Evaluating both "Normal" and "Ectopic" Cardiac Cycles in Patients with Arrhythmias Using Free-Breathing Compressed Sensing MRI with Physiological Motion Synchronization

Li Feng[1], Leon Axel[1], Darragh Halpenny[1], Larry Latson[1], Jian Xu[2], Daniel K Sodickson[1], and Ricardo Otazo[1]
[1]*Bernard and Irene Schwartz Center for Biomedical Imaging, Department of Radiology, New York University, School of Medicine, New York, New York, United States,*
[2]*Siemens Medical Solutions, New York, New York, United States*

Target Audience: Scientists, researchers and clinicians who have interest in rapid cardiac MRI using compressed sensing reconstruction and evaluation of myocardial function in patients with arrhythmias

Introduction: Evaluation of myocardial function with MRI is challenging in patients with arrhythmias, such as premature ventricular contractions (PVCs) or atrial fibrillation, due to the difficulty of synchronizing disparate cardiac cycles. In order to achieve adequate image quality in these patients, the ECG signal is usually monitored so that the "ectopic" cardiac cycles can be discarded before image synchronization and reconstruction. However, those discarded "ectopic" cardiac cycles could potentially provide clinical information for specific cardiac diseases. For example, it is known that the premature ventricular contractions in PVC patients have a different pattern than the normal ventricular contractions. Therefore it may be clinically useful if both "normal" and "ectopic" cardiac cycles can be reconstructed for clinical use. The application of compressed sensing to real-time cine imaging is a promising tool to enable free-breathing real-time cine imaging with adequate spatiotemporal resolution on patients with impaired breath-hold capabilities or arrhythmias [1-2]. However, conventional temporal compressed sensing does not account for respiratory motion or arrhythmias, and thus only moderate performance is achieved in these cases. In this work, we propose to acquire data continuously using a golden-angle radial sampling scheme, and to reconstruct separated but synchronized cardiac and respiratory motion dimensions, allowing for cardiac cycles with differing lengths. Specifically for the case of arrhythmias, both "normal" and "ectopic" cardiac cycles can be distinguished according to the length of cardiac cycles and grouped for separated reconstruction, which provides additional information for potential clinical use. The performance of the proposed method in patients (with both normal sinus rhythm and different kinds of arrhythmias) was compared against the standard clinical breath-hold approach using retrospective ECG-gating.

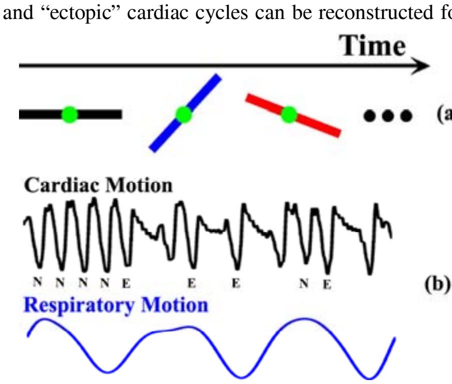

Fig. 1: (a) Continuous data acquisition. (b) Cardiac / respiratory motion detection in the presence of arrhythmias. N: normal E: ectopic

Methods: Both breath-hold cine MRI (Cartesian, retrospective ECG-gating) and free-breathing cine MRI (golden-angle radial, no external gating/triggering) pulse sequences were implemented with b-SSFP readouts on a 1.5T MRI scanner (Avanto, Siemens) equipped with a 12-element receive coil array. Relevant imaging parameters for breath-hold cine are: spatial resolution=1.8x1.8mm^2, slice thickness=8mm, TR/TE=2.5/1.25ms, FA=50-70^o and BW=1305Hz/pixel. Relevant imaging parameters for free breathing cine are: spatial resolution=2x2mm^2, slice thickness=8mm, TR/TE≈2.8/1.4ms, FA=70^o, BW=1375Hz/pixel. Cardiac imaging with a HIPAA-compliant and IRB-approved protocol was performed on 14 patients (mean age=56). 7 patients had normal sinus rhythm, 7 patients had arrhythmias (4 bigeminy PVCs, 2 atrial fibrillation, 1 second degree block). One short axis (SAX) and one 4 chamber long axis (LAX) cine image set were acquired on each patient; the acquisition time for both sequences was about 12~15s for one slice. Breath-hold cine reconstruction was performed on-line in the scanner, and free-breathing cine reconstruction was performed off-line in MATLAB (MathWorks, MA). Specifically, for free-breathing cine imaging, the k-space centers (kx=ky=0) in each spoke (green dots, Fig 1a) were used to extract physiological motion signals, including both cardiac contraction and respiration simultaneously (Fig 1b), from coil elements that were close to the heart and diaphragm, respectively, as described in [3-4]. Local minima in central-k-space signal were detected as end systole positions. Using the detected motion signals, data were retrospectively sorted and synchronized to separately reconstruct cardiac cycles with different lengths at different respiratory states. A multicoil compressed sensing approach [5-6] was used to reconstruct the undersampled datasets, employing a different total variation constraint along cardiac and respiratory dimensions, respectively. A 5th order temporal medial filter was used to further remove the residual streaking artifact. All the reconstructed datasets were blinded and randomized for image quality assessment by two radiologists, with scoring criteria as following: 5: excellent, 4: very good, 3: good, 2: poor, 1: non-diagnostic. Results from two readers were averaged (represented by mean ± standard deviation) and divided into two groups: one group with normal sinus rhythm and the other group with arrhythmias.

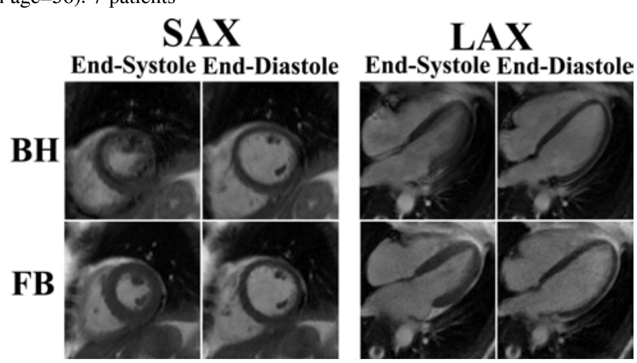

Fig. 2: Comparison between breath-hold cine imaging with retrospective ECG-gating and free-breathing cine imaging with cardio-respiratory synchronization in a patient with 2nd degree heart block.
BH: breath-hold. FB: free-breathing. SAX: short axis. LAX: long axis.

Results: Fig 2 shows both breath-hold cine and free-breathing cine images of one patient with 2nd degree block. When compared to the clinical standard approach, which is sensitive to arrhythmias, the proposed free-breathing approach produced superior image quality, due to the ability to differentiate "normal" and "ectopic" cycles, as also seen from Table 1 (group 2). For patients with normal sinus rhythm, the results from both approaches are good with adequate diagnostic image quality (Table 1, group 1). Fig 3 shows free-breathing cine images reconstructed from both "normal" and "ectopic" cycles on the same patient as in Fig 2.

Technique	Group 1	Group 2
BH	3.82 ± 0.52	1.96 ± 0.83
FB	3.06 ± 0.58	3.05 ± 0.69

Table 1. Image quality comparison between breath-hold and free-breathing cine Images. Group 1 includes patients with normal sinus rhythm and group 2 includes patients with arrhythmias
BH: breath-hold. FB: free-breathing

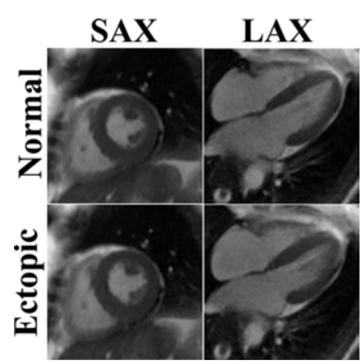

Fig. 3: Reconstruction of free-breathing end-systolic cardiac phases from both "normal" and "ectopic" cardiac cycles.

Conclusion: This work proposed an approach for reconstructing cardiac cine images in patients with arrhythmias, with superior image quality than the standard breath-hold approach using free-breathing compressed sensing MRI with physiological motion synchronization. In addition, the approach can be used to reconstruct both "normal" and "ectopic" cardiac cycles in those patients. The "ectopic" cycles could produce different clinically useful information, e.g., due to the naturally varying length of cardiac cycles, which may change in the cardiac function, or different contraction patterns of ectopic beats.

References: [1] Feng L, et al. MRM 2013 Jul;70(1):64-74; [2] Feng L, et al. ISMRM 2012 p225. [3] Liu J, et al. MRM 2010; 63:1230–1237. [4] Feng L, et al. ISMRM 2013 p 606. [5] Otazo R et al. MRM 2010 Sep;64(3):767-76. [6] Feng L et al. MRM 2013 doi: 10.1002/mrm/24980