Impact of Compressed Sensing Cardiac Cine in a busy clinical practice

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Introduction

Since its foundation in 2008, the dedicated cardiovascular MRI facility at the Institut Cardiovasculaire Paris Sud (ICPS – Cardiovascular Institute Paris-Sud), has seen around 45,000 patients. Of these, ca. 70–75% underwent a stress MR perfusion examination. In 2017 alone, over 5,400 patients were scanned, with the MR examination duration averaging 20 minutes. This tempo has been achieved thanks to thorough planning and staffing of the reception and preparation areas, scanning and reading environment as well as to careful optimization of the entire examination process, from patient reception, preparation and coaching, to accessory selection, protocol tuning and workflow management.

Cardiovascular MRI at ICPS

The stress CMR perfusion examination at ICPS consists of localization, followed by long-axis cines, stress perfusion, short-axis cines and late-enhancement. Image viewing, quality control and interpretation are done in parallel on a dedicated reading console running *syngo*.via located in the MR control room. Reporting is performed alongside reading using a software package[1] (Clinigrid software, Hemolia Inc., Paris, France) written especially for the CMR practice at ICPS which, as well as combining audio, image and text input, also serves as a database, capable of providing statistical information about patient cohort, throughput etc.

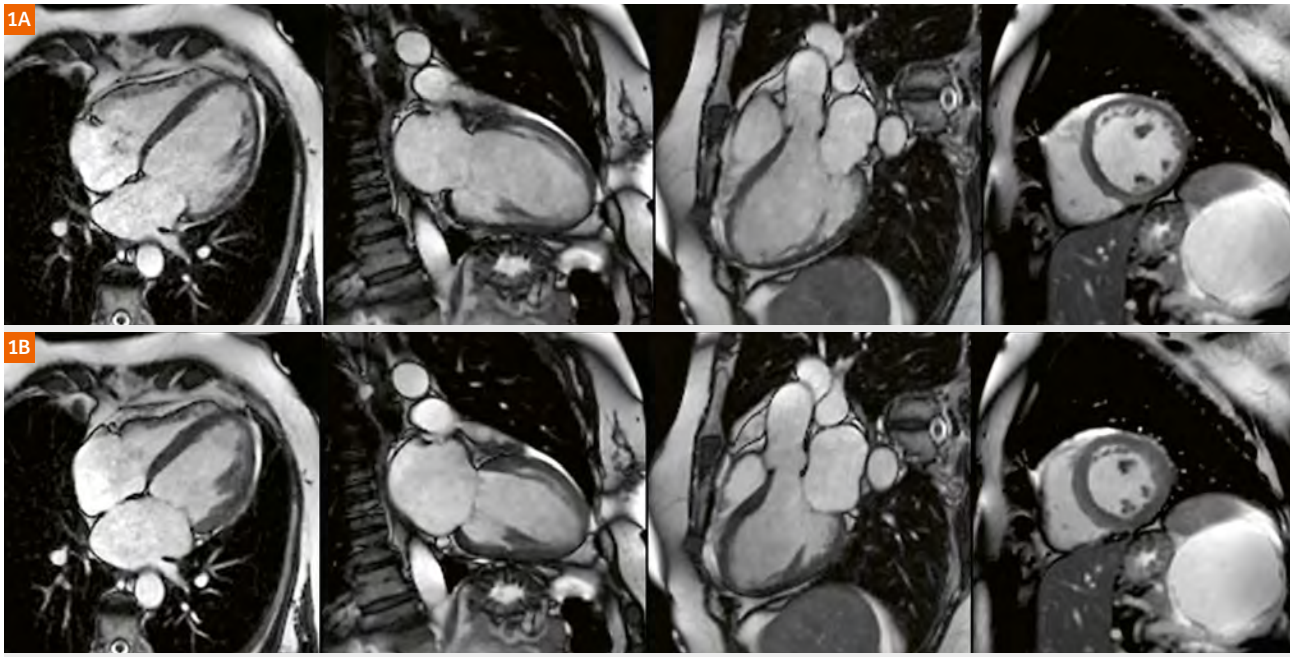

Figure 1:
Compressed Sensing Cine retrogated images obtained in diastole **(1A)** and systole **(1B)** using a two-shot imaging protocol in a patient with dilated cardiomyopathy.

[1] The information shown herein refers to products of 3rd party manufacturers and thus are in their regulatory responsibility. Please contact the 3rd party manufacturer for further information.

Ventricular function assessment

The assessment of left ventricular (LV) function is a core feature of every MR examination of the heart. Until September 2017, we typically performed LV function analysis using PAT-GRAPPA accelerated segmented retrogated cine TrueFISP with a PAT factor of 2. This approach is considered a gold standard in the MR imaging business, and in spite of lengthy and multiple breath-holds, it is generally well-accepted by patients and clinicians. In patients with breath-hold difficulties or arrhythmia, we resorted to prospectively triggered cine TrueFISP combined with TPAT imaging and a PAT factor of 3. The introduction of Compressed Sensing (CS) Cardiac Cine with *syngo* MR E11C-AP02 changed our examination workflow considerably. In particular, the prototype CS Cardiac Cine software[2], which allows for retrogated cine imaging across two heartbeats, has become our workhorse method for LV function assessment. Thus, following a brief investigative period including cross-comparisons with the current gold standard, we switched all our standard CMR imaging protocols to use CS Cine with retrogating. This has meant that we have been able to shorten the average stress perfusion CMR examination by 3 to 4 minutes, thereby increasing our patient throughput and improving patient comfort. As a direct consequence, we are now able to scan around 15 more patients per week.

Retrogated Compressed Sensing Cardiac Cine

The so-called "two-shot" CS Cine Retro method allows for a reduction in the total number of breath-holds required to assess left ventricular function both visually and quantitatively, as well as a shortening of the breath-hold duration itself. In general we employ an imaging protocol with a total acceleration factor of ~6.5, an in-plane spatial resolution of 1.5 mm x 1.5 mm and a temporal resolution of the order of 40 ms; slice thickness is usually 8 mm. The acquisition duration is three heartbeats per slice, the first heartbeat being a non-imaging "dummy" heartbeat, with application of gradients and RF pulses to ensure that the magnetization has reached the steady state. Example images obtained in a patient with dilated cardiomyopathy are shown in Figure 1. Despite the high *k*-space under-sampling factor, endo- and epicardial boundaries are sharp, small trabecular structures and valves are clearly visible and, most importantly, the excellent temporal resolution ensures that wall-motion assessment and quantitative analysis are feasible. Figure 2 shows another representative example of a three-chamber cine obtained using CS Cine Retro.

In the case of patients with severe arrhythmia, or those who are unable to hold their breath, the real-time CS Cine sequence is now our alternative method of choice for the assessment of LV function. Albeit with a somewhat inferior spatial and temporal resolution compared with the two-shot CS Cine Retro method, real-time CS Cine nevertheless allows for a distinctly better image quality when evaluated against standard PAT-accelerated real-time imaging. With appropriate usage of adaptive triggering, or alternatively imaging across 1.5 cycles, it also allows for complete cycle cine imaging, necessary for accurate quantitative analysis. Figure 3 compares the two-shot CS Cine Retro method with real-time CS Cine obtained in a deaf patient in whom the conveyance of breath-hold commands was complicated. The images shown in Figure 4 illustrate the usage of the arrhythmia rejection option in CS Cine Retro to achieve clinically acceptable image quality.

The advantages of CS Cine Retro are not limited to scan time shortening alone. The method incorporates a means to trade scan time for extremely high temporal and/or spatial resolution in a single breath-hold. Thus, the so-called eight-shot protocol, which splits the acquisition over eight heartbeats, allows for the thus far inconceivable acquisition of single slice cine images with a temporal resolution of 10 ms and an in-plane spatial resolution of 1.2 mm x 1.2 mm in a total scan time of 9 heartbeats. An example of such an acquisition is shown in Figure 5.

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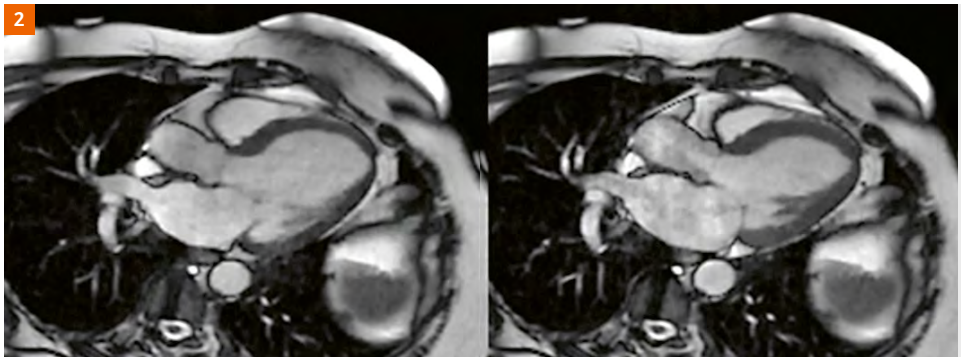

Figure 2:
Three-chamber CS Cine retrogated images obtained at end-diastole and end-systole.

[2] WIP, the product is currently under development and is not for sale in the US and in other countries. Its future availability cannot be ensured.

Figure 3:
Comparison of CS Cine Retro **(3A)** with CS Cine real-time **(3B)**, obtained in a deaf patient and without breath-holding.

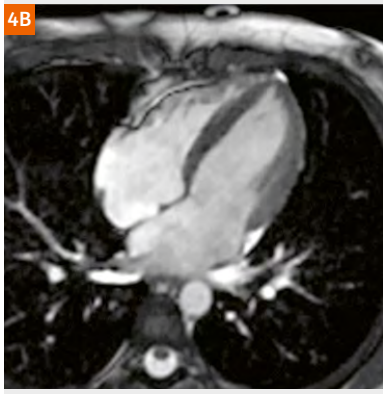

Figure 4:
CS Cine Retro images obtained without **(4A)** and with **(4B)** the arrhythmia rejection scanning option in a patient with heart rate irregularities.

Figure 5:
Three-chamber cine obtained in a healthy volunteer using an eight-shot CS Cine Retro imaging protocol.

Conclusion

Compressed Sensing Cardiac Cine is proving to be a game-changer in the field of cardiovascular MRI. The prototype retrogated CS Cine package allows for significantly shorter scan times without loss of diagnostic information. This in turn is beneficial not only for patients, but also in further improving workflow and in expanding the usage of MRI in the assessment of cardiovascular diseases.

Acknowledgements

The authors would like to thank their colleagues at the Institut Cardiovasculaire Paris Sud, as well as their collaborators at Siemens Healthineers, in particular Carmel Hayes, Christoph Forman, Michaela Schmidt, Solenn Toupin and Matthieu Lepetit-Coiffé, for their valuable contributions to the development and testing of the prototype CS Cine Retro package in a busy clinical practice.

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