high would remove relevant data in addition to the noise (blurriness), and too low factors would lead to insufficient artifact reduction.

In 3D CS, k-space random undersampling is obtained by using the variable density Poisson disk distribution in the ky-kz plane. This approach limits the maximum and minimum distance between k-space points^{2,3} by drawing a disk around each point in such a way that no additional samples are allowed inside that disk. This allows evenly distributed samples and avoids clustering⁴.

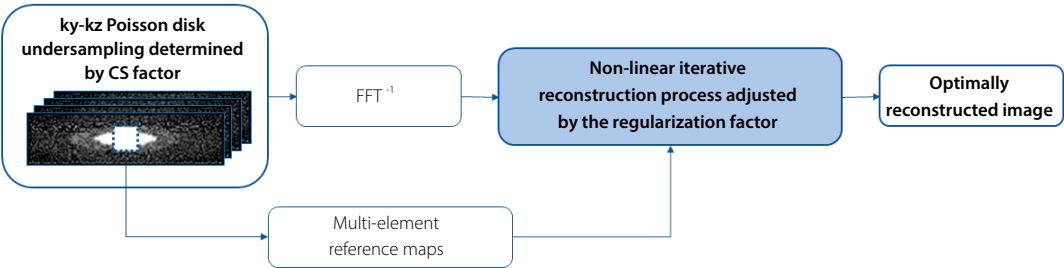


Figure 1 Flowchart showing the 3D CS acquisition process.

Table 1 Acquisition parameters for 2D Standard and 3D CS protocols for the three different anatomical regions.

	ANKLE				KNEE				HIP			
	2D STD			3D CS	2D STD			3D CS	2D STD			3D CS
	AX	COR	SAG		AX	COR	SAG		AX	COR	SAG	
TR(s)/TE(ms)	2.7/22	2.7/22	2.7/22	1.0/65	2.2/22	2.2/22	2.2/22	1.0/65	2.3/22	2.4/36	2.5/36	1.0/49
Recon. Resolution (mm²)	0.2 × 0.2			0.3 × 0.3	0.2 × 0.2			0.4 × 0.4	0.3 × 0.3			0.4 × 0.4
Slice Thickness (mm)	2.5			0.3 (recon)	2.5			0.4 (recon)	2.5			0.4 (recon)
CS factors (PE/SE)	-			2 × 2	-			2 × 2	-			2 × 2
Regularization factor	-			2	-			2	-			2
Scan Time	3:32	3:04	3:26	5:39	3:46	3:14	3:14	5:39	3:26	3:32	3:22	5:39
	=10:02				=10:14				=10:20			
Time gain	-			44%	-			45%	-			45%

Compressed SPEEDER 3D versus Standard 2D protocol

In this study, we evaluated the potential of 3D CS for MSK imaging by performing MRI examinations on five patients in three different anatomical areas (ankle, knee and hip). The scans were performed on a Vantage Galan 3T (Canon Medical Systems) with a 16ch Flex coil. MRI sessions consisted of acquiring a standard protocol including Proton density-weighted (PDw) sequences with fat saturation in three planes (sagittal, coronal and axial) and a fast protocol based on 3D CS. Acquisition parameters are detailed in Table 1.

The resulting images from both protocols were qualitatively evaluated based on visual inspection by an experienced radiologist. This evaluation confirmed that images acquired with 3D CS are comparable to standard 2D images in terms of image quality and diagnostic value (Figure 2). Apart from accelerating scan times, this kind of protocol - including isotropic 3D images - allows performing multi-planar reconstruction (MPR) in such a way that images acquired in a specific plane can be converted to any desired plane without adding scan time.

1. Achieve scan time reduction while maintaining diagnostic image quality

The overall image quality of the 3D acquisitions was satisfactory, compatible with diagnosis and stable among all cases. Thanks to a high contrast, pathological areas were easily discriminated and characterized. Therefore, 3D CS acquisitions present information that is relevant for diagnosis while providing a 45% scan time reduction compared to three separate standard 2D acquisitions with comparable resolution.

Figures 3 and 4 are examples of 3D CS MPRs for a knee and a hip case, respectively. Figure 2, 3 and 4 show how the cartilage contours and chondral lesions can be depicted and characterized. For instance, Figure 4 shows both articular space and cartilage with optimal definition for diagnosis. Figure 3 is a clear example that the tendons can be clearly observed, presenting a homogeneous black signal. In addition, the cysts present in the acetabular bone fragment in Figure 4 can be easily visualized as a benefit of the thin slice thickness.

Based on these results, the Compressed SPEEDER technique allows the addition of 3D sequences in routine protocols for MSK imaging.

For instance, having a single 2D scan with a very high in-plane resolution to find small lesions in a certain plane in combination with a fast 3D scan to cover all other orientations at once is ideal.

“The introduction of the 3D CS technique to our daily routine opens the door to new possibilities and combinations of 2D and 3D acquisitions within protocols that contribute to improve the workflow and patient's comfort.”

Xavier Alomar, M.D.

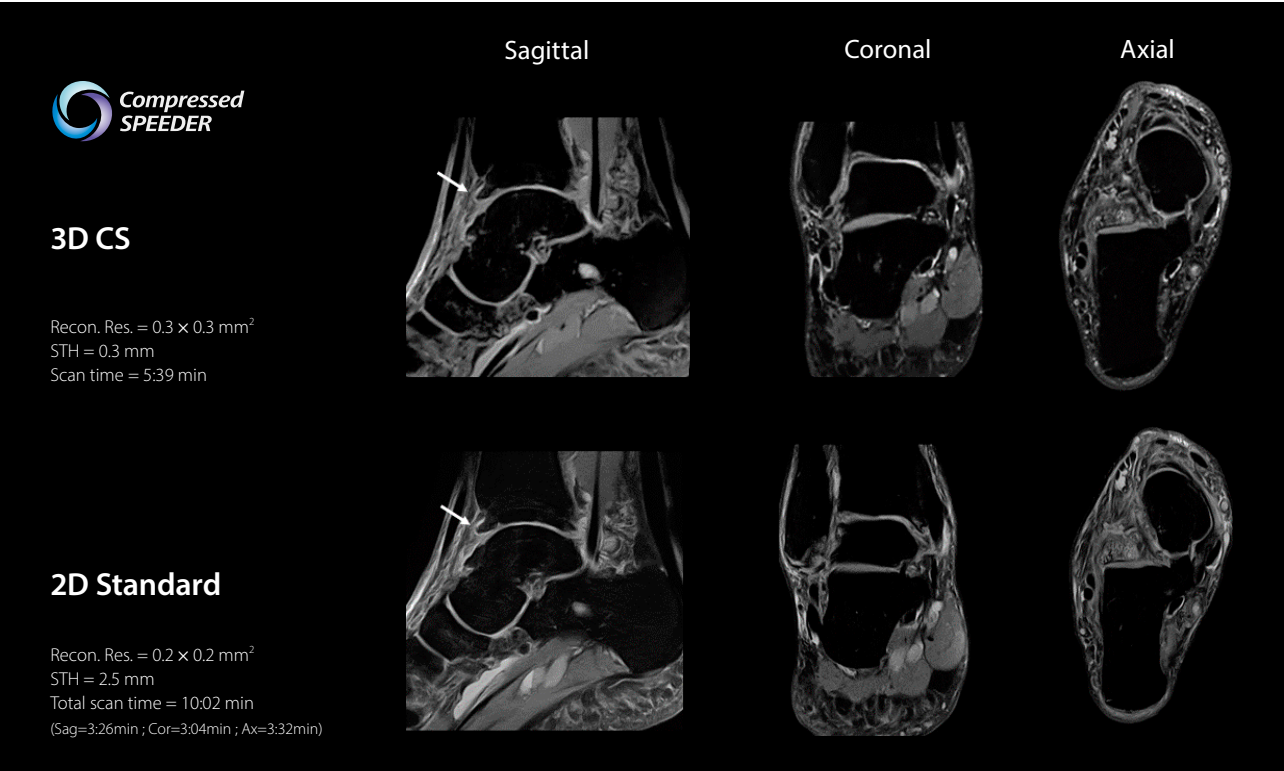


Figure 2 Illustrative images from 3D CS and 2D standard protocols in a patient with advanced joint degeneration (white arrows point anterior a tibial bone prominence pinching the tibio-astragalus articulation). 3D CS protocol (upper row) was acquired in the sagittal plane with resolution=0.3 × 0.3 × 0.3 mm³ and scan time=5:39 min. Coronal and axial planes were generated using multiplanar reconstruction. Standard PDw FS protocol (lower row) was acquired in sagittal, coronal and axial planes with resolution=0.2 × 0.2 mm², slice thickness=2.5 mm and total scan time=10:02 min.

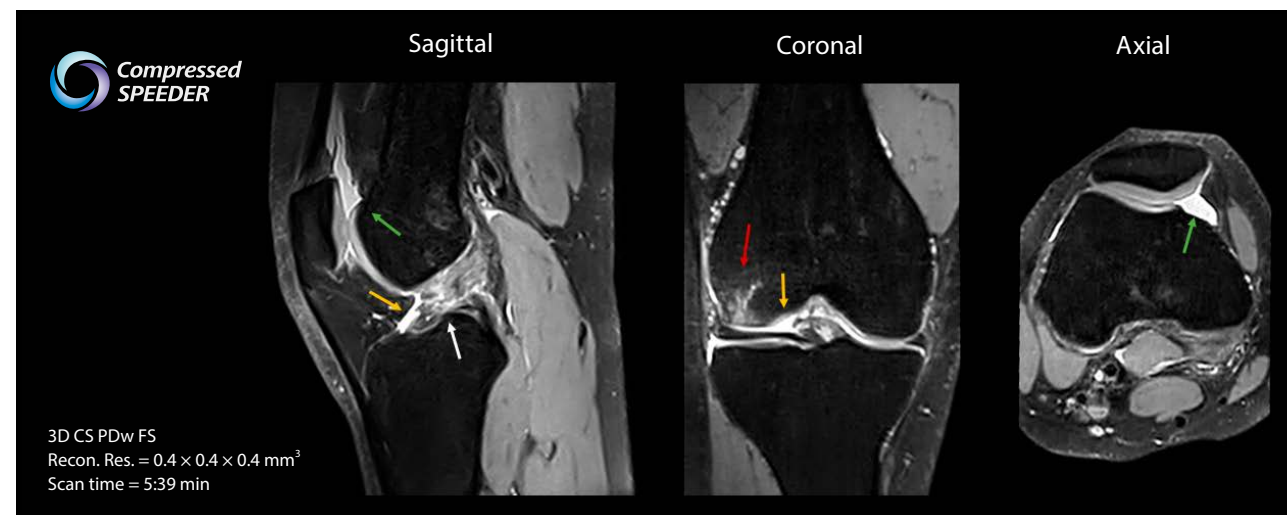


Figure 3 Sagittal, coronal and axial multi-planar reconstructions of 3D CS PDw FS images of a patient affected by an acute complete tear of the anterior cruciate ligament (white arrow) with an external femoral contusion (red arrow). There are bone contusions in the external femoral compartment, as well as an increase in articular fluid in the femoral patellar (green arrows) and femorotibial joints (yellow arrows), surrounding the anterior cruciate ligament.

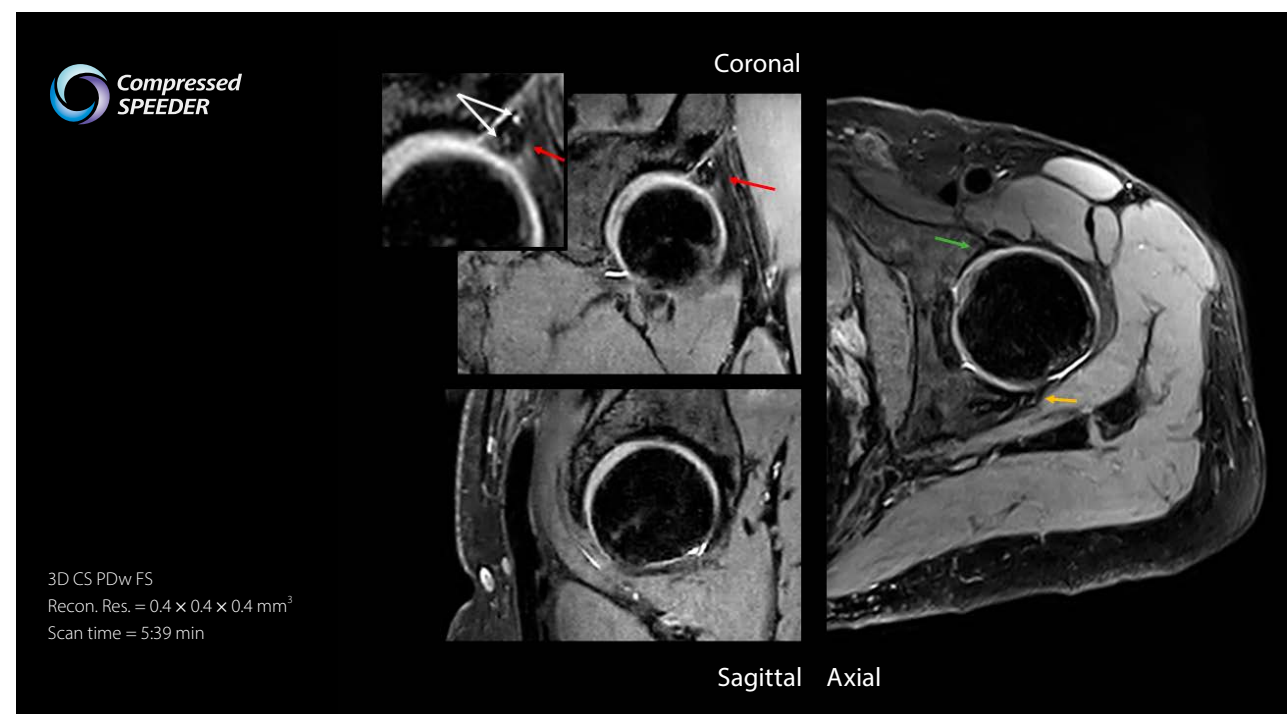


Figure 4 Sagittal, coronal and axial multi-planar reconstructions of 3D CS PDw FS images of a patient with an acetabular bone fragment in the hip (red arrows). This bone fragment is associated with subcortical cysts (white arrows) and cortical irregularities. The anterior and posterior labrum cartilage (green and yellow arrows, respectively) present the expected triangular shape.

2. Pulsatile flow artifact reduction

Another benefit of using 3D CS that was observed among these cases is a reduction of pulsatile flow artifacts compared to 2D acquisitions. The vessel contours are well defined, and the blood signal is homogeneously black in all 3D PDw FS reformats, while the corresponding 2D

scans present flow artifacts (Figure 5), which may affect diagnosis in some circumstances. The sagittal plane of Figure 4 is another example of the lack of flow artifacts in the 3D CS. This phenomenon could also be especially beneficial in studies such as pubic symphysis, where pulsatile artifacts hinder the diagnosis in some occasions.

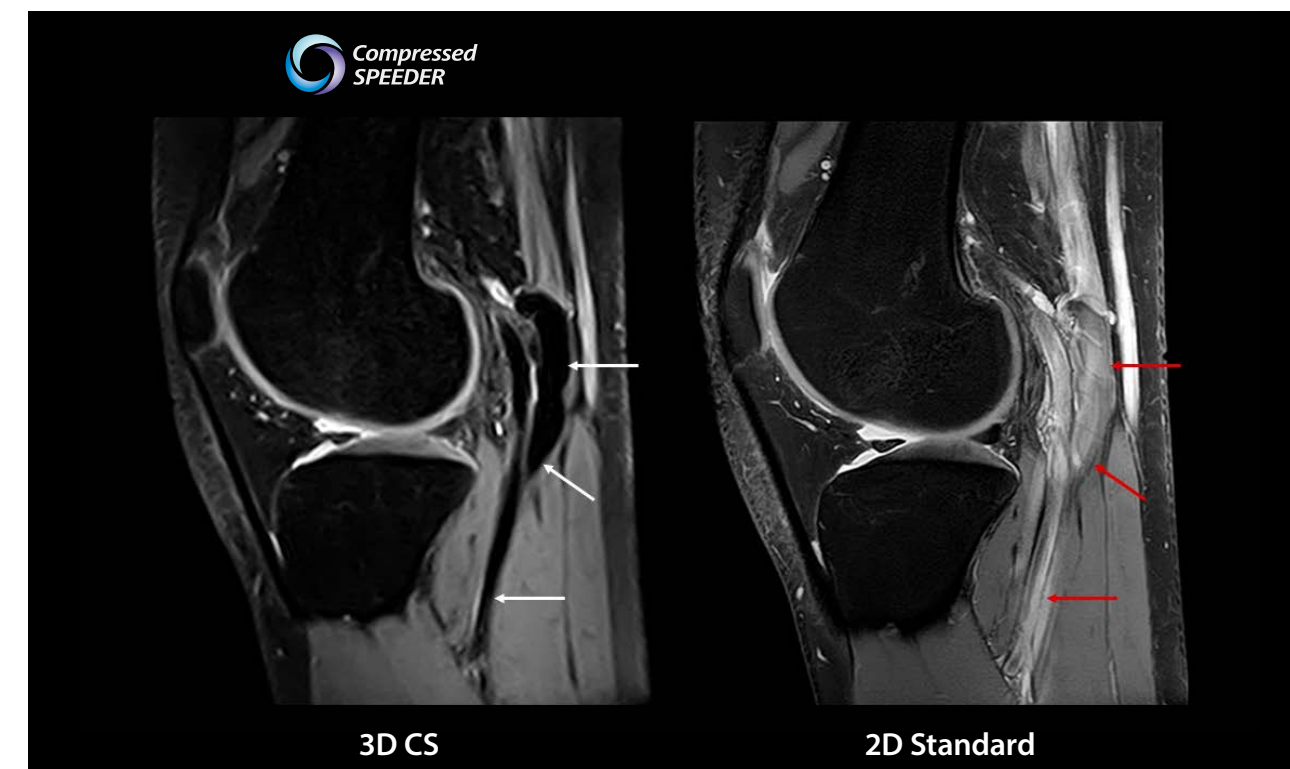


Figure 5 3D CS MPR reconstruction (left) and standard 2D (right) scans in the sagittal plane. Comparison of vessel image quality between the 3D (white arrows) and the 2D (red arrows) images.

3. Reconstruction in any plane without losing anatomical detail

One of the benefits of 3D isotropic acquisitions is that it is possible to reconstruct the acquired image in any desired plane. The MPR reconstructions obtained from the 3D CS acquisitions of this study present the same image quality as the originally acquired plane. Therefore, all planes as well suitable for diagnosis. This allows for the evaluation of pathology with confidence using images generated from the most convenient perspective and angulation. In addition, the MPR images enable following the course of structures such as ligaments or nerves.

“3D CS provides remarkable MPR reconstructions with a quality well suitable for diagnosis. Therefore, with a single acquisition it is possible to reconstruct any plane that I want with an identical image quality to the acquired one.”

Conclusions

This study focused on the diagnostic ability to use 3D CS in a clinical context. It showed that 3D CS could be used to replace multiple 2D scans in order to significantly accelerate the total acquisition time by 45% thereby improving workflow and patient comfort. 3D CS also provided additional advantages compared to 2D scans, like the use of MPR and the reduction of pulsatile flow artifacts.

“Introducing the 3D Compressed SPEEDER technique has been a significant milestone to improve the balance between image quality and scan time reduction. I’m convinced that 3D acquisitions are the future of MR and this innovation has brought us a step closer in that direction.”

Xavier Alomar, M.D.

References

1. Donoho, D. L. Compressed sensing. *IEEE Transactions on information theory*, 2006. 52(4), 1289-1306.
2. Hollingsworth, K. G. Reducing acquisition time in clinical MRI by data undersampling and compressed sensing reconstruction. *Physics in Medicine & Biology*, 2015. 60(21), R297.
3. Cook, R. L. Stochastic sampling in computer graphics. *ACM Transactions on Graphics (TOG)*, 1986. 5(1), 51-72.
4. Levine, E., Daniel, B., Vasanawala, S., Hargreaves, B., & Saranathan, M. 3D Cartesian MRI with compressed sensing and variable view sharing using complementary poisson-disc sampling. *Magnetic resonance in medicine*, 2017. 77(5), 1774–1785.

Clinical and Scientific Canon Medical support



Alba Iruela
Clinical Scientist Junior
Canon Medical Systems Spain and Portugal



Alicia Palomar
Clinical Scientist Junior
Canon Medical Systems Spain and Portugal



Alberto Heredia-Escámez
MRI Clinical Applications Specialist
Canon Medical Systems Spain and Portugal



Valentin H. Prevost, Ph.D.
MR Clinical Scientist
Canon Medical Systems Corporation

CANON MEDICAL SYSTEMS CORPORATION

<https://global.medical.canon>

©Canon Medical Systems Corporation 2021. All rights reserved.
Design and specifications are subject to change without notice.
MWPMR0011EA 2021-10 CMSC/Produced in Japan

Canon Medical Systems Corporation meets internationally recognized standards for Quality Management System ISO 9001, ISO 13485. Canon Medical Systems Corporation meets the Environmental Management System standard ISO 14001.

Vantage Galan and Made for Life are trademarks of Canon Medical Systems Corporation.

Made For life